University of Southern Queesnland
Faculty of Health Engineering and Sciences

Asset Management Modelling

A Dissertation submitted by
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Abstract

Road Pavements are very dynamic in their nature and require constant maintenance for it to carry out their functionality of transportation. Their dynamic nature can affect their residual life hence constant monitoring is required so that their state of wellbeing is known. It is without a doubt that there are many remedies made available to combat against defects which may be present in a road pavement some more expensive than others. However early prevention can generally minimise the chances of encountering the catastrophic effects which may fellow if a pavement is not taken care of .

Pavement management systems (PMS) are widely used among many institutions to monitor road pavements . However some are much more better equipped than other at simulating road deterioration. The research which has been conducted has taken two former councils Wyong shire Council and Gosford City Council , pavement management systems known as SMEC and Assetics respectively , and has developed a series of deterioration tools that are each catered for a particular class of road . The classes of road which were of interest included minor roads, access roads, distribution roads. Access and Distribution roads were located in the Wyong area while the minor roads were in the Gosford locality .

In addition to developing a deterioration tools for Assetics and SMEC , a deterioration tool for moloney was also attempted. The Moloney deterioration tool did not have a specific class of road .

Using the developed deterioration tools each one was applied to its corresponding class of road as well as each other’s.

As well as assessing how well each deterioration tool can simulate its own class of road , the detonation tools were also assessed on how applicable they can be to each other’s in terms of simulating deterioration.

As expected each deterioration tool was to simulate its own class of road quite well but the result did show that the Moloney model was able to model distribution roads better than SMEC and the Assetics minor deterioration tool was more suited to modelling the access roads in the Wyong area.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Janahan Karunaharan

[redacted]

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Abbreviations

WSC- Wyong Shire Council

GCC- Gosford City Council.

PMS – Pavement management systems

1.0 Introduction

Currently in New South Wales local governments are being amalgamated meaning some councils will be governing larger jurisdictions than what they were previously**.** Meaning larger road networks maintenance . The former Wyong Shire Council (WSC) and Gosford City council (GCC) are currently in the processing of merging. Both former councils used separate pavement management systems to main their respective road networks. WSC used an application known as SMEC while GCC used an application known as Assetics. However it is at this point of time that a decision needs to be made about which system to adopt. The research study in which the paper is dedicated to endeavours to explore segments of each council's road network and analyse which pavement management system i.e Assetics or SMEC is applicable to certain classes of road in a network . In addition Moloneys model will be introduced and will also be applied to both of these former councils road networks .

1.1 Background

It is without a doubt that transportation is quite a vital aspect to the economy in any country as there many stakeholders who depend on it to go about their day to day lives (M. Muhammad ,2010) . Having a sustaining road network is indeed a worthy investment compared to most other form of transportation popular mode of transport is conventionally by motor vehicle in most first world countries. However road pavements are known to be very dynamic as their general nature very much influenced by many factors such as traffic loading, material used, construction techniques applied and environmental exposure .

Asset management is a widely practiced among most government department and private enterprises. The ability to be able to manage assets so that they are performing at an acceptable level can only be achieved by constantly monitoring the residual life remaining and serviceability. Residual life directly correlates with serviceability, however poor survivability can occur prematurely. Capital work programs are generally fuelled by rehabilitation orientated projects so that current assets such as roads and drainage can be renewed. Maintaining a pavement often means extending the life span of the road and trying to meet the road user's needs . This is generally accomplished by resorting to treatments for particular road defects . Previous conventions that were widely practiced among local councils many decades ago was to allow the pavement to deteriorate to a point where ride quality and structural capacity were unacceptable making the road a danger to the public . The problem with these methods means structural capacity will degrade to such a low point rehabilitation can be costly and time consuming.

A pavement management system is equipped with a budgeting tool which can allocate funds to certain parts of the network so that specific condition ratings can be maintained. . A PMS can optimise funding by coming up with corrective and effective rehabilitation techniques and know what point of time a rehabilitation regime should take place.

Being able to forecast rehabilitation is a much needed application so that future demands can be managed and so capital injection can be conservatively. Data mining is a concept of computer science which is slowly being more applicable to other fields. Forecasting is underpinned by data mining, only because future data can be derived from the current data at hand. Local government often resort to Pavement management systems (PMS) to help them govern and maintain their road network. Embedded within a PMS are pavement deterioration tools which generally would have data mining capability.

1.2 Project aims

- To research and develop deterioration tools which can imitate deterioration on a particular class of road . These classes of road include distributor, access, , minor within the former Wyong and Gosford jurisdiction.
- To check how well each of these deterioration tools simulate the degradation process of its assigned class of road .
- To make recommendation based on findings which deterioration tool is appropriate for particular class of road .
- To check if a deterioration tool can simulate not just it own class of road but other ones to .

1.3 Proposed approach

Data collection

The former WSC and GCC will provide a spreadsheet of every pavement that makes up their Respective road network. Each spreadsheet will compromise of pavement condition index and the length of each road. Only certain road classes will be examined and taken to interest.

Moloney's model will also be attempted to be modelled based on publication provided by coff's Harbour city council

Deterioration modelling

WSY distribution roads, access road and GCC minor roads will formulated individually using the entire spreadsheet provided by these former councils.

Deterioration modelling analysis

A random twenty roads will be selected from each road class and a deterioration tool will be formulated based on each of these roads alone . Regression analysis and P-value will attempted to be found when comparing each deterioration tool and sample of roads in which a deterioration tool was produced from .

1.4 Report Structure

-Introduction

-Literature review

- Methodology

- Results and Discussion

-Conclusion and recommendations.

2. Literature Review

The following literature review will examine road pavements and provide insight into their general nature in terms of deterioration .The intention of the literature is to examine how councils undergo asset management and to explore how deterioration effects them. International and domestic asset management schemes such as lifecycle patterns have been closely looks at . In addition previous studies will be explored so that techniques and certain steps can be adopted for the study in which the paper Is dedicated to.

2.1 Pavement Deterioration Contributors

It is a well known fact that pavement damage is a result of pavement wear. Pavement wear is the ongoing process of several deterioration processes happening simultaneously such as traffic and environmental conditions. A pavements condition can be evaluated from the amount of traffic and the general mass of the traffic loadings.

2.1.1 Road Classing

It would appear that local council have a duty when maintaining roads that are in their network. But a road network can be diverse in terms of classing. The intention of having a road hierarchy is so that local residents can gain an idea of design and construction parameters and maintenance targets (Manningham , 2004) .

Because the research will be primarily focused on two different WSC and GCC, their current road hierarchy will be defined.

Access Roads – Road that provide a passageway to properties and mainly located in residential areas such as courts and avenues . These particular classes of roads are known to facilitate bicycles and pedestrian the most compared to rest of the road hierarchy (LGAM,2017). Can be either sealed or unsealed depending on how much safety is required (Southern Shire Grampians council,2013)

Minor Roads – A general road term.   Roads that come second in importance at an unsignalled intersection and would normally have to give to on coming traffic (LGAM, 2017) .

Arterial – This particular road class is maintained by state government authorities and provides a passage from one region to another . Generally these roads take the form of highways and freeways.

Distributor Roads – Disperses traffic to arterial roads . These roads generally have two way traffic and do allow for road side parking (LGAM,2017).

Collector Roads – A road that can provide a passage way through residential, industrial and commercial areas. Generally they have high traffic levels second to arterial roads . While two way traffic does occur on these roads parking can be facilitated (LGAM,2017).

2.12 Road wear.

Commercial vehicles are the prime perpetrators of pavement failure. The only true way of gauging road deterioration is by weighing actual Lorries, busses and semi-trailers etc. Road wear differs from metropolitan and urban areas due to demographics. Traffic composition is a contributing factor which influences road wear (Aust roads part 5H, 2009) . The way a pavement is arranged and material quality which is utilised is generally how a pavement withstands the road wear. Excessive road wear can lead to pavement failure which can have detrimental effects to road users and the general public.

There are various implications when an asset fails not just to the custodians but to the community, such as traffic congestions and road crashes. The way in which a road can be maintained financially is debatable (Lake Macquarie, 2012). There are two ways of going about it either do regular maintenance such as attending to minor defects or replace the entire road once the road has failed completely.

An Australia Equivalent standard axle is pretty much 80kn(USQ , 2017) to the pavement. It is used to describe by a load Equivalent factor where an axel load is said to be equivalent to a number of applications of a standard axel load.

$$\frac{N_s}{N} = \left[\frac{P}{P_S}\right]^a$$

Equation 1: ESA equation

(USQ CIV 3407 , 2014)

As shown in the equation 1 there are a number of variables that are factored . Ns is the number of equivalent standard axles (ESA) while “a” is a variable which depends on the pavement material and the road authority. As the axle load alters the power law changes in turn and reflects the life expectancy of the road. The formal term used to describe this variable is “Load Equivalent Factor”

Load equivalent factor is when an axel load is said to be equivalent to a number of applications of a standard axel load and is generally to the power of four when used in Australia
(USQ CIV 3407 , 2014)

2.13 Geology

For any public authority the geology of the surrounding area is most vital to know about in order to implement good pavement design. The bigger the road network the more vital it is to have a PMS which can take into consideration of the surrounding geology . Reactive clays are common geological substance which is embedded in certain sections of the network. Reactive clays can cause deterioration faster than any other factor and for that reasons needs to be implemented in the PMS so that modelling of this particular section of the network can be done individually assuming the PMS can take this into account . The level in which a pavement management system can accurately model a network depends on the environmental conditions of each region and their effects on the pavement deterioration model (coulhoun, 1997) .

2.14 Weathering

A key contributor to pavement failure is bad weather. Water is a key contributor towards pavement failure and is causes ponding and seepage into the core of the pavement. Water is notoriously known to undermine road pavements. When moisture makes its way through a pavement it can weaken the subgrade hence undermining the foundation. The interlocking capability between particles would also be compromised as it would cause displacement reducing the friction factor (A.K Gupta, 2015).

2.2 Symptoms of Road Deterioration

There are five forms of road deformations which can have adverse effects on a road pavement. They are mainly rutting, ravelling, shoving, depressions and Swell (AK Gupta, 2015, P3). The following sections will examine each of these types thoroughly.

2.21 Cracking

Distress symptoms of this nature generally occur during the early stages and often occur as wide and distributed. The entry of water to these cracks is generally the worst cause that can happen as explained in section 2.12 . Treatments which can be used include binder which is low in viscosity. Fine premix or bituminous slurry are used for wider cracks. Complete reconstruction of the pavement may be needed when cracking is accompanied with deflection (AK Gupta, 2015).

Cracking can be classified as longitudinal and fatigue cracking . Longitudinal cracking runs parallel to the kerb and gutter and can come as a series all which are all parallel (Gosford transport asset management plan,2014)

Figure 1. Longitudinal cracking

Gosford city council 2014 Transport Asset management plan p.102

Transverse cracking usually form at the right hand angle of the centreline of the road and can be caused by movement of the pavement due to temperature . Crocodile cracking usually occurs when the surface of the road becomes very thin due to fatigue and polygon shaped crack appear . Fatigue caused traffic loading, eventually potholes start to form these crocodile cracks.

Figure 2. crocodile cracking

Gosford City Council Transport Asset management plan p.165

2.22 Rutting

The separation of pavement material that creates corridors in the wheel path. Very severe rutting may hold water. Rutting signifies failure in one or more layers in the pavement. The width of the rutting can demonstrate which layer has failed (A.K Gupta et al ,2006). Normally attributed to lack of thickness and poor compaction.

Figure 3 . Corrugated

Gosford City Council Transport Asset management plan p.165

2.23Corrugation

Occurs when vehicles accelerate and decelerate. Can be repaired with an overlay or surface milling .Some cases would require a deep milling before resurfacing (A.K Gupta et al. 2006).

2.24Shoving

A form of plastic movement in the asphalt concrete surface layer that creates a localised bulging of the pavement (A.K Gupta et al . 2006). Thinning of the road pavement as well as poor bond between layers are the causes of this type deformation.

Figure 4: Shoving

Gosford City Council Transport Asset management plan p.165

2.25 Depressions

Bowl shaped areas that may have been caused by cracking. Depressions cause roughness and allow water to collect . Caused by localised consolidation or movement of the supporting layers beneath the surface course due to instability (A.K Gupta et al. 2015). Poor compaction can be a key factor as well .

Figure 5: Depressions

Gosford City Council Transport Asset management plan p.113

2.26 Potholes

Caused by a lack of reinforcement and excessive traffic loading . A progressive deformation which starts up at the top layer and works downwards. Poor drainage is very much the instigator of pot holing (A.K Gupta et al, 2015). Traffic loading can abrade weak part of the road surface llowing moisture to enter .

2.3 Asset Management

Asset management is very much about utilizing civil infrastructures with a combination of management strategies in place such as capital injection for maintenance purposes as well as gaining an adequate level of service (Australian Infrastructure Financial Management manual,2015) .

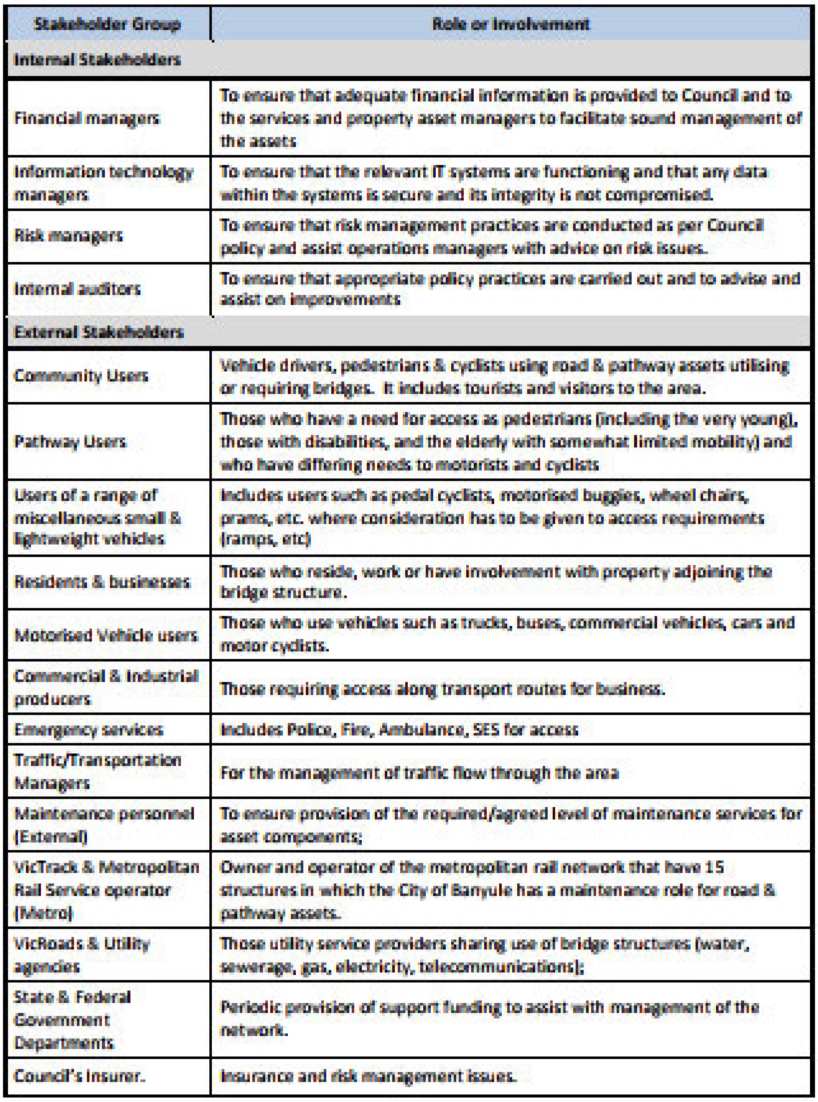
Many local governments and road authorities are very wary of the way in which an asset such as road pavement, drainage or any other form of civil infrastructure performs. Its ability to perform to an appropriate level is much needed so that it can cater for local communities and visitors to the area. Level of service can be defined as the capability of a device to carry out a task . The intention of monitoring residual life of an asset is to prevent asset failure from occurring. As discussed in section 2.1 the need for safer roads is very much to do with public liability and avoiding litigation.

There are many systems in place which local councils and Road authorities can use such as audits and strategic asset management programs (SAMP) . SAMP is a series of steps which can be taken for maintenance purposes

Road related asset management can be very diverse in terms of asset maintenance regimes. The following are the general principals when coming up with an asset management regime. The initial step taken when devising an asset management strategy is to evaluate how much input does the asset play towards the road network. Followed by defining what failure means for that asset and the ramification if it was to fail towards road users, custodians and the community. Finally how much does the asset contribute towards the network. In other words is it a stand along device or contributes to a greater one. (Randwick city council Road Pavement asset management, 2004).

2.31 Stake Holders

There are a number of stakeholders involved in asset management. These include the community, Residents and businesses ,Pedestrians, Users of vehicles such as bicycles, Motorised vehicles, Tourists and visitors, Emergency services, Traffic and Transportation managers, Construction and maintenance personnel who build and maintain asset components, Utility agencies that use the road reserve for their infrastructure (Waverly city, council) . All these parties have an interest in the wellbeing of a local road especially when it plays a key role in the journey to get to their destination safe and sound.



Stakeholder Group	Role or Involvement
Internal Stakeholders	
Financial managers	To ensure that adequate financial information is provided to Council and to the services and property asset managers to facilitate sound management of the assets
Information technology managers	To ensure that the relevant IT systems are functioning and that any data within the systems is secure and its integrity is not compromised.
Risk managers	To ensure that risk management practices are conducted as per Council policy and assist operations managers with advice on risk issues.
Internal auditors	To ensure that appropriate policy practices are carried out and to advise and assist on improvements
External Stakeholders	
Community Users	Vehicle drivers, pedestrians & cyclists using road & pathway assets utilising or requiring bridges. It includes tourists and visitors to the area.
Pathway Users	Those who have a need for access as pedestrians (including the very young), those with disabilities, and the elderly with somewhat limited mobility) and who have differing needs to motorists and cyclists
Users of a range of miscellaneous small & lightweight vehicles	Includes users such as pedal cyclists, motorised buggies, wheel chairs, prams, etc. where consideration has to be given to access requirements (ramps, etc)
Residents & businesses	Those who reside, work or have involvement with property adjoining the bridge structure.
Motorised Vehicle users	Those who use vehicles such as trucks, buses, commercial vehicles, cars and motor cyclists.
Commercial & Industrial producers	Those requiring access along transport routes for business.
Emergency services	Includes Police, Fire, Ambulance, SES for access
Traffic/Transportation Managers	For the management of traffic flow through the area
Maintenance personnel (External)	To ensure provision of the required/agreed level of maintenance services for asset components;
VicTrack & Metropolitan Rail Service operator (Metro)	Owner and operator of the metropolitan rail network that have 15 structures in which the City of Banyule has a maintenance role for road & pathway assets.
VicRoads & Utility agencies	Those utility service providers sharing use of bridge structures (water, sewerage, gas, electricity, telecommunications);
State & Federal Government Departments	Periodic provision of support funding to assist with management of the network.
Council's Insurer.	Insurance and risk management issues.

Figure 6. p. 12 Banyule City Council Asset management plan

(Banyule city Council Asset Management plan 2014.)

Figure 7 Above is an extract from Banyule city council . The road network is relied on many parties as tabulated and stresses how important it is to maintain it .

2.32 Strategic Asset management (SAMP)

The intention of a SAMP is to quantify the extent of works necessary to bring an asset to an acceptable standard that can cater for all stakeholders (Waverly city council, 2014, p.43).

An organisation can only invest so much capital in civil infrastructure. With its limited financial capacity appropriate decision have to be made in terms of ongoing maintenance costs.

Most often a prediction model is used to help facilitate the forecasting stage. However to generate informative output relevant parameters are required such as the general future demand.

Triggers which can start future demands need to be recognised in order to be incorporated into a SAMP. Unexpected events can have expensive consequences and may lead to augmentations or even expanding the road network (Lake Macquarie, 2013, p. 34) .

2.33 Demand Management

To meet demand levels demand management programs are needded to be resorted to hence the necessity for a SAMP. Measures which can be in place to help facilitate this include deferring or reducing the need of a new asset. Place restrictions on time or nature of use for example heavy vehicle limitations and speed (Randwick City council ,2004) . When councils design a road it generally has limitations in terms load, which can be defined as serviceability

2.34 Life Cycle Management plan

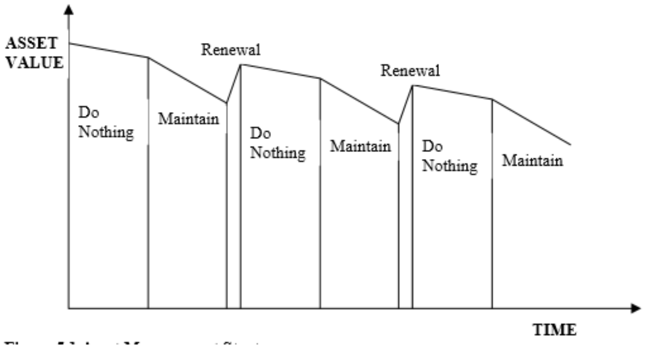


Figure 7 asset Life cycle

Randwick City Council 2004, PP.17

Figure 7shows a typical asset life cycle. The economic value of the assets devalues during the 'Do nothing' phase . The maintenance phase allows for activities to be done so that deterioration doesn't take up the whole value of the asset. The decline value of the asset at each renewal indicates that there is only so much treatment that can be applied to the asset before it becomes unviable. I.e the asset becomes classed as beyond economic repair (Randwick,2004) .

2.35 Serviceability

The level of service provided by a road can be measured by rutting and roughness generally. Rutting can be used to gauge transverse deformations of the pavement. Any ruts that has a depth of excess of 3mm may pond water during heavy rainfall creating dangerous conditions (Underwood 1995, p.77). Roughness influence ride quality and dynamic loads and drainage.

2.4 Modes of service failure

Aust Roads 2009 defines failure occurring in two ways "on – off" and "continuous". On-off generally means the asset has a complete loss of service. The cause of the nature of the failure maybe due to the age or because the intended life span has been exceeded. Assets that do fail generally have information available about the failure expectations from the manufacturer inventory records and experience of other road authorities (Lake Macquarie, 2012, Asset management plan transportation, p.45) . This is assuming some of these assets come from a commercial dealer.

Continuous failure means the asset is providing a service which is less than the satisfactory level required. Generally the life cycle has a number of factors such as the rate of degradation, environmental factors etc. A degradation curve may be developed from monitoring the condition of a large sample of the assets over time and an estimate is made of the age of the asset every time the asset lacks performance (Lake Macquarie, 2012) .

2.5 Pavement Indicators

With any road authority or local council, key performance indicators (KPI) play a vital role when governing the wellbeing of a road visual appearance, structural capacity and performance are vital aspects which underpin KPIs. As discussed previously there are many stakeholders who are affiliated with the road network and it is in the interest of the asset owner to maintain it to a certain standard. The following section will explore how pavement damage can be classified and measured.

2.51 Asset management Pavement management systems.

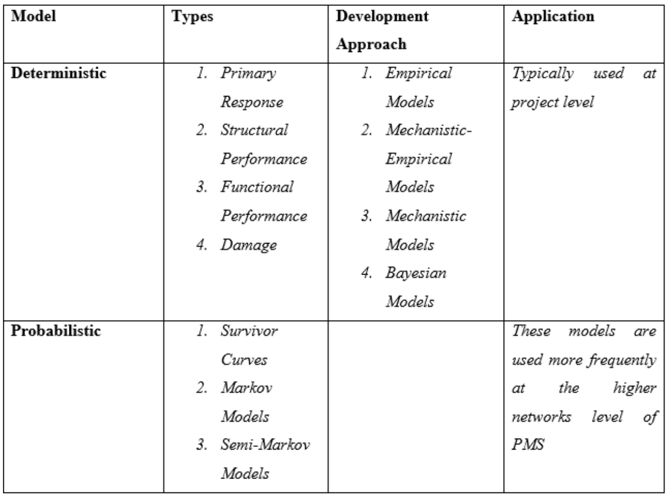
A pavement management system is very much a software which can be used for road defect inventory. Most public authorities utilize one so that road networks can be thoroughly analysed and maintained to a certain standard. Capital work programs are generated from Pavement management systems.

Embedded in this software are other application such as financial planning program and a GIS application. Priority setting in capital works is another tool which can constitute a PMS. PMS can be used as a long term planning tool that can anticipate pavement deterioration due to environmental effects and traffic loading (R. Mallick &T. El Korchi, 2013). The use of GIS for pavement management is very common . What makes GIS applicable to a PMS is the fact that locations of road conditions and location. Both of which are attribute and spatial data. Historical data such as road construction time, condition history and maintenance data. One of the key features of a GIS includes the ability to overlay different layers of information . The unique layering system allows for road condition data to be stored on one layer, pavement construction on another layer . Having some rectangular coordinates information to go along with it makes it a very dynamic tool . Topology identifies features that are within a certain distance from another feature, or features totally within another feature. This is a driving force of GIS (R. Mallick &T. El Korchi, 2013).

2.6 Asset management Prediction Models

With any road authority or local council, key performance indicators (KPI) play a vital role when governing the wellbeing of a road's visual appearance, structural capacity and performance. As discussed previously there are many stakeholders who are affiliated with the road network and it is in the interest of the asset owner to maintain it to a certain standard. The following section will explore how pavement damage can be classified and measured.

There are two principals which govern the way that a deterioration model operates, probabilistic and deterministic. A deterministic method encompass empirical, mechanistic and empirical-mechanistic (R. Mallick &T. El Korchi,2013) . The intention of simulating pavement deterioration is to very much identify pavements that are worsening at a faster rate than others. Furthermore being able to determine causes may assist with maintenance recommendations (B. Francis, L. Nelson, 2014). Figure 8 tabulates the various methods available to assess and simulate pavement deterioration



Model	**Types**	**Development Approach**	**Application**
Deterministic	1. *Primary Response* 2. *Structural Performance* 3. *Functional Performance* 4. *Damage*	1. *Empirical Models* 2. *Mechanistic-Empirical Models* 3. *Mechanistic Models* 4. *Bayesian Models*	*Typically used at project level*
Probabilistic	1. *Survivor Curves* 2. *Markov Models* 3. *Semi-Markov Models*		*These models are used more frequently at the higher networks level of PMS*

Figure 8 Prediction model types

(W. Vanderheydan,2001)

Having a predication model which can help forecast a condition of a road is most beneficial to most organisations. For funding and procurement purposes this is most essential. Predication models are commonly known to establish correlations between numbers of years a pavement may have against an algorithm which computes a particular a quantitative measurement of a pavement wellbeing. Some prediction models are much more sophisticated than others and are able to consider other parameters.

Generally there are seven pavement performance criteria. Inventory, Roughness, Rutting , Strength , Cracking and skid resistance as well as texture. The intention of performance modelling Is to forecast pavement performance if current condition of that pavement were consistent. Life cycle analysis is very much the term used when analysing a pavements performance. A pavement performance in a year can be described by one single figure. This single digit generally takes form as a PCI value and may be found over various segments of a road network. Figure 8 tabulates different types of modelling techniques that can be employed for modelling purposes.

2.61 Deterministic

A pavement performance in which there is a regression between a number of variables .

Performance models which is believed to have a number of variables associated with it when it comes to pavement performance. The stochastic element of pavement performance is overlooked (underwood,1995). This subgroup of modelling can be likened to mathematical models in which “outcomes are precisely determined through known relationships among states and events” (Khan et al, 2008) .

Pavements often perform better if not worse than what would normally be predicted from a deterministic approach. The output that is produced between these two types of models is completely different. Deterministic models give a single vale of a future condition of a pavement while a probabilistic output in the probability distribution of a specific aspect of the pavement. Probabilistic outputs are generally in the form of a range of values. Qualitative measurement would then take place. Very range would correlate with a description such as ‘good’, ‘very good’. These description will then be the final output (R. Mallick &T. El Korchi,2013).

2.611 Primary response measures

Change in stress, strain and deflection due to imposed loads are generally deemed as primary response . Useful for designing new pavements with known material however does not allow to formulate prediction models which models deterioration. Although it can be insightful about the factors which influence pavement behaviour (Ausroad Part 5H, 2009).

2.612 Structural performance Indicators

The ability for a road to sustain a certain load is a key parameter which needs to be assessed when deducing serviceability. In Australia there is grave concern about the structural capacity of roads being consumed along heavy road freight routes due to road freight tasks and legal axel limits (Austroads Part 5H, 2009) . The following are quantitative ways of gauging structural performance.

2.6121 Structural Number

Can provide structural information regarding a pavement

When assessing a road pavement visible defects along a pavement such as cracking will not provide insight into the structural condition of a pavement. According to Austroads 2009 Guide to Asset management part 5H the summation of the thickness of the layer multiplied with the modulus of elasticity can provide an indication of a pavement structural capacity.

2.6122 Modified Structural Number

This indicator is identical to the structural number but it takes into account of the subgrade which contributes to the serviceability of the pavement . The indicator takes into account of the CBR (California bearing ratio) and decides to give a negative contribution when CBR is less than 3% and a positive value when greater than 3% (Aust roads Part 5H Performing Modelling,2009) . This indicator is incorporated in HDM III. Deflection testing devices such as the Benkleman beam, Falling weight deflectometre and deflectograph can all be used to estimate the modified structural number (Austroads, 2009) . These devices will not be explored in this study as it is outside the scope of the study.

2.62 Functional performance Indicators

Functional performance indicators are usually used when evaluating long term performance.

The following distress measures can play a role in pavement performance indices.

2.621 Pavement Condition Rating (PCR)

Used to measure roughness and can be expressed from 0 -100 .Can be described by the following equation. (Kp Goerge et al, 1989) .

$$PCR = RR^{0.6}DR^{0.4}$$

Equation 2:Pavement conditioning

Where RR = Roughness rating and DR Distress rating

2.622 Pavement Serviceability Index (PSI)

Individual distresses weighed and combined . If it was to be combined then it would be termed as a composite index. Originates from Present serviceability rating developed by the AASHO in which a panel of ratters would drive on top of segment and make judgment on the level of service. Hence PSI was developed in which a coefficient was assigned to that particular deformation and hence an equation was created (Z.Li,2005). The coefficient was a mean value in which the panel had determined.

2.623 International Roughness index (IRI)

Based on the response of a generic motor vehicle to gauge roughness of the road surface. By obtaining a suitably accurate measurement of the profile of the road it processes through an algorithm so that data can be created and imitates the way a reference vehicle would respond to a roughness inputs and accumulates the suspension travel (R.Underwood, 1995). It can be measured by a stand alone device .

Roughness of a road may seem as an appropriate indicator in terms of performance. Economic evaluation of the life span of a road is seen to be related to road maintenance costs. Many road authorities around the world try to use road roughness as major parameter for their performance modelling purposes. However it should be noted that road roughness alone is not a good parameter to base road rehabilitation rectification processes. There are many other factors and measures that need to be taken into account (R. Underwood, 1995).

2.624 Pavement Damage Factors

Multiple factors can be taken into account when coming up with a pavement performance model or only variable can be used to represent time and traffic load. This particular variable would represent how much deterioration traffic load and time would cause. Pavement structural design models is normally based on how much damage a pavement is subjected to caused by axles of various loads. This can be represented by the equation 1.

The equivalent factor indicates the amount of damage a pavement sustains when different axle loads and groups are used. In Australia granular pavements are widely used and for that reason 4th power is used. Although this was discovered by the American Association of State Highways , Queensland Main Roads have done their own independent testing and have found the same result (Austroads part 5H, 2009).

Damage factors are not indicators of long term pavement performance but mostly used for assessing various pavement design options. A pavement's end of life or critical condition is not clearly defined and exactly how damage factors are derived are not very clear .

The output of a probabilistic performance prediction model is the probability distribution of the condition attribute at a certain point in time.

2.63 Developed Approach

2.631 Mechanistic

Models which are based on this kind are non –existent. Based on a fundamental and primary response approach such as elastic theory (Z.Li , 2005,) . Based on theoretical information about pavement performance but are calibrated using regression analysis (Lytton 1987). Must adhere to known boundary conditions and physical limits. I.E every local authority has a threshold what may seem acceptable in terms of road condition.

2.632 Mechanistic – empirical models

Based on theoretical information about pavement performance but are calibrated using regression analysis (Lytton 1987). Must adhere to known boundary conditions and physical limits. If correctly modelled can be they can be applied beyond the range of data from which the are developed (Z. Li , 2005,). Data relating to time that describes deterioration of different pavements that have been effected by loading and environmental factors. While also taking into account of deflection by considering different materials and loadings .

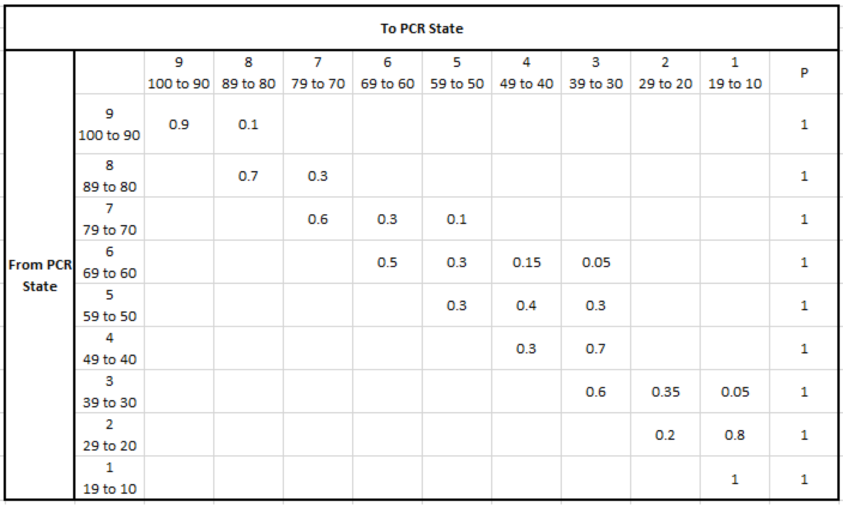
2.633 Empirical Models

Developed from regression analysis of experimental or observed data. When the performance of a pavement is ambiguous these types of models are a good model to adapt. Mainly used in tropical countries.

Associates dependent variables with independent variables of pavement performance and finds a correlation between the two. From the trend it then gives a single value to the dependent variable.

2.64 Probabilistic

Recognises the random probability distribution of pavement performance. By finding patterns and statistical likelihoods of the variables that contribute to a single dependent variable. It operates under the principal that future conditions can be determined from the current state of the pavement if the likelihood of it occurring is known (Li et al, 2002).



		To PCR State									
		9 100 to 90	8 89 to 80	7 79 to 70	6 69 to 60	5 59 to 50	4 49 to 40	3 39 to 30	2 29 to 20	1 19 to 10	P
From PCR State	9 100 to 90	0.9	0.1								1
	8 89 to 80		0.7	0.3							1
	7 79 to 70			0.6	0.3	0.1					1
	6 69 to 60				0.5	0.3	0.15	0.05			1
	5 59 to 50					0.3	0.4	0.3			1
	4 49 to 40						0.3	0.7			1
	3 39 to 30							0.6	0.35	0.05	1
	2 29 to 20								0.2	0.8	1
	1 19 to 10									1	1

Figure 9 : Transition probabilistic matrix

(N. Garber et al , Traffic and highway engineering).

The figure above is a Markovian model and shows the likelihood that a pavement in one condition will change to another. This is known as a transition probabilistic matrix Pavement condition ratings are transferred in to discrete condition states. If a pavement has a PCR is within 20-29 then the probability is 0.8 that the following year the pavement condition will be within 10- 19 . The Markovian omits any information regarding how a pavement got to that condition in previous years. But focuses on the coming year of the possibility being in a particular state (N.Garber et al ,2009). Often the transition matrix is based on expert opinions or historical data.

2.6 41 Continues pavement modelling.

Forecasts future failure probabilities. Incorporates Bayesian models which are formed from observed data combined with expert experience using Bayesian regression techniques. Bayesian regression was initiated to deal with small quantities of poor quality observed data.

Both Markov and semi – Markov approaches do require probability transition matrixes as it governs the process of change between pavements. Because the Markov and Semi Markov have different ways of process they both require different PTMS (Ercisli, 2015).

It is widely believed that a pavement transferable matrix system PTMS is made up of averages of previous PTMs. There are a number of reasons in which PTMS can be thought as being inaccurate as there are cases in which the number of variables is greater than the number of observations. When little observation data is available both of these mechanisms are very useful.

2.65 Pavement condition Index (PCI)

Measure of a piece of highway based upon visual observation . The rating system goes from 1 to 5. 0 being completely awful while five is perfect. However it can be ranged from 1 to 10. One being the best condition while ten being the worst or vice versa.

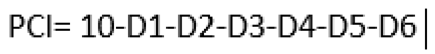
Because of the way in which the distress measures are weighted and combined to formulate these indices they wouldn't be appropriate to measure long term pavement performance. Age is a major variable in the calculation of the PCI as time passes road deterioration can be measured and correlated. The passing of time and monitoring how much remaining life there is a good comparison, as it enables the possibility of developing trends. This particular type of indicator does have some limitations such as unable to identify subsurface issues nor does it look into structural capacity . The general steps taken to produce a PCI value include the following .

- Locate signs of distress and create a segment on the road .
- Distinguish the distress sown on that particular pavement
- Quantity the level of severity of the distress shown on pavement
- Enter data into software in which a PCI will be generated .
- Extrapolate PCI values so that a simulation can take place over the natural life of the pavement (I. Nelson et al, 2014)

2.66 SMEC and Assetics PCI calculation

SMEC is a pavement management system which will be used as a deterioration tool of interest for the purposes of this research study. The following section will demonstrate the way in which SMEC computes it own PCI values. Most PMS have their own criterion I.e. they have their own formulas and way of calculating their PCI's. For instance the following is an example of how SMEC calculates their PCI's. The following is a script for computing PCIs published by SMEC and featured in "SMEC Pavement management and road inventory system, 2015" .

Equation 3 SMEC PCI generating



PCI= 10-D1-D2-D3-D4-D5-D6

D1 = Deduct points for roughness

MAX . (0,((-4.361411*10^-9*AADT^2)+(4.91687*10^-4*AADT)+7.74)*(ROUGH-2.65)

Equation 4: D1

MAX . (0,((-4.361411*10^-9*AADT^2)+(4.91687*10^-4*AADT)+7.74)*(ROUGH-2.65)

ADDT= Annual Average daily traffic

ROUGH = Pavement roughness in units NASSARA roughness

D2 = Deduct points for all crack

$$\mathrm{MIN}(10,\ ACRACK*0.17)$$

Equation 5 : SMEC D2

Where ACRACK = Percentage of the pavement cracked.

D3= Deduct points for wide cracks

= WRCRACK = percentage of the pavement area with wide cracks.

Equation 6: SMEC D3

D4 = Deduct points for potholes

$$\mathrm{Min}(5,POTH*10)$$

Equation 7: SMEC D4

POTH= Percentage being potholed.

D5 = Deduct points for rutting

$$=RUT*0.125$$

Equation 8: SMEC D5

RUT= MEAN RUT DEPTH in mm

D6 = Deduct points for ravelling

$$= RAREA * 0.02$$

Equation 9: SMEC D6

RAREA = percentage of the area ravelled.

(SMEC Pavement management and road inventory system, 2015)

It should be noted that a negative value can be generated as the deductions are accumulative.

2.661 Ascetics – PCI Generation

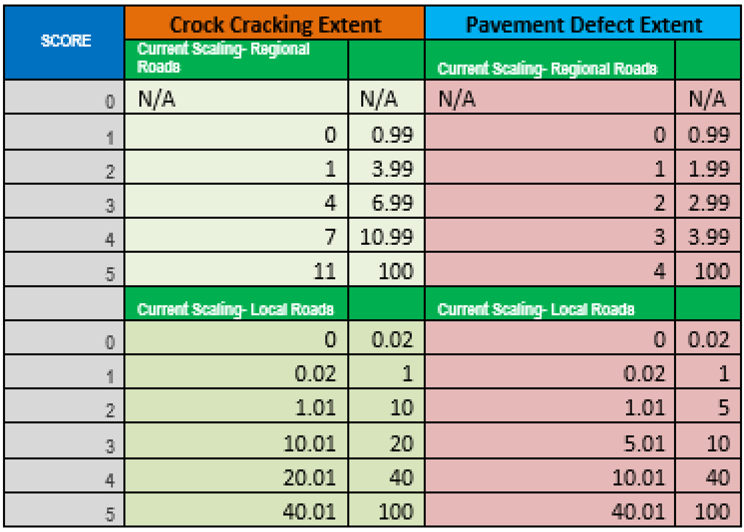
As mentioned in 2.6.14 PCI is very much a rating that is rated out of five. GCC describes the each rating as the following as detailed in the tables below

Table 1: Assetics PCI qualitative description

PCI	Description
1	Very Good Cyclic maintenance required
2	Good minor maintenance required plus cyclic maintenance
3	Fair . Significant maintenance required.
4	Poor. Significant upgrades required .
5	Very poor. Unserviceable

The qualitative description is very similar to how SMEC assigns its qualitative descriptions despite the fact SMEC is out of a rating of ten . Tables 1 describes the scoring system which is in place when assigning a PCI value . Basically every defect such as potholes cracking, ravelling and stripping is given a score . The combined is then assigned to a PCI . All cracking defects are calculated separately to pavement defect extents . Which ever s taken for a PCI evaluation.

Gosford cities council way of generating a PCI value is quite different to the way in which Wyong shire council generates their own PCI values.



SCORE	Crock Cracking Extent		Pavement Defect Extent	
	Current Scaling- Regional Roads		Current Scaling- Regional Roads	
0	N/A	N/A	N/A	N/A
1	0	0.99	0	0.99
2	1	3.99	1	1.99
3	4	6.99	2	2.99
4	7	10.99	3	3.99
5	11	100	4	100
	Current Scaling- Local Roads		Current Scaling- Local Roads	
0	0	0.02	0	0.02
1	0.02	1	0.02	1
2	1.01	10	1.01	5
3	10.01	20	5.01	10
4	20.01	40	10.01	40
5	40.01	100	40.01	100

Table 2: GCC PCI distribution bins

The table above shows that in the far right column the percentage of the segment of road which is affected by the defect while in the left column indicates the condition bin which it belongs to. The highest value between the Crock cracking extent of the pavement defect in question is considered to be the PCI value. However as shown in table 2 it would have to be placed into a particular distribution bin in which it would be then assigned the corresponding PCI value.

2.662 Comparison between SMEC and Assetics PCI value generation.

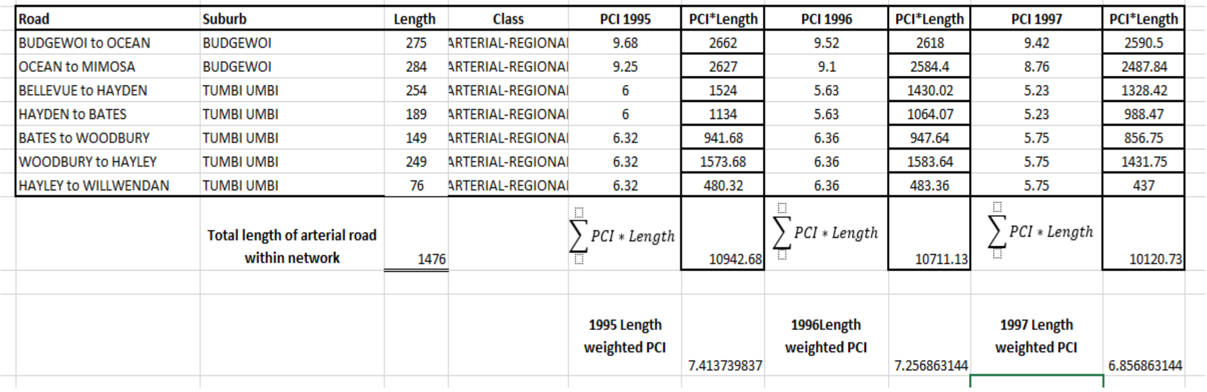
From what has been presented in the table the way both systems generate PCI values is quite different from one another, and can be generated due to the way in which both systems are either empirical or probabilistic. After interviewing the asset management team at WSC and GCC it was found that the Ascetics PMS required a lot of user operative intervention. Unlike SMEC which is fairly independent and required minimal operator input.

2.7 Length weighted Average PCI

With an array of PCI values generated from each council having an overall PCI value which can be used to represent a particular class of road for one particular year would be idyllic. However the computation to perform this would need take into account the length of each road has been surveyed as well as the PCI value for that individual road . These are the two parameters which would make up the length weighted average.

For the benefit of the study a length weighted average will need to applied as the data provided only PCI values for every road segment as well as the length.   *"Establishing optimal pavement maintenance standards using the HDM-4 Model for Bangladesh'* written by Misbah Khan and Jennaro Odoki *provides* an equation which takes form as detailed below.

$$= \sum PCI * lenght\ of\ road / \sum Class\ of\ road\ within\ the\ network$$



Road	Suburb	Length	Class	PCI 1995	PCI*Length	PCI 1996	PCI*Length	PCI 1997	PCI*Length
BUDGEWOI to OCEAN	BUDGEWOI	275	ARTERIAL-REGIONAI	9.68	2662	9.52	2618	9.42	2590.5
OCEAN to MIMOSA	BUDGEWOI	284	ARTERIAL-REGIONAI	9.25	2627	9.1	2584.4	8.76	2487.84
BELLEVUE to HAYDEN	TUMBI UMBI	254	ARTERIAL-REGIONAI	6	1524	5.63	1430.02	5.23	1328.42
HAYDEN to BATES	TUMBI UMBI	189	ARTERIAL-REGIONAI	6	1134	5.63	1064.07	5.23	988.47
BATES to WOODBURY	TUMBI UMBI	149	ARTERIAL-REGIONAI	6.32	941.68	6.36	947.64	5.75	856.75
WOODBURY to HAYLEY	TUMBI UMBI	249	ARTERIAL-REGIONAI	6.32	1573.68	6.36	1583.64	5.75	1431.75
HAYLEY to WILLWENDAN	TUMBI UMBI	76	ARTERIAL-REGIONAI	6.32	480.32	6.36	483.36	5.75	437
	Total length of arterial road within network	1476		$\sum PCI * Length$	10942.68	$\sum PCI * Length$	10711.13	$\sum PCI * Length$	10120.73
				1995 Length weighted PCI	7.413739837	**1996Length weighted PCI**	7.256863144	**1997 Length weighted PCI**	6.856863144

Figure 10:Length weighted Average Sample

It can be seen in the above figure how the length weighted average was applied to the data provided from both councils. Essentially as the equation describes the PCI is multiplied by the length of the road. Once every road of the same class and same year has been computed, these number are added together and divided by the length of the network of that particular class

2.8 Examinations of other councils

For the following section will examine the councils of interest .

2.81 Southern Grampians Shire Council Asset management

The following is a case study in which Southern Grampian Shire Council has conducted on their road network. A publication was released by the council which is based on road infrastructure. The asset management publication will be examined and the way In which the shire conducts its life cycle analysis will be speculated .

2.812 Southern Grampians Shire Council

Many local governments have a road network which is aimed at being safe convenient for transporting people and goods. Southern Grampians shire council has a road hierarchy system in which appropriate management, engineering standards and planning practices are applied based on its functionality. By having such a system in place it allows for appropriate resources that are in greater need in which leads to greater justification.

In order to maintain a certain level of service financial input in required. Otherwise level of service may need to be reduced. Financial aid is generally given by other tiers of government at State and Federal level.

2.813 Cost Reduction

One of the ways In which Southern Grampians Shire Councils attempts to save funds is through demoting certain roads. Demoting a road class can occur which in turn means a reduction in maintenance and renewal cost. Load limits may need to be introduced due to the demotion.

Southern Grampians shire council highlighted the following ramifications that can result when load limits are introduced (Southern Grampians Shire Council, 2013) .

- Large cargo trucks may move onto highways which are maintained by road authorities .
- On boundary roads with traffic generators in neighbourhood Council areas negotiate a more agreeable maintenance management.

2.814 Responsibility as Custodians

The council has certain responsibilities as custodians of the infrastructure :

- Cost effective life cycle management
- Ensure satisfactory level of service is provided by the piece of infrastructure.

However ongoing issues include:

- Excavating in an appropriate manner by service providers and contractors.
- Management mechanisms which can allow over weight and over dimensioned vehicles.
- Southern Grampians shire council recognises that by having large B double vehicles it reduces the number of vehicles required to transport a given number of freight. At present Southern Grampian Shire council has 19 local roads which are suitable for heavy vehicles. (Southern Grampians Shire Council, 2013)

2.815 Asset condition report

The intention of condition survey is to assess the competency of the civil infrastructure. Like most councils a contractor is brought upon to profile the roads picking up specific defects and providing the data back to the local council.

Southern Shire Grampians council has adopted the Moloney Asset management intervention level . The rating systems goes from 0 to 10 .

Table 3 Moloneys rating system

Southern Grampian shire council, 2013

0	New
1	Near new
2	Excellent
3	Very good
4	Good
5	Fair
6	Fair to Poor
7	Poor
8	Very Poor
9	Extremely Poor
10	Failed

2.816 Asset Degradation

Once the first survey has been accomplished a performance curve can be created in which decline in quality can be estimated. The transition change can be used to derive statistical probability for future degradation. This is very much the very core of prediction modelling.

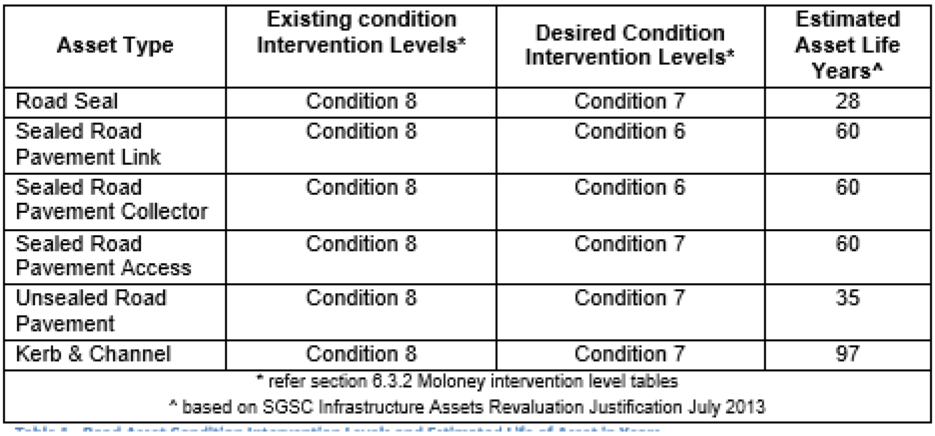
The performance curve can also be used for financial modelling for budgeting purposes. For justification purposes they can be used. From what was covered in section 2.6 the Molony's model can be described as being probabilistic .

2.817 Intervention Levels

The Moloney's report generally gives its outputs in terms of PCI & year. Southern Grampian shire council recognises that there are a number of variables which can influence a roads pavements life cycle and that routine maintenance can certainly improve an asset life span. Geometric design , Structural composure, weather patterns , traffic counts and vehicle loadings (Southern Grampian shire council, 2013). The publication details that strategies that are employed to reduce deterioration include the following

- Road network is maintained in accordance with agreed levels of service.
- Defects are rectified in advance in pavement resealing works.

4.2 General Road Asset intervention condition



Asset Type	Existing condition Intervention Levels*	Desired Condition Intervention Levels*	Estimated Asset Life Years^
Road Seal	Condition 8	Condition 7	28
Sealed Road Pavement Link	Condition 8	Condition 6	60
Sealed Road Pavement Collector	Condition 8	Condition 6	60
Sealed Road Pavement Access	Condition 8	Condition 7	60
Unsealed Road Pavement	Condition 8	Condition 7	35
Kerb & Channel	Condition 8	Condition 7	97

* refer section 6.3.2 Moloney intervention level tables

^ based on SGSC Infrastructure Assets Revaluation Justification July 2013

Figure 11 Road Asset Condition Intervention levels and estimated life of asset p .7

Figure 11 which was featured in the Asset management publication released by Southern Grampians shire council demonstrates the general intervention level and the estimated asset life if these interventions were to be in place.

Figure 11 is very explicit when specifying an asset component and infers that the design life is very much to do with material that make up the asset. It would seem that sprays generally have a shorter life expectancy than an urban sealed road. It is assumed that the physical life expectancy is the length of time in which the asset can function while having intervention measures in place.

It can be seen that most of the network is only attended to when certain parts of the network Is in a very poor state. The demographics of Southern shire Grampians council is unknown however judging by the life expectancy from their assets and the general life expectancy featured in figure 11 it can be seen that Southern Grampians shire council has a slower rate of deterioration. This maybe due to the sustainable demand as well as the serviceability that these devices can provide. Figure 11 is the general expectation in which a device can be expected to last for.

2.82 Gosford City council Asset management

For the purpose of this paper Gosford city council (GCC) will be examined closely . The former Gosford city council now known as Central Coast council classifies roads into three the following

- State
- Regional
- Local

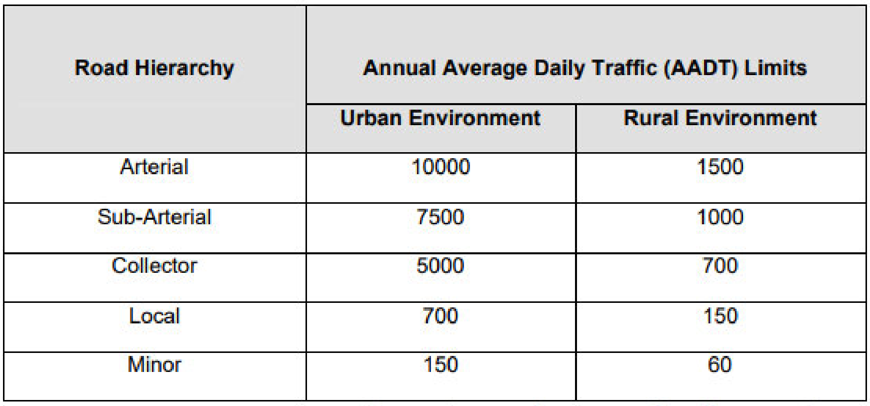
It then further classifies local roads into the following .

(Gosford Asset management for transportation, 2014)

- Collector
- Minor
- Local access
- Local rural

The intention of having these levels of roads is so that the Pavement management System can make the necessary arrangement in terms of which particular roads require a particular treatment. Appropriate funding can be allocated to each road type and in depth analysis of road deterioration, traffic usage patterns can also be assisted by having these classifications (Gosford Asset management for transportation, 2014) .

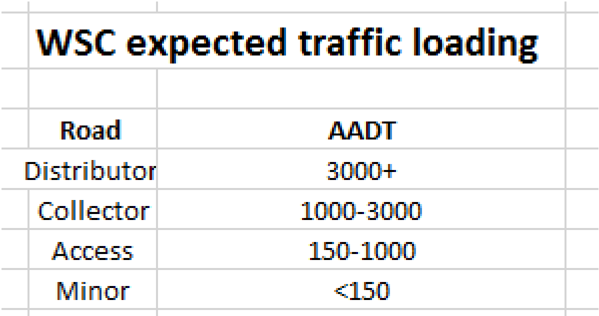
The table below shows how much traffic in terms of AADT that the previous Gosford city council would be expecting .



Road Hierarchy	Annual Average Daily Traffic (AADT) Limits	
	Urban Environment	Rural Environment
Arterial	10000	1500
Sub-Arterial	7500	1000
Collector	5000	700
Local	700	150
Minor	150	60

Table 5: AADT Gosford network

Gosford Asset management for transportation, 2014



WSC expected traffic loading

Road	AADT
Distributor	3000+
Collector	1000-3000
Access	150-1000
Minor	<150

Table 6: WSC expected Traffic Loading

IT can be seen that traffic loadings between WSC and GCC are some what similar but have some different road types .

2.821 Assetics

As previously mentioned in other parts of the literature, Gosford city council uses Pavement management system known as Assetics which has a number of features in built into it . The three components which are integral to the program includes the following .

- Mydata
- Myvaluer
- Mypredictor

myPredictor is an application in which Gosford city council utilises to come up with deterioration model after road condition data and information has been collected (Gosford Asset management for transportation, 2014). Mydata is the database in which road defect is entered into which in turn feeds the information into myPredictor . Myvaluer keeps record of the financial portfolio and provides reporting facility (Gosford Asset management for transportation, 2014) . Mypredictor as very much a strategic tool which allows users to come up with strategic management procedures and maintenance schemes (Gosford Asset management for transportation, 2014). True results is only found by doing comparisons to other local government trends in which tweaking may take place. Mypredictor is purely about making deterioration curves based on regression analysis (Gosford Asset management for transportation, 2014).

It can be seen that surface condition is used which has a whole other criterion governing it . However it is the greater value between the PCI and SCI is taken as the overall index. Surface condition index was not explored only because it is outside the scope of the study.

Table 7 : Prioritiation of works

Gosford Asset management for transportation, 2014

Criteria	Weighting
Significant safety issues present	assessed on project basis- high priority
Present Condition (PCI, SCI)	Optimised by MyPredictor
Hierarchy (Collector, Local Access, Minor)	Optimised by MyPredictor
Community Sensitivity	to be documented

The table above demonstrates how myPredictor places each criteria which greatly influences the prioritisation of capita works. It would seem that maintenance would take place regarless if there is no condition index.

Figure 12 LOS Decline

Gosford Asset management for transportation, 2014

The figure 12 above was generated by myPredictor and includes both the Regional and local road network. The average PCI from the degradation curve happens to be 1.35 while the average Surface condition index is 2.56 . The schematic diagram above shows the lack of decline in PCI values SCI which in turn means how well maintained GCC road network is. It is unknown what exactly governs the Surface condition Index however the figure does show that PCI values is very stable which reflects the PCI distribution bins the lack of variety it has to offer.

The figure below shows the change in condition in the road network in years to come . The output generated has taken into account of the funding available and the ways roads are prioritised . It can be seen that the change in PCI value particularly in the condition one only increases as the years go by. This maybe due to the lack of funding available in coming years.

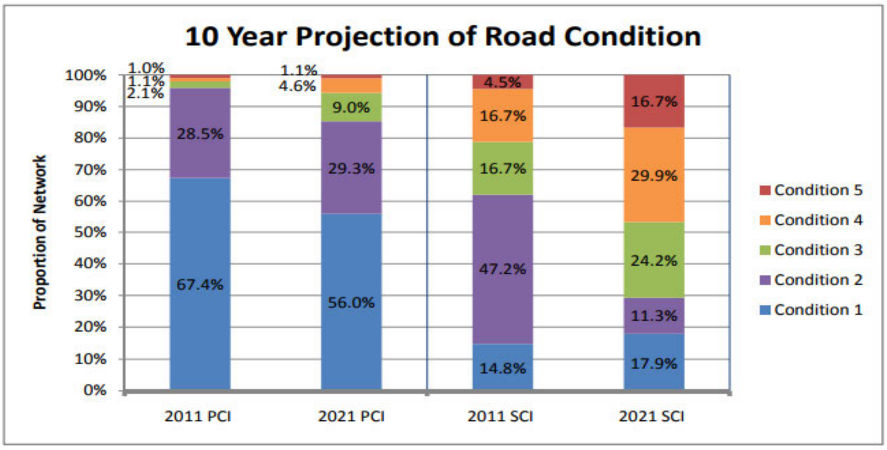


Figure 13 Gosford Asset management Projected Road condition

Gosford Asset management for transportation, 2014

According to the Gosford city Council Transport Asset management plan, more vehicle collisions more insurances claims as well more user dissatisfaction will result if the road network was to

Deteriorate at this rate. Highlighting the urgency of the matter.

2.822 Asset Information Systems

Southern Grampians shire council uses an inventory system known as Conquest to record its asset management data, which is linked to the GIS system MapInfo.

The whole idea of this system is to generate outputs such as condition graphs of the network, maintenance and rehabilitation programs.

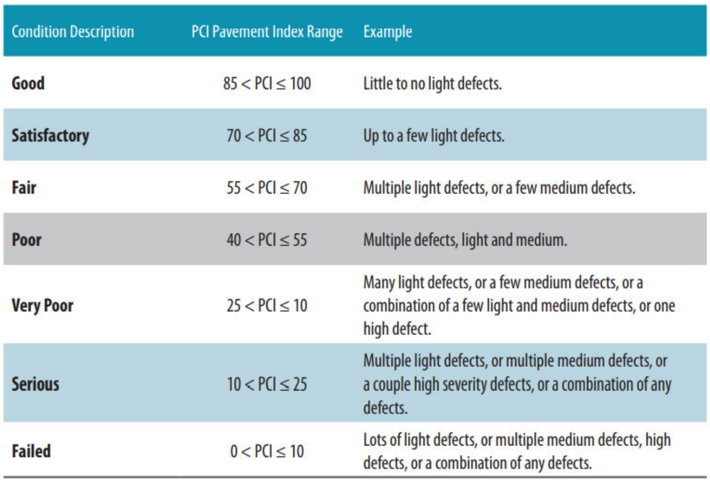
2. 83 Summary of Findings

It can be seen that Southern Shire Grampians Council uses a diverse range of pavement defect regimes in terms of identification. The Moloneys model requires a lot of input parameters which is needed in order for it to produce the necessary output. However to some degree it can be found that there is some level of customisation allowance within the model. Both Gosford City Council and Southern Grampians shire council have been looked into in terms of the way each council conducts their asset management . Gosford is located in the Central coast and divides its network as either being urban or rural and seems to keep a steady value as depicted in figure 12 . Southern Grampians shire council hasn't got sophisticated network segregation tactics employed over its own road network. Located in South West Victoria, Southern shire Grampians council is very much a complete rural area but has a very low PCI intervention level.

2.831 Start of life and End of life pavement PCI values .

This part of the literature review will be examining the shape formation of deterioration curves . Asset management locally and internationally are examined and interviews with design engineers have been conducted. As stated in chapter one, a deterioration modelling curve will be attempted to be developed. For that deteriors curves and applying criterion will be explored.

It can be seen in figure 15 that the intervention level is generally when the PCI value is around 8 and by having this regime it allows the pavement to have an extensive life span. The City of Saskatoon located in Canada presents a table of PCI range values and a qualitative description.



Condition Description	PCI Pavement Index Range	Example
Good	85 < PCI ≤ 100	Little to no light defects.
Satisfactory	70 < PCI ≤ 85	Up to a few light defects.
Fair	55 < PCI ≤ 70	Multiple light defects, or a few medium defects.
Poor	40 < PCI ≤ 55	Multiple defects, light and medium.
Very Poor	25 < PCI ≤ 10	Many light defects, or a few medium defects, or a combination of a few light and medium defects, or one high defect.
Serious	10 < PCI ≤ 25	Multiple light defects, or multiple medium defects, or a couple high severity defects, or a combination of any defects.
Failed	0 < PCI ≤ 10	Lots of light defects, or multiple medium defects, high defects, or a combination of any defects.

Figure 15 PCI Condition descriptions

City of Saskatoon Asset Management,2015, p.7

As discussed in the asset management plan publication released by the City of Saskatoon it is not common to have PCI value of 90- 100% in their inventory, as it also mentions that it is best to have the road go through a life cycle before applying treatment. It would seem that having a PCI of 90- 100% would be pretty rare for the City of Saskatoon and that it would have to be a brand new road in order to achieve that rating. Failed road can be seen to have a PCI value between 0 and 10 . Southern

Grampians Shire council has also classified a failed road as a PCI of 10. It also classifies a new road as a 0 and a near new road as a 1 .

2.84 Campbelltown City Council

Like most our local governments Campbelltown city council applies their own asset maintenance strategy across their own road network. Figure 4.8 depicts how the council goes about their typical maintenance regime. Table 8 describes the range of PCI values which can be used to quantify the description given in figure 14 .

Qualitative measure	PCI threshold
0 - 2.5	Very Poor condition
2.5 - 4	Poor condition
4.0-6.0	Average condition
6.0-8.0	Good condition
8.0-10	Excellent condition.

Table 8 Qualitative descriptions

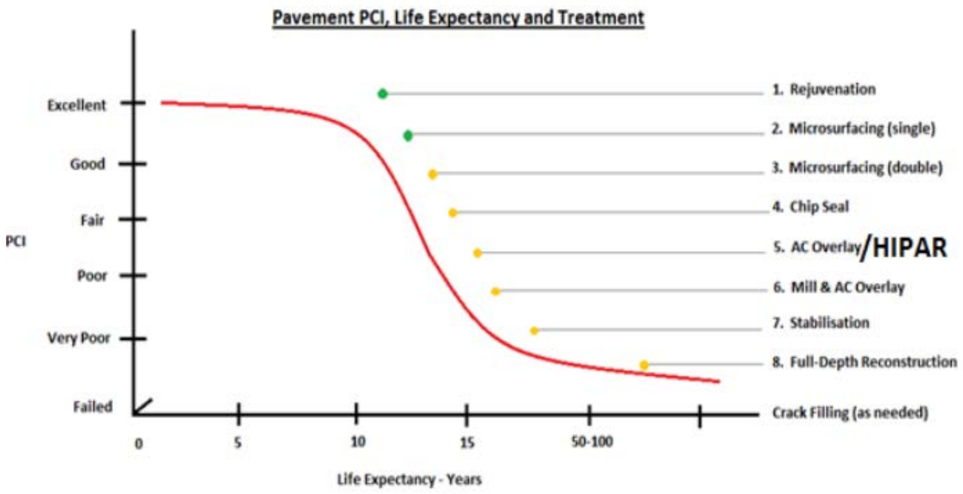


Figure 14 Cambelltown city council Road deterioration

Sustainable pavement Management startedgy p.19

City and County of San Francisco and Campbelltown city council both have deterioration curves that are of similar shape as shown in figure 15 . It should be noted that both of these figures do not have the exact same curvature only because they are in different road networks in two different countries.

2.845 Expected pattern of Deterioration

Earlier parts of the literature found that different civil devices deteriorate at different rates such as Southern Grampians Shire council's road network . However it would be fair to assume that there is a common deterioration trend among all local government jurisdictions. Figure 15 is an extraction from *City and Country of San Francisco Safe streets and Road repair* which shows the general deterioration across their road network .

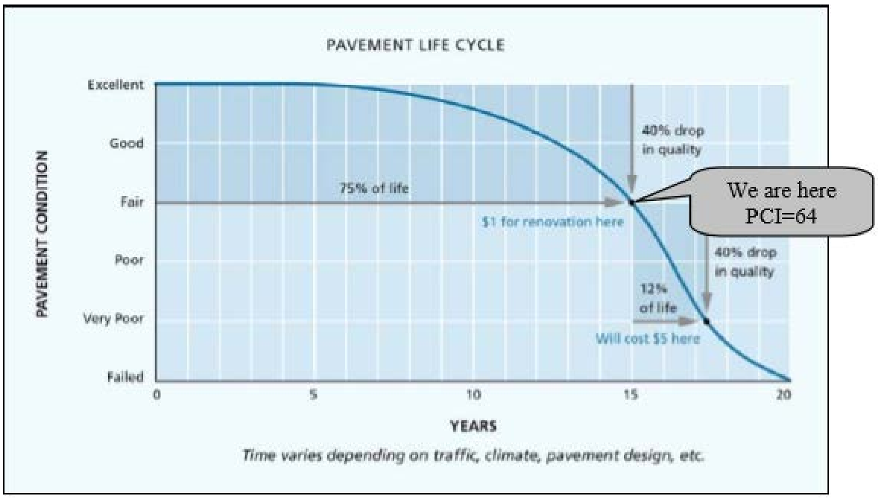


Figure 15: City and Country of San Francisco Deterioration Curve

City and County of San Francisco Asset management

If Southern Shire Grampians council PCI values were to be placed accordingly to each pavement condition for the City and Country of San Francisco, the PCI values would start off with a 2 and eventually a PCI value of 5 at fifteen years. At 17.5 years it would be a PCI of 6 and a PCI of seven at twenty years . While this may be a very crude way of describe a pavement that has a life span of twenty years it can certainly provide a snap shot of how a pavement can deteriorate .

For the purposes of this research the deterioration trend will be developed will somewhat resemble the curvature as shown in figure three . However as explained in chapter 1 the only data type of deterioration in which the research is interested In is only deterioration without any intervention .

2.846 Findings found so far

So far from what the literature has uncovered is that most local councils both domestic and international factor in maintenance regimes when developing a deterioration as expected. In figure 4.3 Gosford City Council makes sure that their network is well taken care of . But because the study at hand is all about developing models in which no treatment is provided a few assumptions need to be made .

2.85 Assumption of deterioration models which require no treatment

Figure 14 and 15 deterioration models produced by city and county of San Francisco and Campbell city council show a very steady degrade for the first ten years . Followed by a "deaccelerating curvature " . A certain level of value taken be gathered from both of these graphs in terms of shape. Deterioration normally takes in the form of an upside down quadratics as shown in figure 17 .

Figure 16

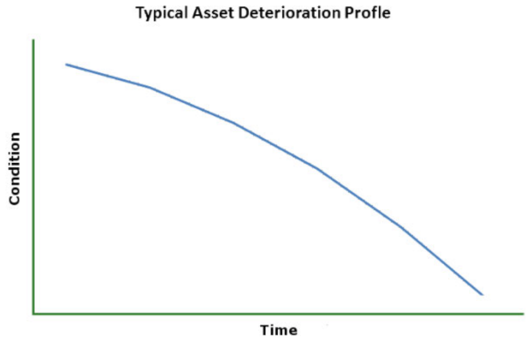
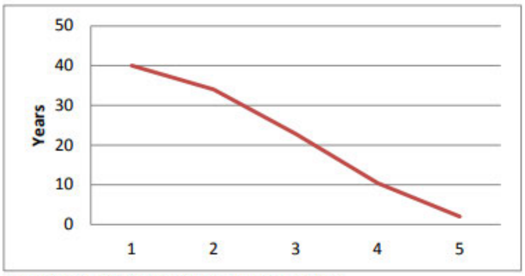


Figure 17: Typical Deterioration

ASSET Insight , 2017

Figure 2.4 is far more consistent in curvature unlike 2.3 and 2.4 . Hence for the purposes of this research modelling of deterioration will be aimed at mimicking an upside down quadratic.

2.86 Untreated pavement data



Remaining life (years) based on condition

Condition	1	2	3	4	5	Total
% of life in condition	15	28	31	21	5	100
Years in condition	6	11.2	12.4	8.4	2	40

Figure 18: Coff Harbour City Council Asset Management

Coff Harbour Asset Management 2014

Figure 18 was attained from Coffs harbour city councils Transport Asset management plan publication . The figure shows a very similar shape to an upside down quadratic. Chapter three and appendix B will attempt to use this very data in order to formulate an untreated deterioration curve

2.87 Assumption of Initial and Final PCI values

The literature has uncovered that the City of Saskatoon has rarely use PCI values of 90% and 100% as discussed in section 2.5 . Warrnambool city council located in south west Victoria recently was involved in an airport run way upgrade. Design engineer were interviewed in regards to the differences between the standards of road pavements and airport runways. The team mentioned that the main differences between airports and road pavement is that airports have point loads of high magnitude hence high maintenance is required for airport runway. To the point where they are all brand new . One of the designer's personnel opinion was that a PCI was ten was required when designing an airport run way. But to have a road that is of a PCI of ten is not practical, Nor road is ever brand new.

Based on the information provided by design engineers of Warrnambool city council and City of Saskatoon it would be reasonable to assume that a PCI of ten would not achievable on a typical road pavement and that a more conservative initial PCI would be about 9.5 . Public authorities can only allow a road pavement to degrade to such a level before it becomes a danger to the public . Section 2.35 highlights how imperative it is to maintain a pavement serviceability. Although Southern Grampians shire council has described a PCI 10 be a fail which is equivalent to a PCI of zero when the logic is reversed, it be would most conservative to have a minimum PCI of 2.5 . No public authority would ever let a road ever be a danger to the public . In essence for the purpose this this study an initial PCI of 9.5 will be used and finished at 2.5 .

2.88 SMEC

The former Wyong Shire council preferred using a PMS known as SMEC . Just like ascetics SMEC has the ability to store inventory road data and provide financial reports in regards to how a road is performing . Like most other PMS packages it has a mapping component known as mapXtreme which allows layers to be turned on and off (SMEC,2010) . Thematic maps can be made using data sets such as

- Surface type
- Surface Age

- Hierarchy
- Road width
- Pavement Type
- ESA loading (SMEC Pavement Management & Road inventory system 2015)

Custom made maps can be produced in which predicted information in years to come can be represented if current maintenance methods were to continue. Giving the user informative outputs and empowering them with the knowledge of the consequences that may lie ahead.

2.881 HDM4

HDM (Highway maintenance and management system) was created by the World bank and is very much a tool that can forecast the durability of a pavement. Aside from predicting deterioration in coming years the HDM 4 can also do project analysis, strategic analysis and research policy and regulation analysis . Project analysis allows for different options to be in place to combat road defectiveness by allowing the operator to come up with a series of scenarios to such as doing low level road maintenance which may include pothole patching and crack sealing (RHD, 2017) . Heavy duty maintenance such as pavement upgrades , Geometric alteration and realignment . New construction and a staged construction are also options which can be chosen by the operator. Strategic analysis involves subdividing the network into smaller networks according to their condition. While knowing their current state this particular feature can optimise capital injection by evaluating what treatment is best placed into a particular part of the network. The research element to HDM-4 is to enable operators to place scenarios if there was to be a load axle limit to be placed on a road or if there was to be a toll charge on certain roads (RHD, 2017). By placing these parameters the pavement deterioration model can take these factors into consideration and give various outputs.

Built into SMEC this feature is the actual pavement modelling system.

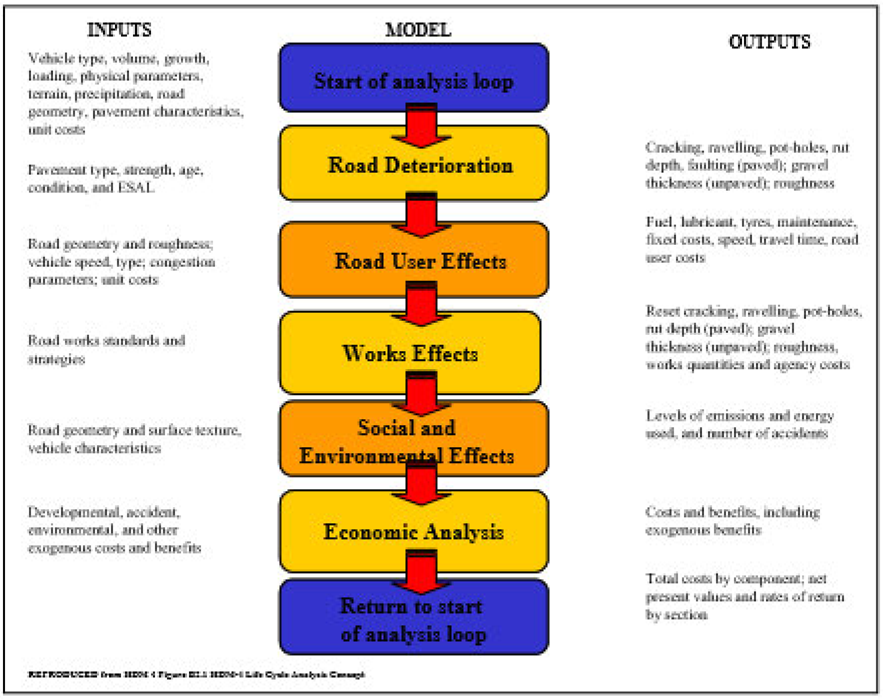


Figure 19: HDM Work Flow

(W. Vandermeer,2001)

2.9 Case Studies of road deterioration.

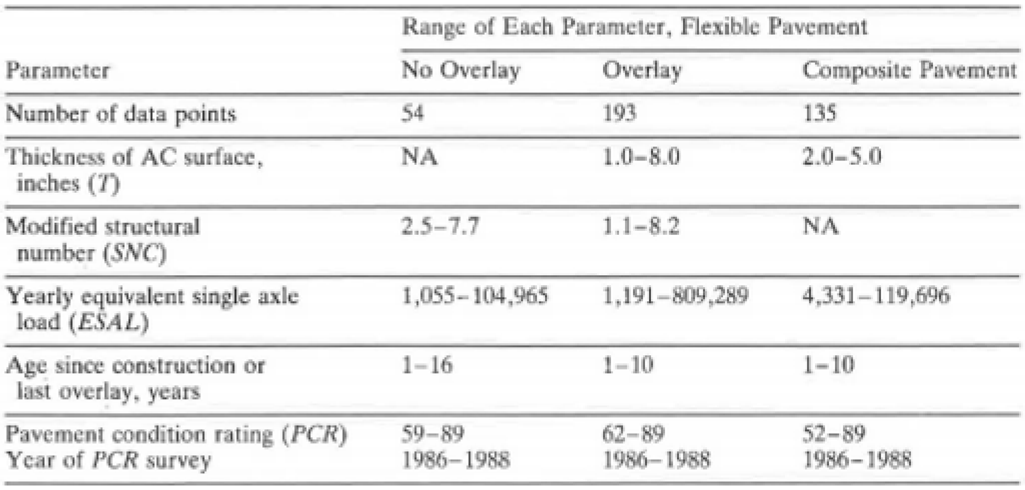
This section of the literature review will attempt to analyse two studies which are very similar in terms of research. Both of studies are analysing modelling techniques with road pavements and produce similar outputs. The techniques being employed can be applied to the research study in which this paper will analyse.

2.91 Model for predicting pavement deterioration (KP. George et al)

Department of Civil Engineering at the University of Mississippi has presented a research paper That examines three type of pavements flexible pavements with no overlay, flexible pavements with one or more overlays and composite pavements and form deterioration models produced from historical data of 2000 miles of road over two years in Mississippi .

Equations formed were compared with existing models both empirical and mechanistic based such as PCR, structural numbers calibrated for granular and cement treated based pavement. The paper acknowledges how complex and dynamic road pavements are and that a strong empirical base and mechanistic model is needed in order to formulate a robust model. From the years of 1986 to 1988 the PMS contained a database of pavement properties such as traffic loading, pavement layer thickness materials, subgrade strength environmental factors and construction techniques and pavement condition data (PCR) shown in table 9 . One of the dilemmas in which the paper highlights in its research study is that not all the roads were placed into service at the same time. So their age isn't identical. However the time in which the data was collected was at a single point of time.

Independent variables which were considered based on past experiences include the following :



	Range of Each Parameter, Flexible Pavement		
Parameter	No Overlay	Overlay	Composite Pavement
Number of data points	54	193	135
Thickness of AC surface, inches (T)	NA	1.0–8.0	2.0–5.0
Modified structural number (SNC)	2.5–7.7	1.1–8.2	NA
Yearly equivalent single axle load ($ESAL$)	1,055–104,965	1,191–809,289	4,331–119,696
Age since construction or last overlay, years	1–16	1–10	1–10
Pavement condition rating (PCR) Year of PCR survey	59–89 1986–1988	62–89 1986–1988	52–89 1986–1988

Table 9:Paramters used for modelling

(KP . George ET AL , 1989)

Regression analysis was followed in which SAS version 5 was resorted to in order to accomplish nonlinear, step wise and regular regression. Non linear modelling was used. The only imposing criteria which was in place was that there had to be a particular start life and end life as well as a low standard error very much.

The following equation were developed using a non linear method acquired from SAS .

Flexible pavements with an overlay and without an overlay and a composite equation were found in the following respectively.

$$PCR(t) = 90 - a\,[\exp\,(\text{Age}^{b}) - 1]\,\log\left[\frac{ESAL}{SNC^{c}}\right]$$

Equation 10: Equation 6

$$PCR_{(t)} = 90 - a[\exp\,(\text{Age}^{b}) - 1]\,\log\left[\frac{ESAL}{SNC^{c*}\,T}\right]$$

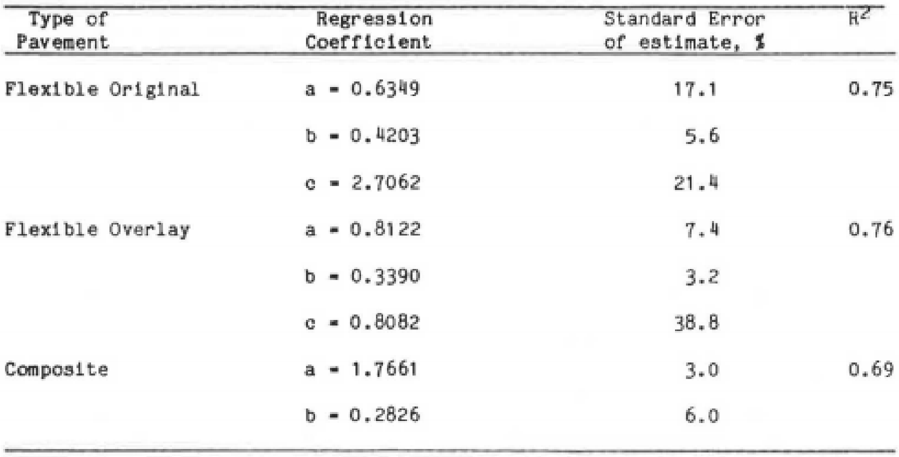
Equation 11:Equation 7

$$PCR_{(t)} = 90 - a\left[\exp\left(\frac{\text{Age}}{T}\right)^{b} - 1\right]\log\,[ESAL]$$

Equation 12: Equation 8

The table below details the coefficients values and the standard error estimates and R^2 values.

A 95% confidence interval was placed which is reflected in the standard error achieved .



Type of Pavement	Regression Coefficient	Standard Error of estimate, %	R²
Flexible Original	a = 0.6349	17.1	0.75
	b = 0.4203	5.6	
	c = 2.7062	21.4	
Flexible Overlay	a = 0.8122	7.4	0.76
	b = 0.3390	3.2	
	c = 0.8082	38.8	
Composite	a = 1.7661	3.0	0.69
	b = 0.2826	6.0	

Table 10: Statistical Output

(KP . George ET AL , 1989)

As a confirmation process a plot of measured against actual PCR is plotted showing that the residuals i.e the difference between the predicted and actual PCR are normally distributed using equation 6 . One of the conditions that is placed is that the trend has to pass through a PCR of 90 and an end of life boundary condition. The increase rate of deterioration after ten years of service is acceptable provided there is no treatment.

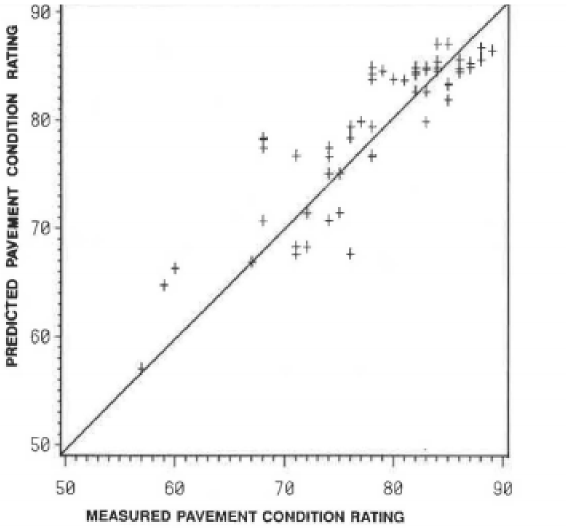


Figure 20: PCR residual validation

(KP George et al 1989)

The above graph shows the correlation between the pavement condition data and the data generated from the equation which depicts pavement with no overlay. The prediction equation derived has found that there are three main parameters involved when evaluating pavement performance. Such parameters include age, yearly traffic and structural number.

Another means in which the author attempts to apply some validation to the study is by modelling equation 6 with another author PCR equation . The validation showed that there was some agreement between both models.

There are three common variables in equation 6,7 , 8 age, yearly traffic and composite structural numbers . The paper explores why age is an important when assessing serviceability of a pavement.

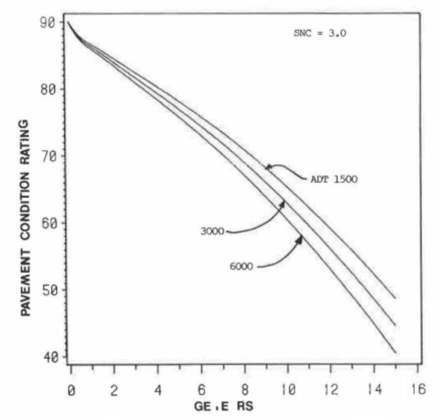


Figure 21: Age vs PCR SNC suppressed

(KP George et al 1989)

Figure 21 shows PCR degrade when structural number is kept constant while different traffic loadings are being applied . Figure 22 shows when the traffic loading Is kept constant but different structural numbers are used. From inspecting figure 21 and 22 the paper remarks that both figures shows a minimal change in PCR meaning age is very much important when predicting pavement deterioration. The author explain that “age is a common factor in cumulative traffic loads and environmental loads over the life cycle period” (KP. George, et al) . The author identifies that age is significant because it is a mutual element for both cumulative traffic loads and environmental loads. However it is found that cumulative traffic loads can be inaccurately calculated due to how objective it can be . While age is accurately is terms of measurement as past inventory records can validate this parameter. Environmental effects encompass expansive clays, subgrade movements and bitumen ageing which can be difficult to quantify.

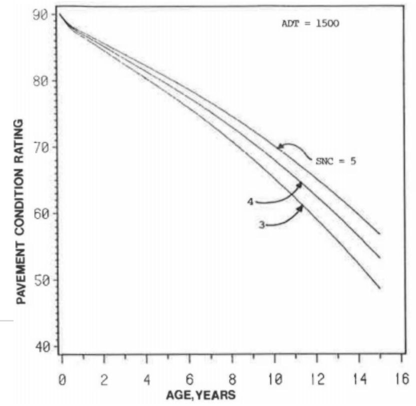


Figure 22: PCR vs AGE Loading suppressed

(KP George et al 1989)

The scattergram presented in figure 23 has the 95 percent confidence interval and 54 data points is shown in figure 3 . Traffic and SNC were suppressed so that age alone could be assessed . ADT values were 3000 while SNC was 3 . A concave down shape was achieved which aligns to popular belief a slow deterioration during early life followed by a surge of deterioration . It is unclear why there are three curves when the paper only talk about the one.

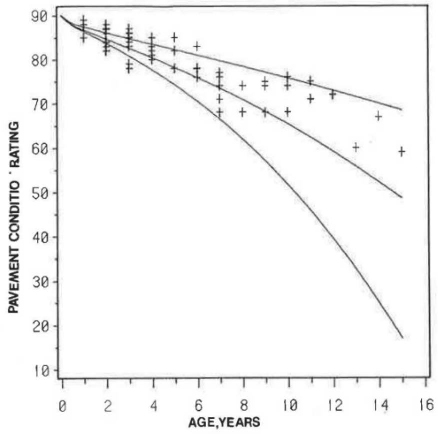


Figure 23: Scatter graph vs curvature

(KP George et al 1989)

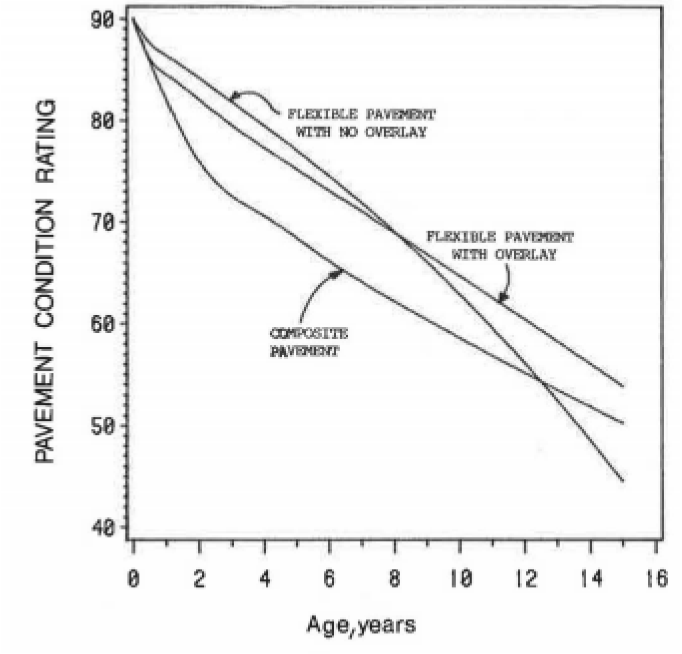


Figure 24: Combines PCR vs AGE

(KP George et al 1989)

Keeping the traffic factor and the structural condition constant the above graph was achieved. It can be seen that the composite trend line is very much concave shape while flexible pavements are more convex. Variables substituted into equations 6,7,8 were ADT =3000 , SNC = 3 and T= inches .

One of the greatest findings in which the author identifies is that age greatly correlates with decline of serviceability.

2.92 Developing pavement performance models for Delaware.

L. Mills, N Anoh- Okine, S. McNeil <http://docs.trb.org/prp/12-2766.pdf>

The following study attempts to analyse the Delaware Department of Transportation road inventory which features functional class, age, pavement condition and overlay treatment (Leslie Mills et al, 2011). . Using the database in which the department used completeness and pavement consistency was looked into . From what the database had to offer models were able to be formed and tested to see whether certain roadway boundaries were met. Statsgrphic Plus 6.1 was the software that enabled these actions to happen (I.Mills et al 2011) . The database classified pavements according to their type. Types that were available included flexible, rigid and composite pavements as well as surface treated pavements . The intention was to produce a model that appears to be probabilistic

Attributes of interest in database.

From the inventory pavement which had a common deterioration were formed into different families . Characteristics which was taken into account included AADT, age, OPCx, edge, fatigue and slab cracking, patching, surface detects structural number and transverse cracking and joint deterioration were also taken into account (l.Mills et al, 2011).

The year the road was constructed and the number of segments with complete data was very much of interest. From what was found there was 95% that had surface treated of segments with complete data (Leslie Mills et al, 2011). While only 69% were composite pavements with complete data, rigid pavements had 39% of segments with complete segments (Leslie Mills et al, 2011). A data set for road structure and surface thickness were excluded in the modelling process only because of the lack of consistency. 11 smaller groups were formed from the families by incorporating pavement structure and functional class of road pavements. Flexible arterial roads was the chosen pavement in which the study decided to base the model on .

The paper presents a histogram which gives the “overall pavement condition index” of a flexible arterial pavement.

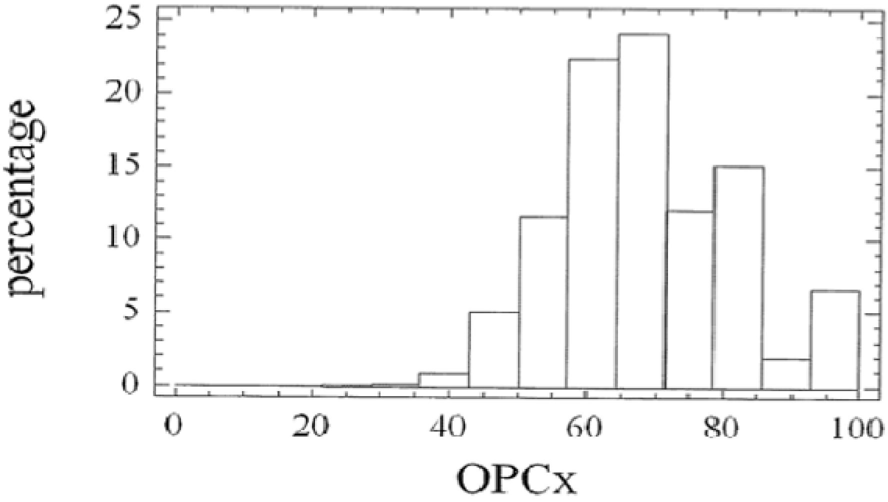


Figure 25 Histogram plot for OPCx for flexible arterials

From Development Pavement Models for Delaware L. Mills et al page 8)

The figure above shows the distribution of the pavements which had some level of condition. The study demonstrates that an inverse relationship exists between age and the over pavement index.

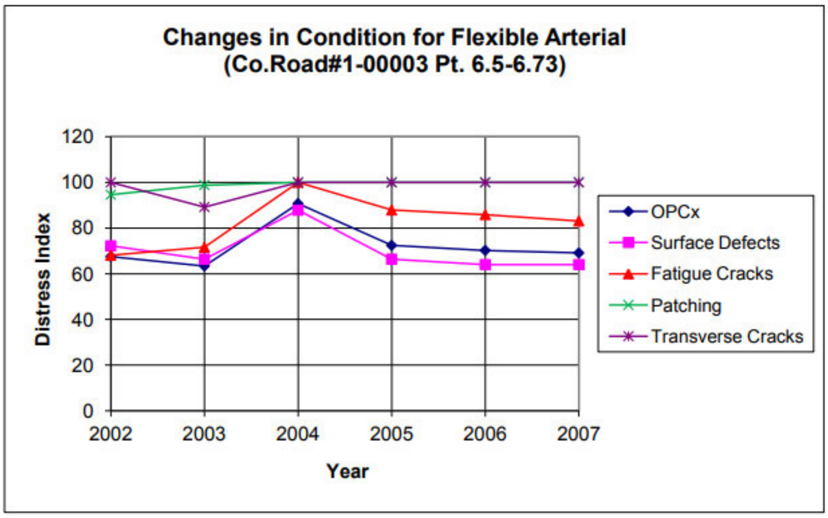


Figure 26: Flexible arterial vs changes in condition

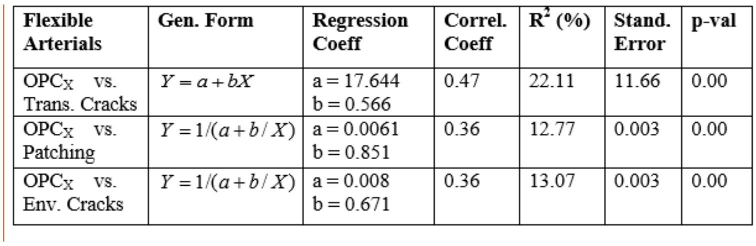
From Development Pavement Models for Delaware L. Mills et al page 8)

Sample data in regards to arterial flexible pavements was obtained . Activates and changes in pavement were modelled against the overall pavement condition index of flexible arterial roads. The figure 26 shows that between 2003 and 2004 there was a rise in distress. Although patching treatment was done in which an overlay was applied creating better serviceability .

2.921 Simple Regression

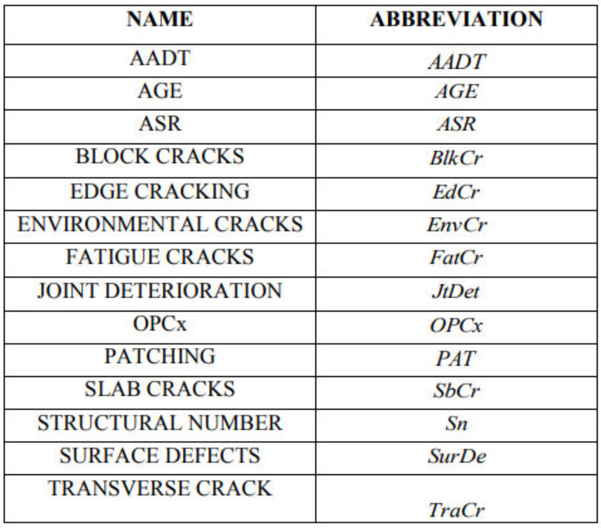
The model that was intended to be developed is aimed to be a mechanistic empirical model Simple Regression analysis was accomplished to determine the impact of individual pavement distress on OPCx values for the flexible arterial roads. Multiple mathematical relationships were analysed both linear and non-linear regression techniques. From the inventory different defects were looked into and different equations were formed which incorporated these defects as well as the OPCx output values.

Table 11 Statistical Parameters (from Development Pavement Models for Delaware L. Mills et al page 11)



Flexible Arterials	Gen. Form	Regression Coeff	Correl. Coeff	R^2 (%)	Stand. Error	p-val
OPC_X vs. Trans. Cracks	$Y = a + bX$	a = 17.644 b = 0.566	0.47	22.11	11.66	0.00
OPC_X vs. Patching	$Y = 1/(a + b/X)$	a = 0.0061 b = 0.851	0.36	12.77	0.003	0.00
OPC_X vs. Env. Cracks	$Y = 1/(a + b/X)$	a = 0.008 b = 0.671	0.36	13.07	0.003	0.00

The study then goes on to analyse a way to create a whole new prediction model . By using independent variables such as detailed in the table below .



NAME	ABBREVIATION
AADT	*AADT*
AGE	*AGE*
ASR	*ASR*
BLOCK CRACKS	*BlkCr*
EDGE CRACKING	*EdCr*
ENVIRONMENTAL CRACKS	*EnvCr*
FATIGUE CRACKS	*FatCr*
JOINT DETERIORATION	*JtDet*
OPCx	*OPCx*
PATCHING	*PAT*
SLAB CRACKS	*SbCr*
STRUCTURAL NUMBER	*Sn*
SURFACE DEFECTS	*SurDe*
TRANSVERSE CRACK	*TraCr*

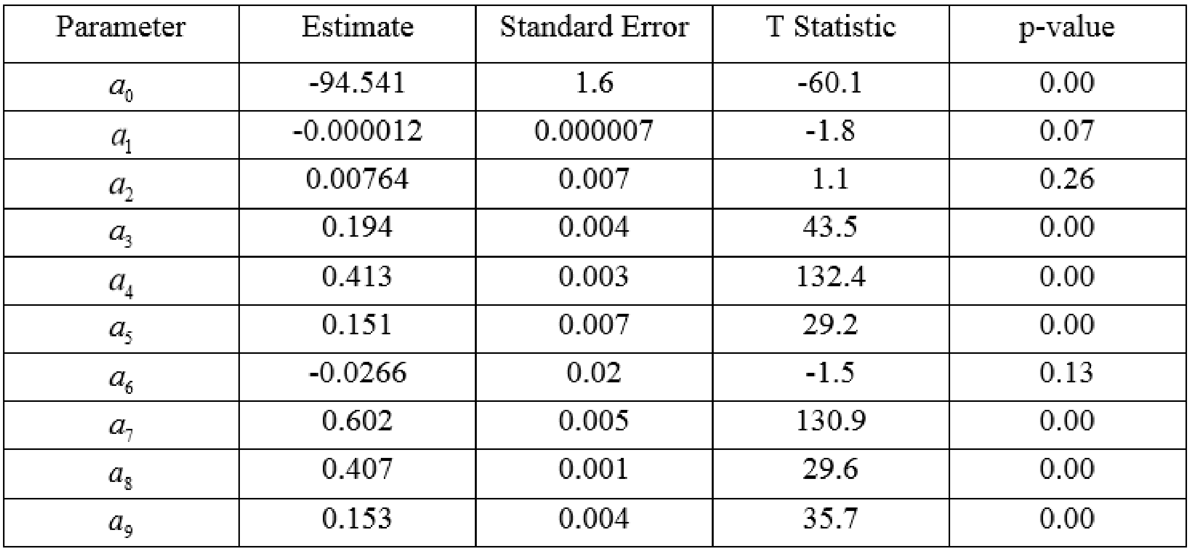
Table 12: Variables of interest

Equation 13 :Equation for fitted model for flexible arterial pavements

$$OPCx = a_0 + a_1 AADT + a_2 AGE + a_3 EnvCr + a_4 FatCr + a_5 PAT + a_6 Sn + a_7 SurDe + a_8 EdCr + a_9 TraCr$$

(From Development Pavement Models for Delaware L. Mills et al page 12)

For each coefficient a standard error was estimated and T-statistic and p-value was also found. The statistical analysis was to try and validate how robust each coefficient is .



Parameter	Estimate	Standard Error	T Statistic	p-value
a_0	-94.541	1.6	-60.1	0.00
a_1	-0.000012	0.000007	-1.8	0.07
a_2	0.00764	0.007	1.1	0.26
a_3	0.194	0.004	43.5	0.00
a_4	0.413	0.003	132.4	0.00
a_5	0.151	0.007	29.2	0.00
a_6	-0.0266	0.02	-1.5	0.13
a_7	0.602	0.005	130.9	0.00
a_8	0.407	0.001	29.6	0.00
a_9	0.153	0.004	35.7	0.00

Table 13: Standard deviations of Parameters

(From Development Pavement Models for Delaware L. Mills et al page 12)

The table above shows the coefficients values as well their statistical competence. Just like previous studies shown throughout the literature review a validation process is required. This particular study has resorted to a number of techniques such as plots of observed versus predicted data, residual analysis and a check for multiple correlation relationships amongst independent variables .

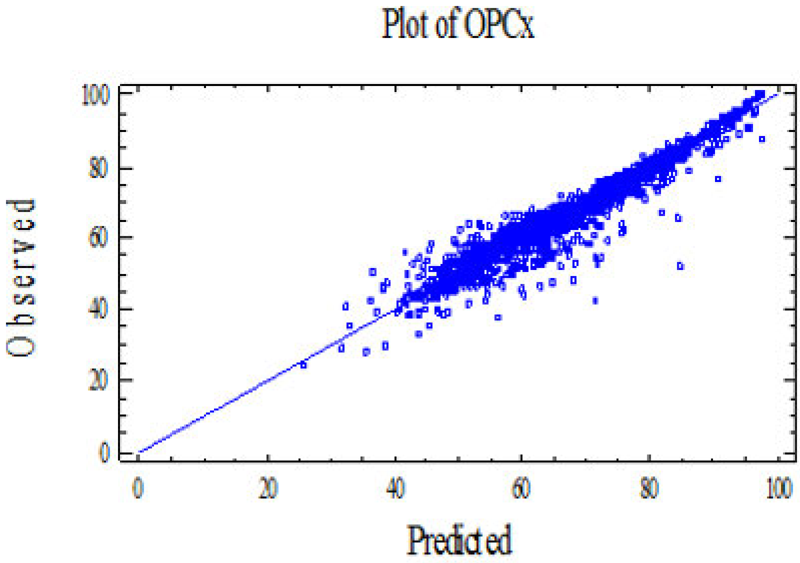


Figure 27: Plot of OPX predicted verses observed

From Development Pavement Models for Delaware L. Mills et al page 8)

The graph as shown above is a relationship between predicted data and observed data. Properties of residuals is that the residuals is equal to zero and that the standard deviation is equal to the standard deviation of the regression curve (Leslie Mills et al, 2011) as shown in the next graph. The two graphs both display different properties of the observations and predications found. Figure 27 shows the raw data and observation on its own while figure 28 shows the relationship of the residuals of both data sets.

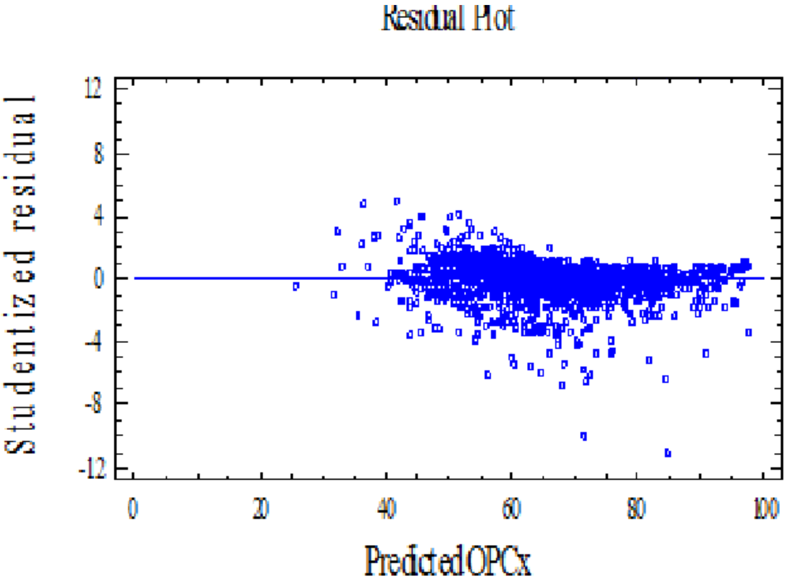


Figure 28: Residual plot

From Development Pavement Models for Delaware L. Mills et al

The graph above demonstrates the OPCX output compared to the output formed from the equation.

2.922 Conclusion

From what the study found because of inconsistencies in the database the model isn't as robust as it should be. Complete information was identified as an issue in the paper . With 70% in total of pavements had complete data. Out of the 70% of the database 39% of rigid pavements had complete information (Leslie Mills et al, 2011).

Thickness of overlay and the traffic loading exerted were found to be main contributors to pavement predication models. With the outputs produced it can be seen that grouping pavements into families based on their structure is a way of contending pavement complexities.

2.923 Finding from case studies

Both studies have used regression analysis when trying to find the coefficients of the variables of their models. Both studies are based on a particular region in the United states and have to resort to some kind of software to produce these calculations. Each study did have the option of looking at different equation formations both linear and non linear. Prediction models for Delaware had resulted in an empirical mechanistic equation while the study conducted by KP George was very much an empirical prediction model only because some of the variables were suppressed. The study has shown how important age is when assessing survivability . This particular paper has proven how age is the strongest variable compared to ESALS and environmental factors . The paper shows when experimenting with prediction models such as pavement deteriorating using statistical measures is not a bad way of validating. Furthermore the author uses condition such as start and end of a pavement life. These findings will be applied similarly to the research that is conducted in which this paper is dedicated to.

The t-statistic measures the value of the regression coefficient divided by its standard deviation of the coefficient thus a measure of precision in which the regression coefficient is measured .

Each study resorts to finding correlations as a way of measuring robustness of a model. The difference between two studies is that the performance modelling for Delware had multiple parameters while the other study was focused on proving that a relationship exists between PCR and age. Common methods between the two studies was very much to do with plotting the observed data against residuals as a form of validation . In both instances it proved to be relatively successful. The study Delware incorporated pavement deformations such as cracking but also remedial factors such as patching . The study conducted by KP . George was producing performance models based on rutting . Furthermore the study demonstrated how age or time passing is a credible independent variable .

2.924 P-Value test

The P-value is a statistical tool that is used to test a hypothesis that there is a statistical relationship between two parameters. The study based on Delaware used a 95% confidence interval when producing its P-value.

The P-value is ruled by the null hypotheses and states that if the P-value is greater than 5% then hypothesis test is statistically significant. However if it is less than 5% then the result are statistically significantly . It would appear the lower in which the p-value is the more it is statistically significant.

Essentially this means that there is a 5% chance of rejecting the null hypothesis. Statistical significance can be achieved when less than 5% as that's when the null hypothesis can be rejected.

$$H_0 : \mu = 0$$

Equation 14: Null hypothesis

$$H_1 : \mu \neq 0$$

Equation 15: Hypothesis

The study Will use equation 10 and 11 when computing the null hypothesis on order to see if there is any statistical significance . But more interestingly by how much . It is a well known fact that there is currently no relationship between r^2 and p-value . R^2 is very much about variation while . By finding R^2 and P-value variation and significance can be found. Significance evidence against the hypothesis that the regression coefficient is zero .

2.93 Summary of key findings

The literature review has provided some insight on how previous studies have attempted to model certain pavement types. The techniques applied by Delaware department of transportation included regression analysis and plotting residuals as a way of checking robustness.

Finding R^2 coefficient is a common source of measurement which these studies constantly resort to. Modelling for predicting pavement deterioration looks into R^2 coefficient as a way of measuring correlation. However the research at hand is quite different to how KP.George conducts his study. The study in which this paper is dedicated to has multiple pavement deterioration equations and aims to compare its self with random data . An interesting way of measuring "robustness" would be to find how much area is between each curve as it maybe an indicator of close alignment . Both studies not looked into alignment because neither study has done any comparison with any curve. P-value would be great interest for the research at hand as it can provide some quantify output of how much to reject the null hypothesis.

2.93 Research of Interest

From what was found in previous studies examined in this literature that has been examined there seems to be no study done on current pavement deterioration models that are widely used in Australian local government councils particularly when making comparisons. The study that is about to be conducted will be focusing on Central Coast Council which was formed from the previous Gosford City Council (GCC) and Wyong Shire Council (WSC). Due to the recent merger Central Coast Council (CCC) is facing some decision making with their pavement management systems which is very much how this study was instigated. Moloneys model , Ascetics and SMEC will be thoroughly examined and compared.

The literature has shown Southern Shire Grampian Council conducts their asset maintenance with great seriousness as there is a lot of funds being put into these assets for the benefit of its community. Yet a question of how robust and worthy a deterioration model in comparison to other deterioration models is yet to be answered. A pavement deterioration model which maybe more suited for a particular class of road has not explored from what was found in the literature review. Techniques such finding the R^2, p-value and the area will be applied to the study.

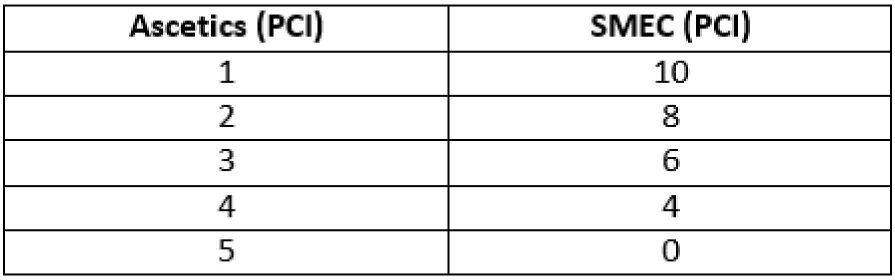
3.0 Methodology

3.1 Aim

Four deterioration tools will be developed.

In addition three random road models will also be developed.

As stated in previous chapters the aim of the study is to assess each deterioration tool and to compare it to three random road models from both the GCC road network and the WSC road network.



Ascetics (PCI)	SMEC (PCI)
1	10
2	8
3	6
4	4
5	0

Table 14 Assetics to SMEC conversion table

3.2 Terminology

There will be two phrases constantly used throughout the paper. They are defined as the following .

Deterioration Tools - A mathematical formula which describes a relationship between deterioration and age of a specific **class of road.**

Random road deterioration model – A mathematical formula which can describe a relationship between twenty random roads from a **“particular class of road” .**

SMEC Major – A mathematical relationship which describes deterioration and age of every Distributed road within the former Wyong jurisdiction.

SMEC Minor – A mathematical relationship which describes deterioration and age of every Access road within the former Wyong jurisdiction.

Assetic Minor - A mathematical relationship which describes deterioration and age of every minor road within the former Gosford jurisdiction.

Wyong Minor - A mathematical formula which can describe a relationship between twenty random access roads.

Wyong Major - A mathematical formula which can describe a relationship between twenty random distributor roads.

Gosford Minor - A mathematical formula which can describe a relationship between twenty random minor roads.

3.2 Summary of steps taken to develop SMEC major, SMEC minor and Assetics minor tools .

1. **Deriving Moloney model**
   Moloney will be incorporated as part of the research.
   Refer to appendix B for technical details of how Moloney model was derived.

2. **Data Acquisition**
   Both former WSC and GCC have provided spreadsheet of historical data of PCI values . GCC unfortunately has only about five years worth of data while WSC has twenty years .

3. **Deterioration tool development .**
   Using the spreadsheet of data values SMEC Major, SMEC Minor and Assetics minor were formulated.

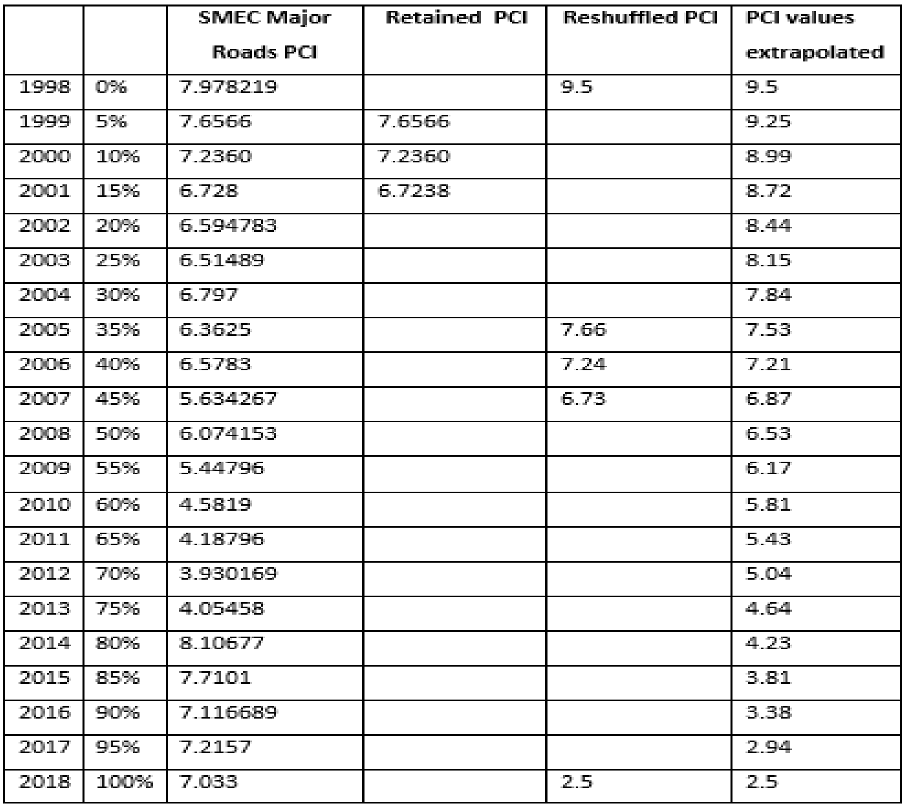
4. **Length weighted average.**
   As described in 2.5 of the literature review a length weighted average was applied to the twenty years of PCI values in the SMEC spreadsheet and five years' worth In the Assetic spreadsheet. For further details refer section 2.5 of literature review.

5. **Filtering**
   An array of length weighted averages has now been generated for each year of PCI values. However as previously stated these are "deterioration tools" hence rehabilitated values should not be incorporated in the modelling. A trend needs to be developed that features decrease in PCI values from year to year.

6. An assumption has been made that the average life span of a road is 20 years

Without any treatment for rehabilitation purposes. However the life span of the road has been described in terms of percentage in intervals of five percent along the x-axis. A percentage of 100% would represent 20 years . Every year that passes represents 5% . **Criterion.** As established in the literature review initial PCI value of 9.5 is placed at 0% life span of a road . In addition a PCI of 2.5 has been placed at 100% .

7. With the filtered array of PCI values, allocating them to the appropriate percentage needs to take place. Based on the findings in the literature review and the what was uncovered in Appendix B about Coff Harbour city council road network. Each PCI value was allocated accordingly to an appropriate percentile value. **Table 16 will be used as an example** . Table 16 under the Column "Reshuffled PCI " shows the PCI values 7.6566, 7.2360 and 6.7238 being placed in what is thought to be the right spot percentage wise . These were from the all length weighted average values .The criterion of 9.5 being the initial and the final PCI being 2.5 was also placed.



		SMEC Major Roads PCI	Retained PCI	Reshuffled PCI	PCI values extrapolated
1998	0%	7.978219		9.5	9.5
1999	5%	7.6566	7.6566		9.25
2000	10%	7.2360	7.2360		8.99
2001	15%	6.728	6.7238		8.72
2002	20%	6.594783			8.44
2003	25%	6.51489			8.15
2004	30%	6.797			7.84
2005	35%	6.3625		7.66	7.53
2006	40%	6.5783		7.24	7.21
2007	45%	5.634267		6.73	6.87
2008	50%	6.074153			6.53
2009	55%	5.44796			6.17
2010	60%	4.5819			5.81
2011	65%	4.18796			5.43
2012	70%	3.930169			5.04
2013	75%	4.05458			4.64
2014	80%	8.10677			4.23
2015	85%	7.7101			3.81
2016	90%	7.116689			3.38
2017	95%	7.2157			2.94
2018	100%	7.033		2.5	2.5

Table 15 SMEC Major data extrapolation

8. . **Modelling.** With the reshuffled PCI values against certain percentages of the life span of the road , a mathematical formula can now be obtained based on the this and the percentage values on the far left . As mentioned in the literature review a quadratic formula has been selected as the formation of the deterioration curve**.** A quadratic formula was produced and all percentage values substituted to provide PCI values. The column “PCI values extrapolated” demonstrates this on the far right column of table 16 .

9. . Interpolation. As found in the literature review Assetics PCI values range from 0-5 . With the length weighted average values computed this need to be interpolated according to table 14 . In other words the length weighted average needs to be converted from a 0-5 scale to a 0-10 scale. .

3.2 Summary of steps taken to develop Wyong major, Wyong minor and Gosford minor random road deterioration models .

The exact same steps have been taken as described in the previous section to develop the random road deterioration models . However there are few minor changes in which the flow chart will describe .

1. **Random selection .** Twenty random roads will be selected from the following pool of roads . Wyong –Distributor road
   Wyong – Access Roads
   Gosford – Minot roads

2. The twenty random roads selected for the Gosford minor roads can now directly converted to a 1-10 according to table 3.1 . No interpolation is required

3.3 Difference between methodology of 3.1 and 3.2

It should be noted that the Assetic minor roads is a very extensive long list of roads . Converting each individual road rating to 1 – 10 scale is not very practical . For that reason interpolation was applied after the length weighted formula was applied .

3.4 Analysis of Deterioration tools and random road deterioration tools .

The following are detailed steps which describe the analysis that examined all seven data sets. The data sets being Moloney, SMEC Major, SMEC minor, ASCETICS Minor, Wyong major roads, Wyong minor Roads and Assetics minor roads.

1. **Pearson's coefficient .**

   The following correlation will be found .

   1) Every Deterioration tools will be correlated with every random road deterioration model
   2) Deterioration Tools will be correlated against each other .

2. **P-value**

   The following p-values will be found through Microsoft Excel .

   4) p-value evaluation was done for every deterioration tool and every random road deterioration model
   5) Among all deterioration tools P-value will be found .
      I.e. All deterioration tools will be evaluated against each other to find all P-values.
   6) Among all random road model P-value will be found

3. **Area between curves**

   Using calculus between the limits of 0 to 1 the following area values will be computed.

   1) Between all deterioration road model curves random road deterioration model curve.
   2) Among all deterioration tools curves.
   3) Among all random road model curves.

4. Results and Discussion

4.1 Recap

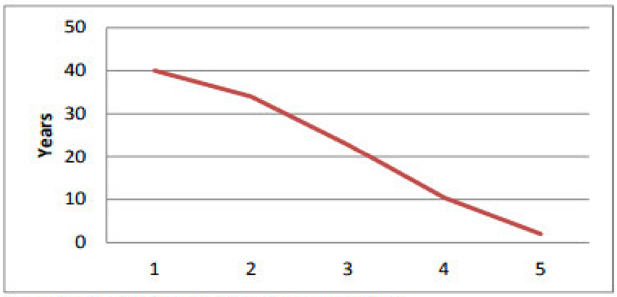
The following chapter is the analysis of the results which was gathered after executing the methodology. As mentioned previously throughout the paper the intention of the study is to perform a validation exercise and a comparison with three different models . A validation in which modelling equations are derived and used to predict the condition of a pavement in terms of their PCI in future years. The predication produced is then compared to the random road deterioration model .

4.2 Modelling Curves

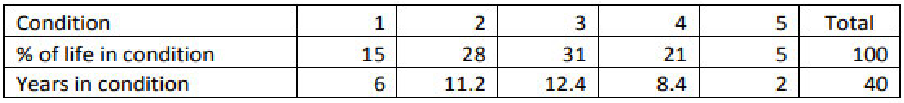
As stated in the chapter 3 SMEC and Ascetics were both developed by using the entire data set provided by the former WSC and GCC . Each model will be shown how they were developed.

4.2 1 Moloney's model

The data in which this model was developed was from a credible source and hence the model would viewed as fit for purpose . However for technical details on how the model was formulated please refer to Appendix B .

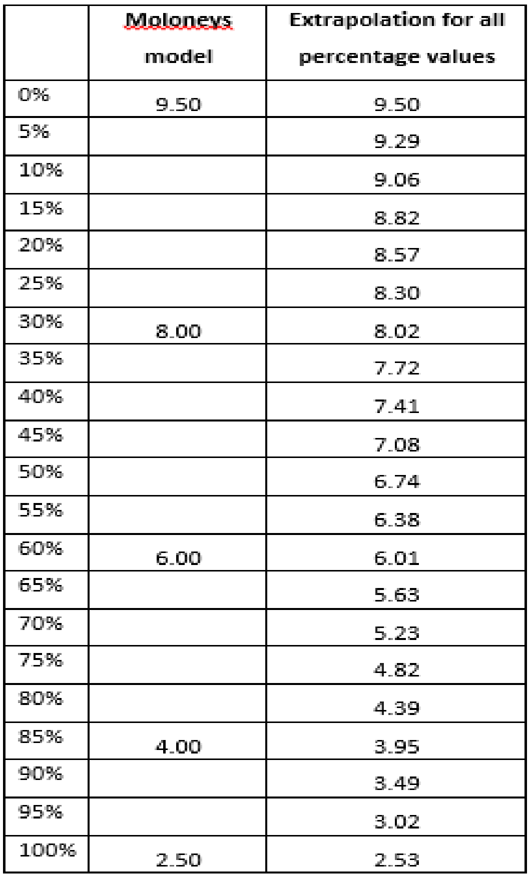


Remaining life (years) based on condition



Condition	1	2	3	4	5	Total
% of life in condition	15	28	31	21	5	100
Years in condition	6	11.2	12.4	8.4	2	40

4.2.1.1 Moloney Extrapolation values



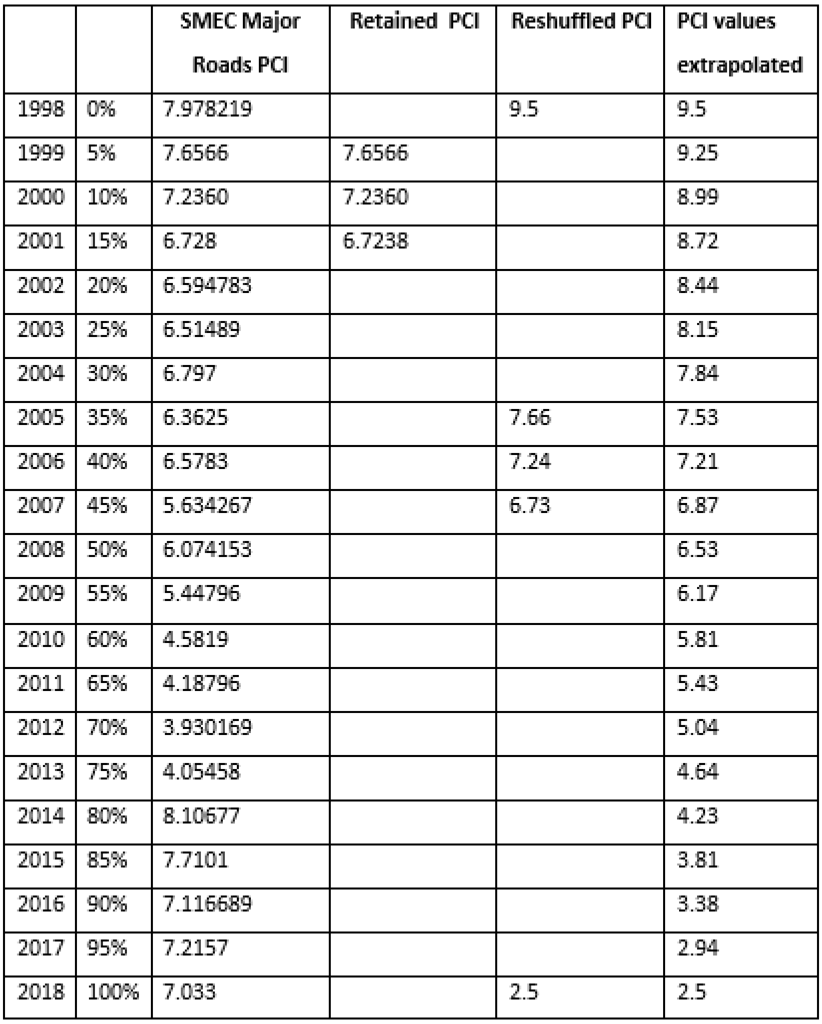
	Moloneys model	Extrapolation for all percentage values
0%	9.50	9.50
5%		9.29
10%		9.06
15%		8.82
20%		8.57
25%		8.30
30%	8.00	8.02
35%		7.72
40%		7.41
45%		7.08
50%		6.74
55%		6.38
60%	6.00	6.01
65%		5.63
70%		5.23
75%		4.82
80%		4.39
85%	4.00	3.95
90%		3.49
95%		3.02
100%	2.50	2.53

Table 15 shows the extrapolated PCI values for all percentage values

Table 16: Moloney Data Extrapolation

4.2.2 SMEC Major roads Data extrapolation .

Table 16 shows the filtered values which deterioration was purely focused on . As shown in the table some of the values were retained from the raw data. The raw data is the length weighted average being applied for all distributor roads from the years of 1998 to 2018 . The reshuffled values are placed accordingly where it is thought to be appropriate In terms the life of the pavement. After placing conditional values and the retained values extrapolation took place in which PCI values were found for all percentage values.

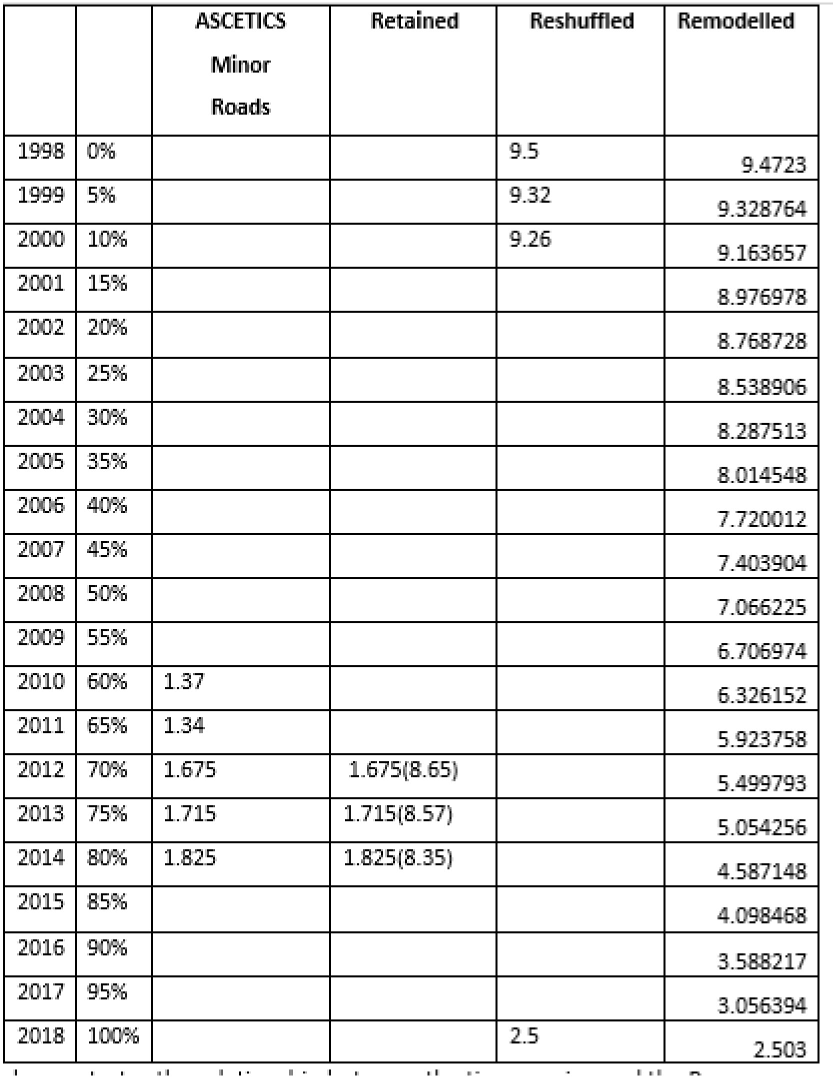


		SMEC Major Roads PCI	Retained PCI	Reshuffled PCI	PCI values extrapolated
1998	0%	7.978219		9.5	9.5
1999	5%	7.6566	7.6566		9.25
2000	10%	7.2360	7.2360		8.99
2001	15%	6.728	6.7238		8.72
2002	20%	6.594783			8.44
2003	25%	6.51489			8.15
2004	30%	6.797			7.84
2005	35%	6.3625		7.66	7.53
2006	40%	6.5783		7.24	7.21
2007	45%	5.634267		6.73	6.87
2008	50%	6.074153			6.53
2009	55%	5.44796			6.17
2010	60%	4.5819			5.81
2011	65%	4.18796			5.43
2012	70%	3.930169			5.04
2013	75%	4.05458			4.64
2014	80%	8.10677			4.23
2015	85%	7.7101			3.81
2016	90%	7.116689			3.38
2017	95%	7.2157			2.94
2018	100%	7.033		2.5	2.5

Table 17 SMEC Major data extrapolation

4.2.3 Assetics Minor Roads

Table 17 shows the values which was gathered from length weight distribution equation from Assetic minor roads spreadsheet of PCI values.

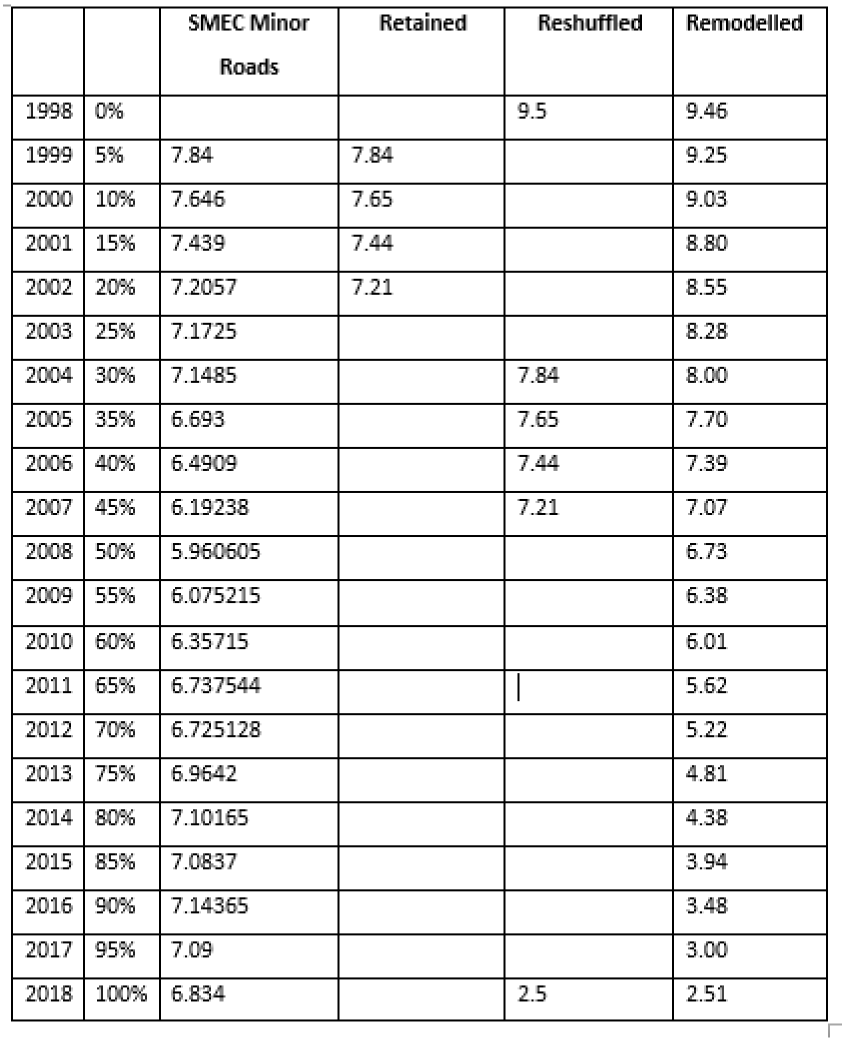


		ASCETICS Minor Roads	Retained	Reshuffled	Remodelled
1998	0%			9.5	9.4723
1999	5%			9.32	9.328764
2000	10%			9.26	9.163657
2001	15%				8.976978
2002	20%				8.768728
2003	25%				8.538906
2004	30%				8.287513
2005	35%				8.014548
2006	40%				7.720012
2007	45%				7.403904
2008	50%				7.066225
2009	55%				6.706974
2010	60%	1.37			6.326152
2011	65%	1.34			5.923758
2012	70%	1.675	1.675(8.65)		5.499793
2013	75%	1.715	1.715(8.57)		5.054256
2014	80%	1.825	1.825(8.35)		4.587148
2015	85%				4.098468
2016	90%				3.588217
2017	95%				3.056394
2018	100%			2.5	2.503

Table 18: Assetic Minor Road Extrapolation

4.2.4 SMEC Minor roads Data extrapolation .

Table 18 is a similar process in attaining PCI values for SMEC minor roads.



		SMEC Minor Roads	Retained	Reshuffled	Remodelled
1998	0%			9.5	9.46
1999	5%	7.84	7.84		9.25
2000	10%	7.646	7.65		9.03
2001	15%	7.439	7.44		8.80
2002	20%	7.2057	7.21		8.55
2003	25%	7.1725			8.28
2004	30%	7.1485		7.84	8.00
2005	35%	6.693		7.65	7.70
2006	40%	6.4909		7.44	7.39
2007	45%	6.19238		7.21	7.07
2008	50%	5.960605			6.73
2009	55%	6.075215			6.38
2010	60%	6.35715			6.01
2011	65%	6.737544			5.62
2012	70%	6.725128			5.22
2013	75%	6.9642			4.81
2014	80%	7.10165			4.38
2015	85%	7.0837			3.94
2016	90%	7.14365			3.48
2017	95%	7.09			3.00
2018	100%	6.834		2.5	2.51

Table 19:SMEC minor Roads

4.2.5 Individual plots of Deterioration tool models

Figure 29 and figure 30 show the plotting of each tool against time .

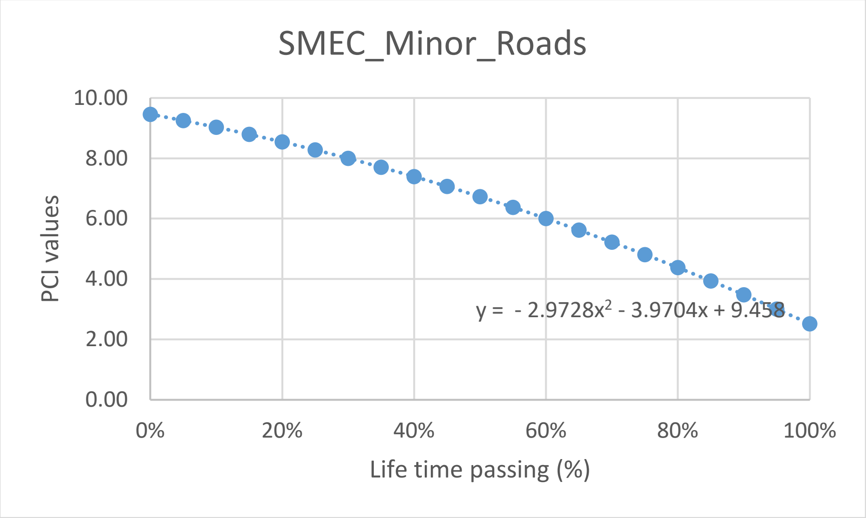


Figure 29-SMEC minor Roads Deterioration curve

As displayed in figure 29 the relationship between the natural life time passing and degenerating PCI value can be described by the quadratic relationship $y = -2.9728x^2 - 3.9704x + 9.458$. As previously explained although this has been labelled as a minor road it actually represents all access roads with the Wyong area. Access roads have been chosen as the class of road of interest due to the functionality of the role it plays as a piece of infrastructure and the research question that the study imposes.

Similarly the relationship between the different classes of road PCI values and the age of the pavement can be described by the following graphs

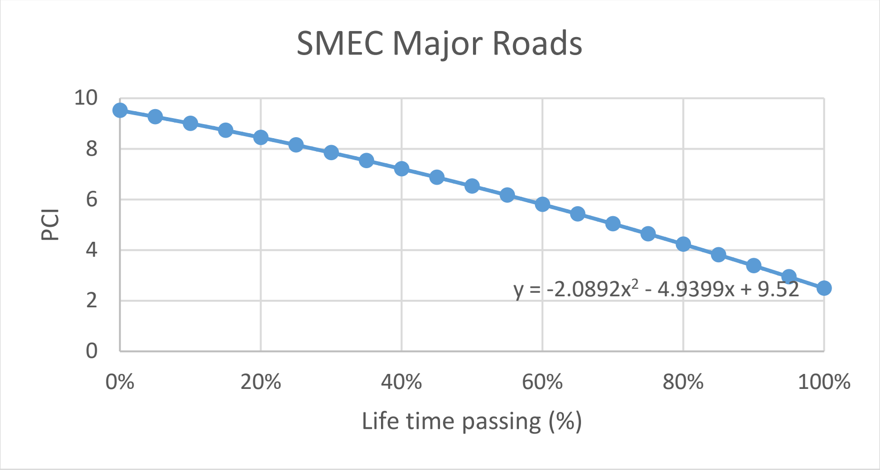


Figure 30: SMEC major Roads Deterioration curve

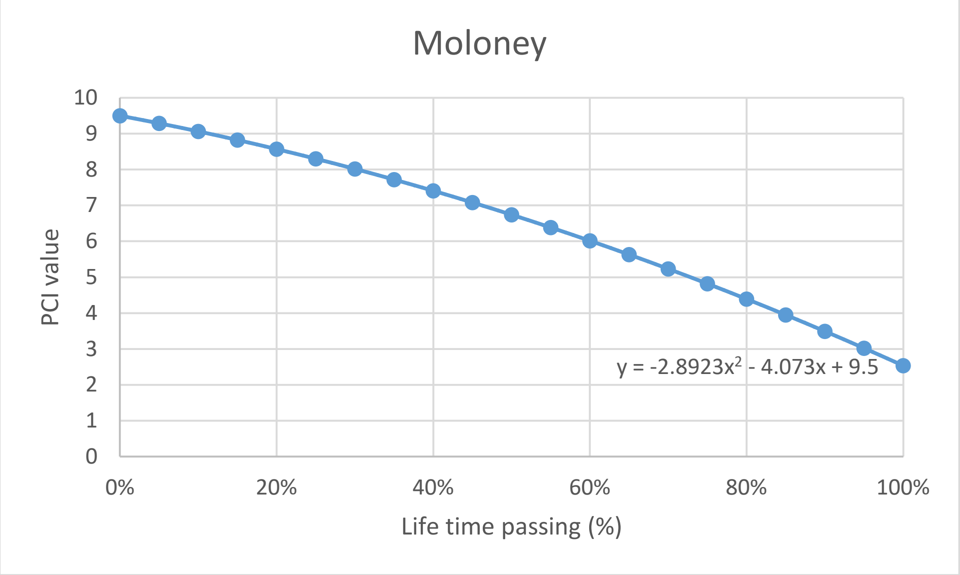


Figure 31:Moloney Roads Deterioration curve

Minor Roads for ascetics PMS when plotted takes the formation as shown below in figure 32 . It can be seen that the relationship is a quadratic equation and that the trend does follow the customary deterioration curvature. Figure 30 and 31 are very much similar in formation .

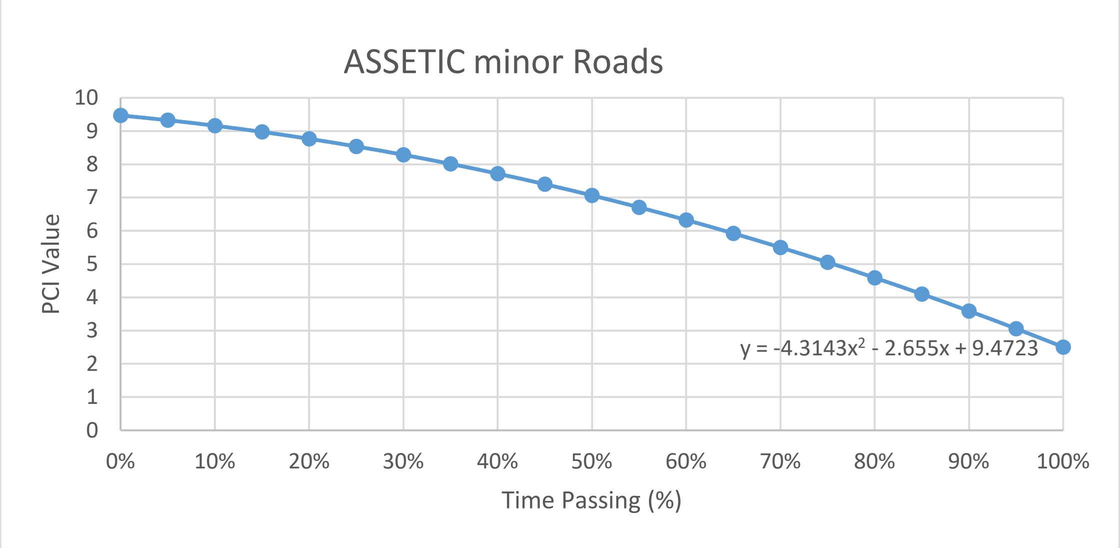


Figure 32:Assetics minor roads deterioration

4. 3 Random Roads

As shown In Chapter 3 the random road data was acquired through a particular process in which random roads were selected and the length weighted average formula was then applied. Table 3.1 shows the random distributed roads.

4.3.1 Wyong major roads.

The following roads were utilised when developing the major roads model . As explained in chapter three (methodology) these roads were randomly selected from the pool of roads that was provided by Wyong shire council.

Road Name	Section	Suburb
BATEAU BAY ROAD	BURRAWONG to ALTONA	BATEAU BAY
BURNS ROAD	EDSON to CHITTAWAY	OURIMBAH
GOOBARABAH AVENUE	LOCAL BOUNDARY #48/46 to DUDLEY	GOROKAN
HOWARTH STREET	WARNER to ROSE	WYONG
HUE HUE ROAD	HOLLOWAY to SANDRA	JILLIBY
HUE HUE ROAD	CULVERT to BUSHELLS RIDGE	JILLIBY
JOHNS ROAD	LOCAL BOUNDARY #180 to POWERPOLE #WY10061	WADALBA
KANANGRA DRIVE	POWERPOLE CH412 to POWERPOLE CH424	CRANGAN BAY
KANANGRA DRIVE	ROSEMEADOW to DEAD END	GWANDALAN
LAKEDGE AVENUE	LOCAL BOUNDARY KINGSFORD SMITH	BERKELEY VALE
MARGARET STREET	ANZAC to NORTH	WYONG
MATARAM ROAD	LOCAL BOUNDARY #25 to SUN ORCHID	WOONGARRAH
MURRAWAL ROAD	KILPA to POWER POLE WY979	WYONGAH
PARRAWEENA ROAD	KANANGRA to GOORAWIN	GWANDALAN
THE CORSO	ROBSON to SPRING VALLEY	GOROKAN
VALES ROAD	POWERPOLE VP407 to CHANGE OF SEAL	MANNERING PARK
WALU AVENUE	LOCAL BOUNDARY #17 to LOCAL BOUNDARY #36	HALEKULANI
SHIRLEY STREET	RED CEDAR to CORAKI	OURIMBAH
YAKALLA STREET	POWERPOLE BV3422 to THE ENTRANCE EAST	BATEAU BAY
ROTHERHAM STREET	LOCAL BOUNDARY CRESTHAVEN	BATEAU BAY
EASTERN ROAD	CASTLEREAGH (East Bound) to GWYDIR	BATEAU BAY
COACHWOOD DRIVE	CUTROCK to CHANGE OF SEAL	OURIMBAH

Table 20: Wyong major Roads

The intention of these random roads is to create a simulation model in which can provide some form of validation for the deterioration model tools .

Table 21: Wyong major road

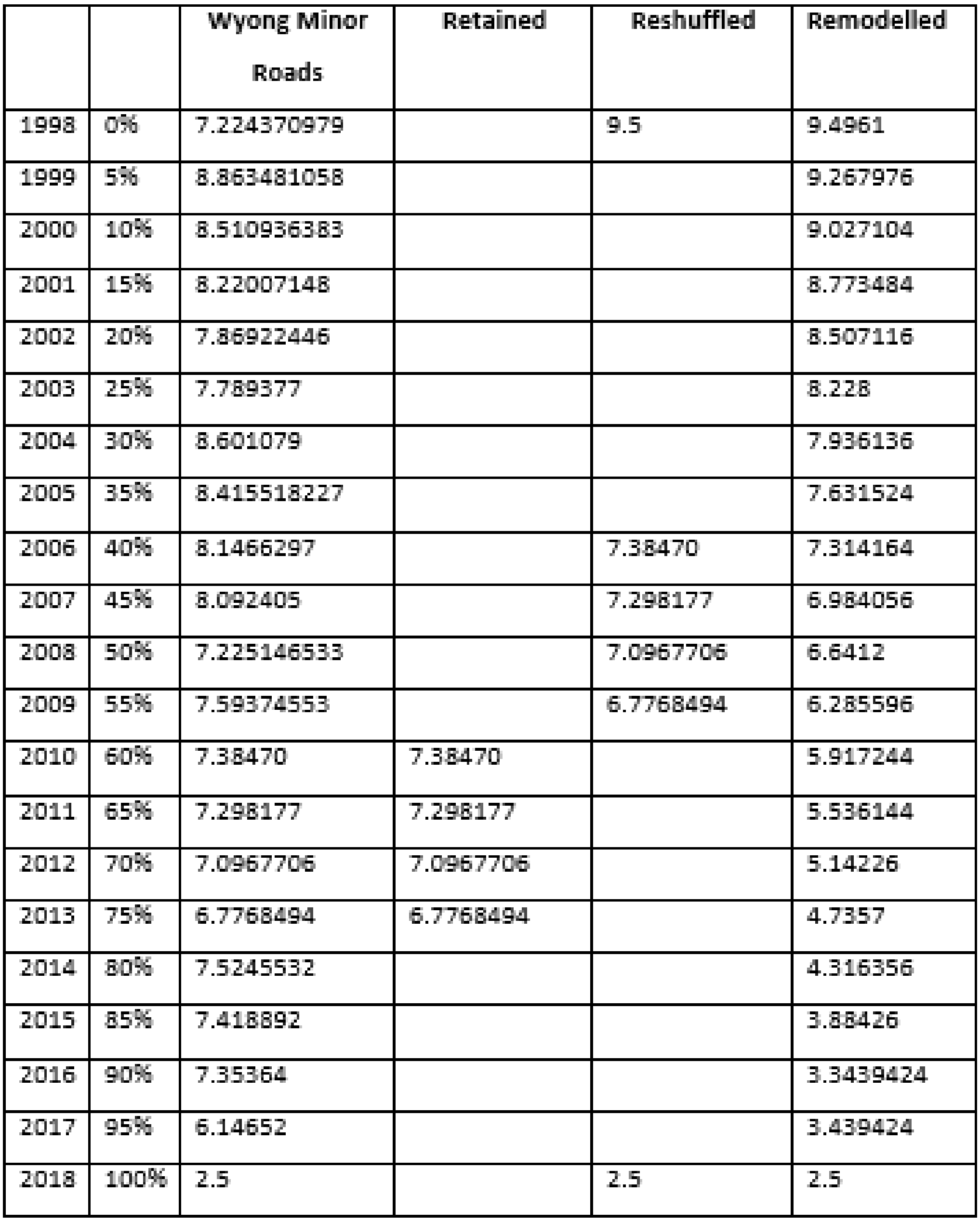
		Wyong Major Roads	Retained	Reshuffled	Remodelled
1998	0%	7.891824112	7.891824112	9.5	9.5
1999	5%	8.00833			9.25
2000	10%	7.77437			8.98
2001	15%	7.3554059	7.3554059		8.71
2002	20%	7.035925344			8.43
2003	25%	6.82044			8.14
2004	30%	6.85371			7.83
2005	35%	6.86169			7.52
2006	40%	6.51882	6.51882	7.3554059	7.19
2007	45%	6.25514	6.25514		6.86
2008	50%	6.00709	6.00709	6.51882	6.51
2009	55%	6.23682		6.25514	6.16
2010	60%	5.5654	5.5654	6.00709	5.79
2011	65%	6.9468		5.5654	5.42
2012	70%	6.70028			5.03
2013	75%	6.8151			4.64
2014	80%	6.84329			4.23
2015	85%	6.14653			3.81
2016	90%	6.29038			3.39
2017	95%	5.96007			2.95
2018	100%	5.69242		2.5	2.5347

4.3.2 Wyong Random Minor roads.

Road Name	**Section**	**Suburb**
BORRODALE AVENUE	LADY PENRHYN to SIR JOSEPH BANKS	BATEAU BAY
STONE STREET	MARY to DEAD END	GOROKAN
ANNIE CLOSE	MORLEY to DEAD END	BATEAU BAY
BOLTON STREET	LANCASTER (EAST) to LANCASTER (WEST)	BATEAU BAY
TARI PLACE	BUFF POINT to DEAD END	BUFF POINT
MUNDARA CLOSE	BUFF POINT to DEAD END	BUFF POINT
ADRIAN CLOSE	ROTHERHAM to DEAD END	BATEAU BAY
LISA CLOSE	CYNTHIA to DEAD END	BATEAU BAY
PARK LANE	BELLEVUE to DEAD END	TUMBI UMBI
ALEX CLOSE	DEAD END(WESTERN) to DEAD END	OURIMBAH
VISCOUNT CLOSE	MARQUIS to DEAD END	SHELLY BEACH
LONSDALE CLOSE	TWIN LAKES to DEAD END	LAKE HAVEN
LONSDALE CLOSE	LONSDALE CLOSE to DEAD END	LAKE HAVEN
MERRO CLOSE	TWIN LAKES to DEAD END	LAKE HAVEN
TUROSS CLOSE	TWIN LAKES to CHANGE OF SEAL	LAKE HAVEN
TUROSS CLOSE	CHANGE OF SEAL to DEAD END	LAKE HAVEN
ERIC MALOUF CLOSE	TUMBI to DEAD END	TUMBI UMBI
KOBY CLOSE	GOROKAN to DEAD END	LAKE HAVEN
MONTANA PLACE	MORLEY to DEAD END	BATEAU BAY
EPSOM PLACE	DUNNING to DEAD END	BATEAU BAY

Table 22: Random wyong minor roads

Using the randomly selected access roads provided by WSC table 21 shows the values that were reattained from these values a deterioration curve was created. Reshuffled values are then produced in which a regression equation for formulated.



		Wyong Minor Roads	Retained	Reshuffled	Remodelled
1998	0%	7.224370979		9.5	9.4961
1999	5%	8.863481058			9.267976
2000	10%	8.510936383			9.027104
2001	15%	8.22007148			8.773484
2002	20%	7.86922446			8.507116
2003	25%	7.789377			8.228
2004	30%	8.601079			7.936136
2005	35%	8.415518227			7.631524
2006	40%	8.1466297		7.38470	7.314164
2007	45%	8.092405		7.298177	6.984056
2008	50%	7.225146533		7.0967706	6.6412
2009	55%	7.59374553		6.7768494	6.285596
2010	60%	7.38470	7.38470		5.917244
2011	65%	7.298177	7.298177		5.536144
2012	70%	7.0967706	7.0967706		5.14226
2013	75%	6.7768494	6.7768494		4.7357
2014	80%	7.5245532			4.316356
2015	85%	7.418892			3.88426
2016	90%	7.35364			3.3439424
2017	95%	6.14652			3.439424
2018	100%	2.5		2.5	2.5

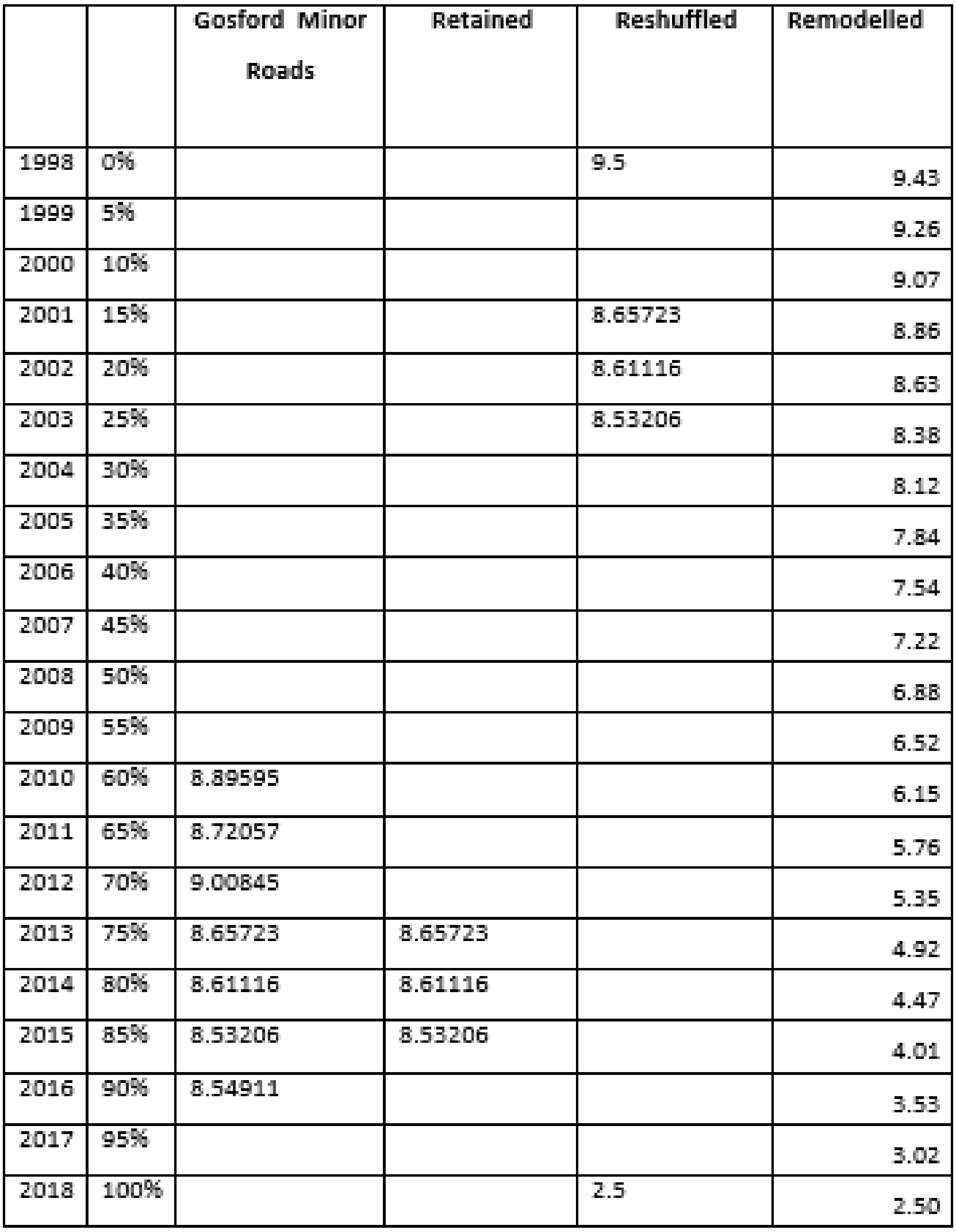
Table 23: Wyong minor roads extrapolated

4.3.3 Gosford Random Minor roads

Asset ID	Asset Name	Segment/Group Name
403750-05	James Dunlop Cl	05
620000-02	Renwick St	02
481700-05	Macquarie Pl	05
101000-05	Abelia Pl	05
101500-05	Abundance St	05
102300-05	Acason Cl	05
102400-05	Ace Rd	05
102500-10	Adam St	10
104800-05	Admiralty Pl	05
105000-05	Adnamira Cl	05
105500-05	Agate Ave	05
106000-05	Airly Rd	05
107500-10	Alanna St	10
108300-05	Albany Sq	05
108500-05	Albany St	05
108500-30	Albany St	30
109200-05	Albatross Cl	05
109500-05	Albert St	05
109500-10	Albert St	10
111000-10	Aldinga Dr	10
111100-05	Alecia Cl	05

Table 24: Gosford random roads chosen

The following roads will be used for random road deterioration curve which will be formulated. Because the PCI values are computed from 1 to 5 a conversion process had to applied as highlighted in the literature review As stated in chapter three Table 11 was used to directly convert these PCI values.



		Gosford Minor Roads	Retained	Reshuffled	Remodelled
1998	0%			9.5	9.43
1999	5%				9.26
2000	10%				9.07
2001	15%			8.65723	8.86
2002	20%			8.61116	8.63
2003	25%			8.53206	8.38
2004	30%				8.12
2005	35%				7.84
2006	40%				7.54
2007	45%				7.22
2008	50%				6.88
2009	55%				6.52
2010	60%	8.89595			6.15
2011	65%	8.72057			5.76
2012	70%	9.00845			5.35
2013	75%	8.65723	8.65723		4.92
2014	80%	8.61116	8.61116		4.47
2015	85%	8.53206	8.53206		4.01
2016	90%	8.54911			3.53
2017	95%				3.02
2018	100%			2.5	2.50

Table 25: Gosford minor roads extrapolated

4.34 Combined Graphs .

Figure 4.3 shows all deterioration tools and random roads models combined together . The results shows how each

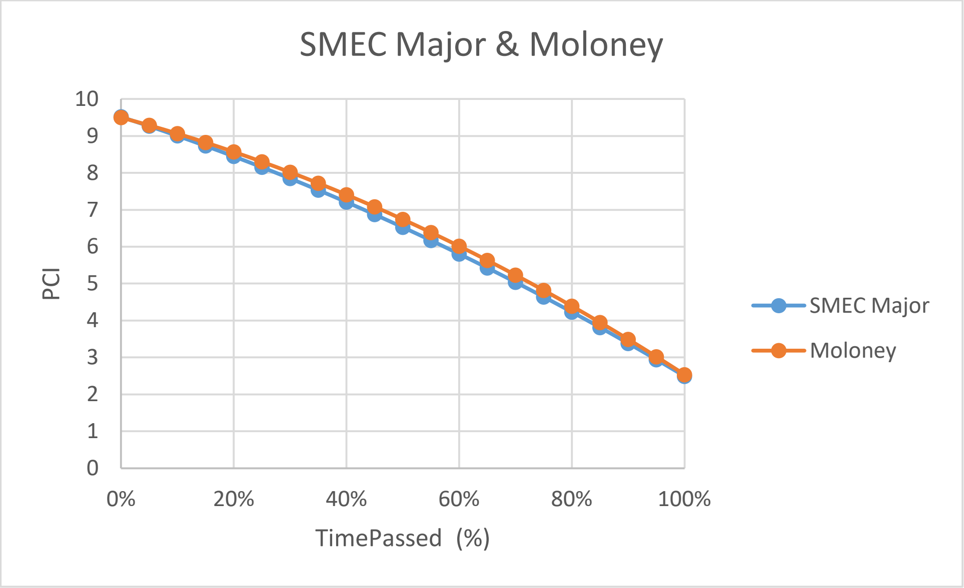
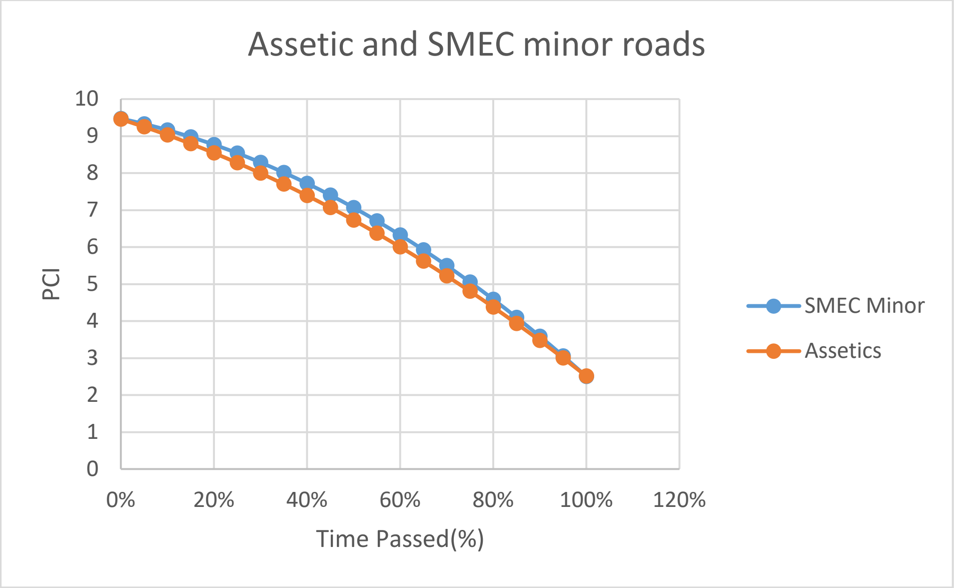


Table 26: SMEC major vs Moloney



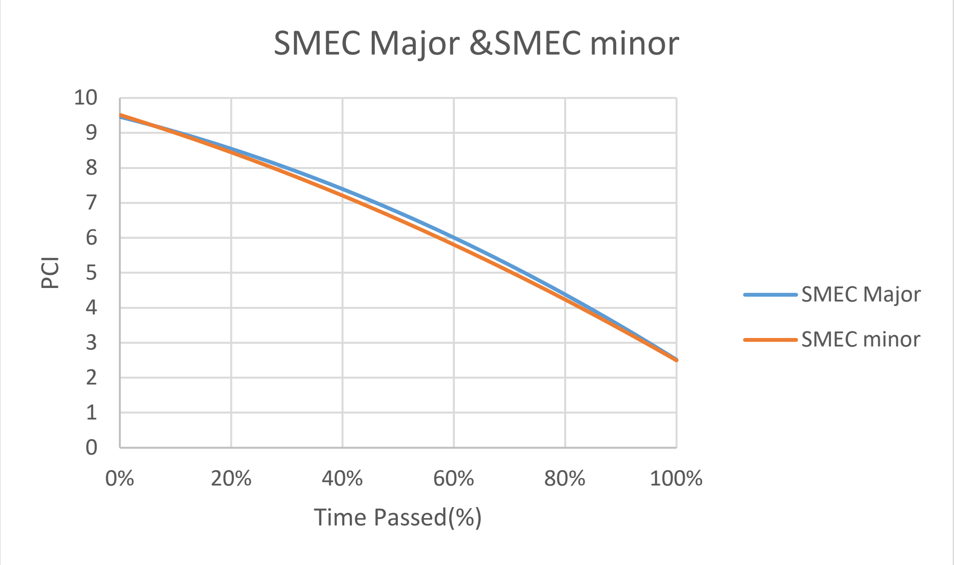


Figure 33:SMEC Major vs SMEC minor

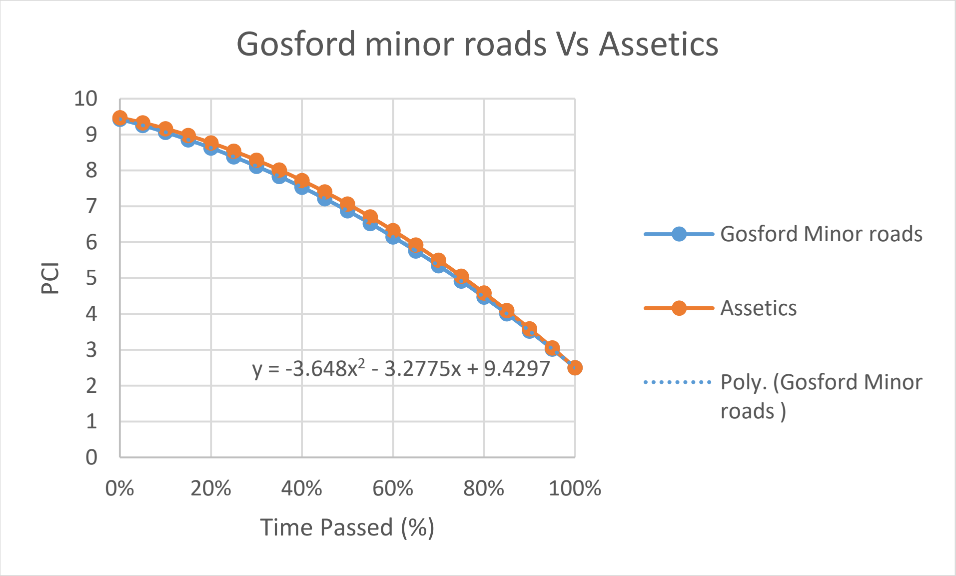


Figure 34: Assetics vs Gosford minor roads

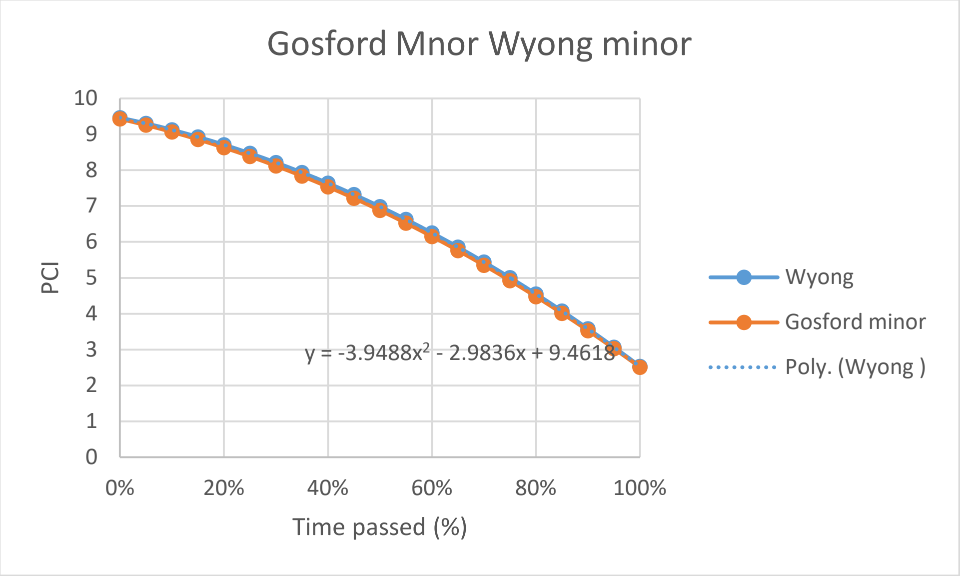


Figure 35 Gosford Minor vs Wyong Minor

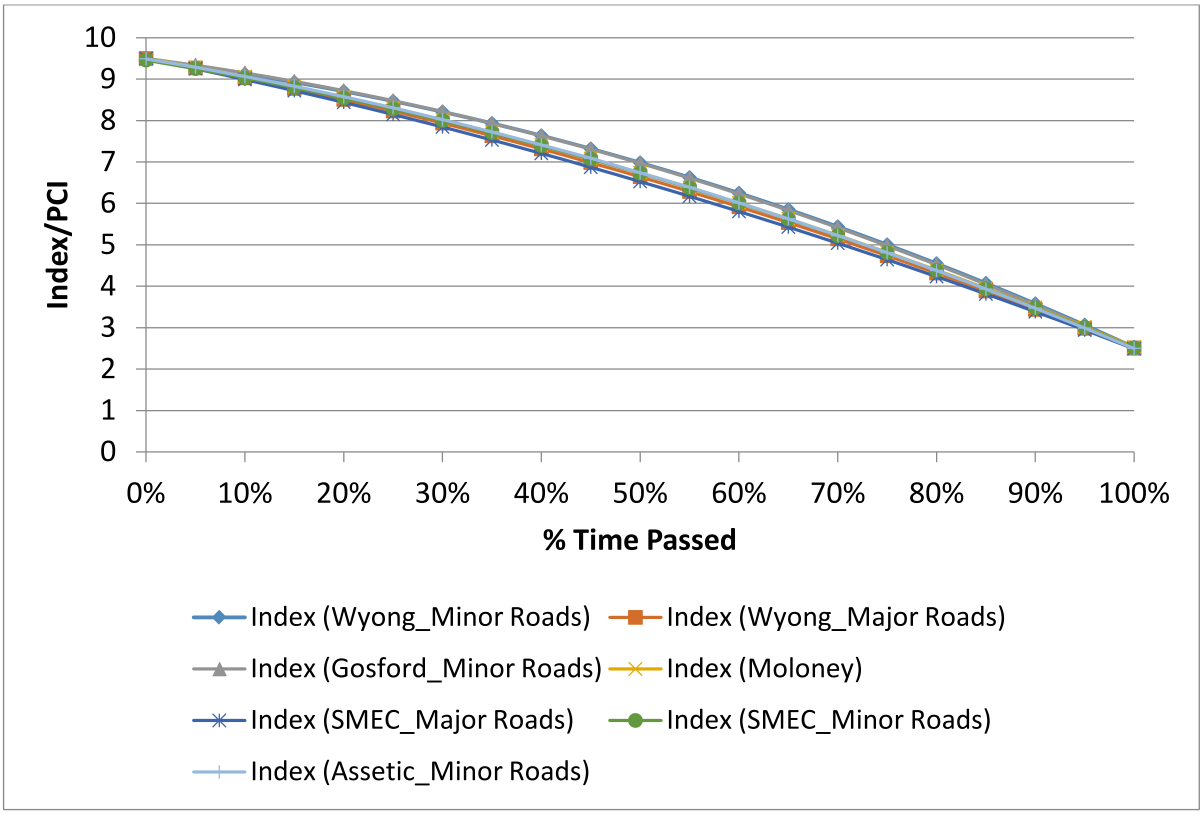


Figure 19- Combined graph

4.4 Computational analysis

4.41 Comparisons between curves

As a validation process statistical testing and measuring gaps between curves has been employed as a form assessment to how thy integrate .

Pavement Prediction Model	**Equation**
SMEC_Minor	$Y=- 2.9728x^2 - 3.9704x + 9.458$
SMEC_Major	$y = -2.0892x^2 - 4.9399x + 9.52$
Assetics_minor	$Y= -4.3143x^2 - 2.655x + 9.4723$
Moloney Model	$y = -2.8923x^2 - 4.073x + 9.5$
Gosford minor roads	$y = -3.648x^2 – 3.2775x + 9.4297$
Wyong minor Roads	$y = -3.9488x^2 – 2.9836x + 9.4618$
Wyong Major Roads	$y = -2.5496x^2 - 4.445x + 9.4961$

Table 27: Formulas for prediction tools

Table 26 shows that how the deterioration tools can be described as a mathematical formula. It can be seen that quadratic formulas has been produced.

4.42 Area between the curves

The table 27 below shows the integration values when each curve is integrated from 0 to 1.

Deterioration models & Random road models	**Integrated Values**	**Difference**
$\int_0^1 Assetics$ - $\int_0^1 SMEC\ major\ roads$	6.7067-6.35365	0.35203
$\int_0^1 Assetics$ -$\int_0^1 Gosford\ Minor\ Roads$	6.7067 – 6.57495	0.13175
$\int_0^1 Assetics$ - $\int_0^1 SMEC\ minor\ roads$	6.7067-6.48187	0.225
$\int_0^1 Moloney$ -$\int_0^1 SMEC\ minor\ roads$	6.4994-6.48187	0.01753
$\int_0^1 Wyong\ Minor\ Roads$ - $\int_0^1 Gosford\ minor\ roads$	6.65373- 6.57495	0.07878
$\int_0^1 Wyong\ Major\ Roads$ - $\int_0^1 Gosford\ minor\ roads$	6.42373 – 6.57495	0.15122
$\int_0^1 Wyong\ Minor\ roads$ - $\int_0^1 Wyong\ major\ roads$	6.65373-6.42373	0.23

$\int_0^1 Wyong\ major\ roads$ - $\int_0^1 SMEC\ major\ roads$	6.42373-6.35365	0.07
$\int_0^1 SMEC\ minor\ roads$ - $\int_0^1 Wyong\ minor\ roads$	6.48187-6.65373	0.17186
$\int_0^1 Moloney$ - $\int_0^1 SMEC\ Major\ Roads$	6.4994 -6.35365	0.14584
$\int_0^1 Ascetic\ minor\ roads$ - $\int_0^1 Moloney$	6.7067 - 6.4994	0.2073
$\int_0^1 Gosford\ Minor\ \ Roads$ -$\int_0^1 Moloney$	6.57495- 6.4994	0.11015
$\int_0^1 Moloney$-$\int_0^1 Wyong\ Major\ Roads$	6.4994- 6.42373	0.07567
$\int_0^1 Moloney$-$\int_0^1 Wyong\ Minor\ Roads$	6.65373- 6.4994	0.04418
$\int_0^1 SMEC\ \ minor$-$\int_0^1 SMEC\ major$	6.48187-6.35365	0.128
$\int_0^1 Assetic\ \ minor$-$\int_0^1 Wyong\ minor$	6.7067 – 6.4994	0.207

Table 28: Calculus Performed between curves

4.43 P-Values

P-values have been computed has shown below . The intention of finding P-values is to see if relationships exist between data sets . In other words to see whether there is a zero relationship between variables. The intention of finding the P-value is to establish to see if there is some kind of affiliation between data sets . As explained in the literature review if the output is lower than 5% then the null hypothesis would have to be rejected .

P-VALUE	MOLONEY	ASCETICS_MIN	GOSFORD_MIN	SMEC_MIN	WYONG_MIn	WYONG_MAJ	SMEC_Maj
SMEC_Maj	$5.48*10^{-30}$	$9.02*10^{-22}$	$1.57*10^{-24}$	$3.91*10^{-29}$	$3.91*10^{-29}$	$3.91*10^{-29}$	=================
Wyong_Maj	$5.74*10^{-37}$	$2.01*10^{-36}$	$2.09*10^{-37}$	$1.45*10^{-28}$			
Wyong_Min	$7.66*10^{-28}$	$2.66*10^{-37}$	$1.91*10^{-38}$			$1.74*10^{-25}$	
SMEC_Min	$2.84*10^{-48}$	$4.13*10^{-36}$	$1.57*10^{-31}$		$1.45*10^{-28}$		
GOSFORD_Min	$1.64*10^{-30}$	$3.9*10^{-32}$					
MOLONEY		$1.44*10^{-25}$	$1.64*10^{-30}$				
ASSCETICS_MIN	$1.44*10^{-25}$		$3.9**10^{-32}$		$2.66*10^{-37}$	$1.01*10^{-23}$	

Table 29: P-Value of all deterioration models and random road models

It can be seen that the P-value is incredibly small. However some of these values are much smaller than others.

4.44 The R^2 value

The R^2 value signifies the line of best fit . Essentially correlation is being measured in which variability of the data set can be measured.

R^2	MOLONEY	ASCETICS_MIN	GOSFORD_MIN	SMEC_MIN	WYONG_MIn	WYONG_MAJ	SMEC_Maj
SMEC_Maj	0.999004469	0.992708	0.996263	0.9988903	0.998776	0.998776	==================
Wyong_Maj	0.999817		0.998139	0.998595			
Wyong_Min	0.998325	0.999831	0.999872	0.995619		0.997035	
SMEC_Min	0.999988	0.997452	0.999315		0.99859		
GOSFORD_Min	0.999123	0.999408					
MOLONEY		0.997094	0.999123				
ASCETICS_MIN	0.997094		0.999408		0.999831	0.995453	

Table 30: P-Value of all deterioration models and random road models

4.45 Average readings gathered

Table 31: Average readings

R^2	Area between curves	P-value
0.99872	0.164	4.52*10^-23

From the readings that have been computed the average has been taken so that comparisons can be made.

4.5 Discussion

In section of the report discussion will take place about the comparisons of results when P-value R^2 and area between curves has been found.

4.51 Graphs depicting deterioration curves

As shown in figure 4.31 the SMEC major roads is deteriorating at a far lesser rate than the SMEC minor roads. Which is quite unusual especially when traffic loading is incredibly higher with the Major roads than the minor roads. The Moloney model can be seen to be deteriorating at a smaller rate than the major roads . The Moloney model is a representation Coff's Harbour city council road network . Out of all models developed it can be seen that the Moloney model has the least amount of manipulation . The Moloney's model developed is a generic model of the entire road network and not just a particular class of roads.

4.52 Graphs depicting random roads.

The data sets such as the Gosford minor roads and Assetics deterioration tool is closely aligned in terms of curvature . However the Assetics minor roads deterioration tool does show a higher rate of deterioration than selected random minor roads. This may be attributed to the fact that those particular selected roads were unusually in terms of deterioration.

4.53 Area between curves

Through the use of calculus the area in between the curves was found so that dissimilarity can be found. No two curves can be perfectly aligned however by finding the area between curves deterioration similarities can be computed. This is for the whole life span of a pavement with an assumed life of twenty years.

4.54 Deterioration tools versus random roads

The smallest area is between the deterioration tool and a random road model is SMEC minor roads and Wyong minor roads followed by Wyong major roads and SMEC major roads . It would appear that Access roads and Distributor roads within the former Wyong jurisdiction can be simulated using the techniques of extrapolation to a very high degree when using area as a form of assessment . This should be to one's expectations considering that the random roads would be within the pool of roads in which the deterioration tools comprise of.

The area between assetics minor roads and Gosford minor roads seem to have the highest area in the "deterioration tools verses random roads category". Assetics rates its own roads from 1 -5, making it difficult to convert every road to a 1-10 scale. For the random twenty roads that was chosen a straightforward conversion was applied before the filtering process . When generating the deterioration curve the entire pool of roads provided by the Asset Management team could not be manually converted to a 1- 10 scale. Only after the length weighted average scale was calculated that a conversion took place to a 1 -10 scale which required interpolation.

The lack of consistency in terms of technique may have hindered the level of alignment in terms of area between Assetics deterioration tool and the minor roads random roads model.

4.55 Area between each set of Random roads model .

Deterioration tools of random roads of interest	Area in-between them
Wyong minor- GoSford minor	0.07878
Wyong major- Gosford minor	0.15122
Wyong minor- Wyong major	0.23

Table 32: Area between curves

As shows in table 31 there is currently three sets of random road data each consisting of twenty roads of their respective road classes i.e Wyong major roads, Wyong minor roads and Gosford minor roads. The smallest area between two set of random roads happens to be between Wyong minor and Gosford minor roads. The minor roads of Gosford does deteriorate in a very similar fashion to how access roads of the Wyong area deteriorate when resorting to this form of assessment. The next smallest area is between Gosford minor roads and Wyong major roads, which has an area of 0.1522. Wyong minor roads and Wyong major roads has an area of 0.23 . It is interesting to see how the deterioration pattern of Access roads in the Gosford area is more similar to the Distributor roads of the Wyong area .

4.56 Area Between each set of Deterioration Tools .

Deterioration tools of comparison.	Difference of Area
Moloney /SMEC minor	0.01753
SMEC maj/ SMEC min	0.128
Moloney /SMEC major	0.14584
Asscetic min/ moloney	0.2073
Assetics/ smec minor	0.225
assetics - smec major	0.35203

Table 33: Area between each Deterioration tool

Just like each set of random roads each deterioration tool will be assessed in terms of alignment. The smallest area between two deterioration curves is Moloney and SMEC minor roads which is 0.01753 followed by SMEC major and SMEC minor roads that has a value of 0.128 . The third largest value in terms of area is between Moloney and SMEC major roads that is of a value of 0.14584 .

Asscetic minor roads and the Moloney model has a value of 0.2703 followed by Assetic minor roads and SMEC minor roads which has a value of 0.225 . It would seem that the generic Moloney model which is meant to represent the entire road network of Coff Harbour city council has some alignment with the entire set of distribution roads and access roads . However it would also seem that the

Moloney model is compatible with Assetic minor roads which means minor roads in the former Gosford area.

The advantage of comparing pavement deterioration models against each other is that we know each deterioration tool was formulated using the entire database of a particular road class. There is no bias factor involved when formulating these deterioration tools hence the area in-between each curve would unbiased.

4.57 In summary of area between curves .

The area between Moloney and Smec Minor roads happens to be the smallest suggesting that the road network of Coff's harbour council road network in indeed similar in terms of minor road deterioration . The third smallest area is between Assetics minor roads and Moloney . It would appear that minor roads and access roads are highly common roads within the road network of Coff's harbour . When comparting deterioration tools to random roads selected the smallest area was found between Wyong minor roads and SMEC minor roads followed by Wyong major roads and SMEC major roads . The technique applied when formulating these models is very much consistent and furthermore the sample of the twenty random roads is already embedded within the roads that was used to make the deterioration models. Moloney's model seems to be more aligned with SMEC minor roads and SMEC major roads.

4.6 P-Value

4.61 P-value between each set of Random roads.

Models of random roads of interest	**P-value**
Wyong minor- GoSford minor	1.91*10^-38
Wyong major- Gosford minor	2.09*10^-27
Wyong minor- Wyong major Moloney – Assetic	1.74*10^-25 1.44*10^-25

Table 34: P-value of Random roads

4.62 P-Value Between each set of Deterioration Tools .

Deterioration tools of comparison.	**P-Value**
Moloney -SMEC minor	$2.84**10^{-48}$
SMEC maj- SMEC min	$3.91*10^{-29}$
Moloney -SMEC major	$5.48*10^{-30}$
Asscetic min - molo	$1.44*10^{-25}$
assetics - smec minor	$4.13*10^{-26}$
assetics - smec major	$9.02**10^{-22}$

Table 35: P-value between each deterioration tool

When the P-value is incredibly low and less than five percent it signifies that the variables i.e the data sets are statistically significant . The results show that all null hypothesis can be rejected as they are all less than five percent . The Assetic deterioration tool model against major tool seems to have the highest P-value and the higher than the average p-value of $4.52*10^{-23}$.

It interesting to see how that P-value between Assetic deterioration model Moloney has the highest P-value of 1.44 $*10^{-25}$when comparing it every other model .

Moloney's is the model in which all data points were utilized. However it is worth noting that the P-value between Moloney's model and SMEC minor roads is $2.48*10^{-48}$ which is far smaller than a P-value between Moloney's model and Wyong minor road which has a P-value of $7.66*10^{-28}$. From these values we can infer that Moloney's model has a far more significant factor when more roads Access roads are used . Furthermore this can suggest that the Road network of Coff's harbour city council maybe more statistically significant to access roads in terms of deterioration.

The P-value between Wyong minor roads and Assetic minor roads which is 2.66 $*10*10^{-37}$Is far less than the p-value between Wyong minor roads and SMEC minor roads that is a value of 1.45 $*10^{-28}$. Minor roads and Access are rather similar in terms of traffic loading . As found in the literature review minor roads are intended to provide a passageway to major road . Banyule City Council experiences an average daily traffic of 845 vehicles/day for its access roads (Banyule City Council 2014) . By definition access roads provide a gateway to residential areas with convenience . An example of an access road would be a court. What can be inferred is that the selected twenty access roads within the former WSC area just happen to imitate the same level of deterioration in which minor roads in the former GCC degrade.

The p-value between the Wyong minor roads and Gosford minor roads is the second lowest P-value found. This signifies that the null hypothesis can be rejected . The fact that data sets have two roads each have seem like a contributing factor to such a low p –value . It should be noted that

4.7R^2 Values between Data sets

The following analysis attempts to look at the R^2 values which have been generated between deterioration tools and random road deterioration models .

4.71 R^2 between each set of Random roads.

As previously discussed in the literature review the r^2 value is of great importance as it can be used to describe correlations. However the fact that the R^2 value is bias should be taken into consideration. After all the trend in very much manipulated by following coffs harbour city council road deterioration trend as form of guidance .

The analysis detailed below will describe the level of correlation between each set of data. It can be seen that the correlation is rather high when comparing every deterioration model and models of random roads.

4.712 Moloney Model Correlation

- When the Moloney model is correlated with Wyong Major roads there can be seen a very high correlation of 0.999817 while there Is only a correlation of 0.999004 with the SMEC_major model .
- Moloney does have a higher correlation with SMEC minor roads than Wyong minor roads While also having a higher correlation with Gosford minor roads than Assetic minor roads.
- Based on these observation it maybe Moloney being a generic model and just a representation of Coff Harbour city council network, it can relate better to higher classes of roads but with a slightly difference in deterioration.
- The random road model are only made up of twenty random roads hence less PCI values to filter through making the extrapolation process based on less data.

4.72 ASSCETICS

- Assetics can be seen to correlate much better with SMEC minor than with SMEC major . This could be attributed to the nature of the pavements in terms of traffic loading . Minor roads generally provide a gateway across major roads access roads more to do with residential areas such as courts and avenues.
- The literature review highlighted how limitation on Wyong Access roads were around 150-1000 AADT while Gosford minor roads have a 60 AADT limitation on rural road and a 150 AADT on urban roads. A common traffic loading may been shared between these types of roads on each network .

4.73 Gosford Minor Roads

- Table 24 shows that Gosford Minor Roads correlates better with SMEC minor road than SMEC major Roads . As mentioned previously this would have to do with the common traffic loading experienced by access roads and minor roads.
- This notion is supported by how SMEC minor correlates better with SMEC major than Wyong Major roads and also how SMEC minor correlates better with Assetic minor.
- The fact Gosford minor roads correlates better with Wyong minor roads than SMEC minor roads maybe to do with the fact they both used twenty random roads each.

Models of random roads of interest	R^2
Wyong minor- GoSford minor	0.999872
Wyong major- Gosford minor	0.998139
Wyong minor- Wyong major	0.997035

Table 36: R^2 between random road models

- Table above shows how Wyong minor roads and Wyong major roads correlate the least and further more is below the average correlation of 0.99872.

4.74 Area Between each set of Deterioration Tools .

Deterioration tools of comparison.	R^2
Moloney -SMEC minor	0.999123
SMEC maj- SMEC min	0.9988903
Moloney -SMEC major	0.999004469
Asscetic min - moloney	0.997094
assetics - smec minor	0.997452
assetics - smec major	0.992708

Table 37: R^2 Between deterioration models

Table 36 shows how Assetics and SMEC major roads correlate the least and are below the average correlation . As stated on numerous occasion this has to do with the deteriorating rate being very different due to the traffic loadings as detailed in the literature review.

As previously discussed in the literature review the $\boldsymbol{R^2}$ value is of great importance as it can be used describe correlation .

4.8 Limitation of study

The study which has been conducted is very much orientated towards three classes of roads, they include Distributor roads and access roads within the former WSC jurisdiction and minor roads that's within the former GCC jurisdiction. The deterioration tools developed were done so under certain assumptions such as the deterioration rate and a certain level of deterioration had to occur at certain milestones of a pavements natural life . An assumption was made that the average lifespan of a pavement is only twenty years and a criterion was applied in which the initial PCI had to be 9.5 and the final being 2.5. It should also be noted both SMEC and Assetics are very different in nature in terms of their simulation ability. SMEC being probabilistic and Assetics being empirical. HDM3 is the driving force behind the simulation of SMEC .

Furthermore extrapolation is a form of data mining, using existing data and creating an array of data . As the literature has shown there are many more variables which need to taken into consideration when trying to develop a robust model . The Central Coast has been known to experience flooding in 2007 which had a catastrophic effect on the structural integrity of the network .

Both former councils did do some defect survey once every four years, contracting service providers to do laser scans at certain parts of the network. This aspect of the study was ignored only because the surveys were done different periods within the four years creating ambiguity. In addition record keeping of when and what parts of the network were surveyed were poorly recorded creating more ambiguity . It is unknown which PCI values provided are surveyed and PCI that have been simulated. But because a filtering process was instilled within the methodology, i.e eliminate any increase of PCI values it is assumed that any survey data was part of this elimination.

As discussed in the literature review correlation i.e R^2 value and P-value have been selected as the statistical measures to check the validation process. Because the nature of the research is to identify any affiliations between the deterioration model and the random road sample correlation would be the most idyllic way of measuring robustness.

Chapter 5

5.1 Aims and Outcomes

- To research and develop models which can imitate deterioration on a particular class of road .
- To check how well each deterioration tool was formulated .
- To make recommendation based on findings which deterioration tool is appropriate for a particular class of road .
- To check if a deterioration tool can simulate not just it own class of road but other roads that of interest to the project

The literature review has shown different forms of deterioration can occur which is then reflected by the PCI value. Both former councils used different PMS packages Assetics and SMEC which brings the phenomenon to the project . Furthermore the Moloney model has ben incorporated into the study as it provides a form of guidance of untreated roads,. Ideally there should some kind of independent variable such as the same defects on the same roads but different processing methods to generate a PCI .

The study has shown how three measurement methods can be applied to the deterioration tools and models. Information in regards to how well correlated, aligned and the level of statistical significance trends are can be derived.

The study has shown that a correlation between each assessment device does exist. It would seem a High R^2 coefficients, low P-values and low areas have likely to be found. Hence the deterioration tools seems to do a good job.

As found in the discussion the best way to assess how good a deterioration tool is by speculating how well the deterioration tool curve matches up wit the random road model.

This can be achieved by using three different ways of measuring compatibility through finding the area between curves, the correlation and the P-vale to measure how statistical significant the data sets are .

5.2 Gosford Minor (Minor roads)

Based on $\boldsymbol{R^2}$ values we can conclude that the access roads of Gosford can be simulated to precision with an Assetics minor road deterioration tool . Second to this would be the SMEC minor deterioration tool.

In terms of P-value the Assetics minor roads has the smallest value followed by SMEC minor roads. The smallest area between curvatures is the Moloneys followed by the Assetics minor roads model. Based on the compelling evidence it would be appropriate to conclude that the Assetics minor road model is most suited to model minor roads in the former Gosford jurisdiction.

5.3 Wyong Minor (Access Roads)

When correlating with Access roads of Wyong the $\boldsymbol{R}^2$ has shown surprisingly that the Assetics minor roads deterioration tool is the most correlated followed by the SMEC major tool . The P value has shown to have some level of agreement as Assetics minor roads is shown to be smallest followed by SMEC major roads. When comparing the areas between curvatures the Moloney model has a smaller area followed by the SMEC minor roads. Based on the findings the Assetics minor roads deterioration tool would have to be the most suited when modelling access roads in the Wyong area.

5.4 Wyong Major (Distribution)

Moloney roads deterioration model has a higher r^2 value followed by SMEC major roads. As for the P-value it can be seen that the Moloney deterioration tool followed by the SMEC major roads deterioration tool has the lowest P-values . Based on the observations Moloney's deterioration tool model is better suited to the Distribution roads of Wyong.

5.5 Recommendations for future study .

The study up until this point has been focused on road class and PMS packages used by the former GCC and WSC. The results have shown that in some cases road deterioration can be better simulated by deterioration tool which is meant for another class of road. This was most evident when speculating about how Wyong access can be simulated with Assetic minor roads.

Despite the fact that twenty roads were used to develop the road deterioration model the Assetics minor road deterioration tool manages to have a closer relationship between datasets to it in terms of correlation and P-value. Chapter four made a link with the literature findings that traffic lading is indeed the main source of deterioration . This cause maybe the reason behind why Assetic minor roads can be used to simulate Wyong access roads.

If this study was to be repeated then to improve the understanding of how deterioration models operate further analysis can be applied such as finding the F-value and examining residual plots . Furthermore comparing the same class of road from each council may be an idyllic comparison rather different classes of road with different traffic loadings.

5.6 Further Studies

While having a deterioration model dedicated to one class of road the concept of a deterioration tool that can mimic an entire roads deterioration can be explored. A deterioration model which can adapt to any class of and evaluate some kind of robust output maybe a good step forward .

Additional parameters can be incorporated into the study such has the geological formation of the pavement and weather patterns . Although the current study was highly empirical exploring a probabilistic model maybe a good concept.

As found in the literature review Assetics fits the description of being empirical while SMEC is more probabilistic . Traffic loading is taken into account when generating a PCI while Assetics only considers traffic loading when finding a remedy for the defect . An additional step maybe to look into geological factor which may deter road pavement failure.

Referees

Assetinsight, 2017, Deterioration model , <http://www.assetinsights.net/Glossary/G_Deterioration_Model.html>, 10/10/2017

A.K Gupta , S. Sharad, 2006, "Pavemet Deterioration and its causes", Journal of Mechanical & Civil Engineering , pp.09-15 . Civil JJ Magdum College for engineering/ Shivaji University , India.

Austroads 2009, Guide To Asset Management Part 5H : Performance Modelling , Australia

Banyule city Council 2014 , Services asset management plan Part D – Bridges, Victoria.

Campbelltown City Council, Road Net work Asset management plan 2016-2026, 2016, NSW .

City and County of San Francisco , Safe streets and Road Repair Bond, 2009 , an Francisco .

City of Saskatoon Building Better Roadways: An Asset management plan for Road ways, 2016, Saskatoon

Colhoun.S,1997 Evaluation of Long Term Pavement Performance and application to a Pavement Management System , Session 6 - Reports from 1997 AAPA Study Tour.

Coffs Harbour City Council , Transport Asset Management plan 2014-2024 , 2014

Ercisli. S , 2015 "Development of Enhanced pavement deterioration curves ' , Thesis Masters of Science in Civil Engineering , Virgina Polytechnic Institute.

Francis B. Nelson III, 2014, Use of Pavement Management to develop Maintenance and Rehabilitation Techniques, 17th Annual National Tribal Transport Conference , nchorage Alaska .

Garber. N , Hoel. L, 2009, Traffic and Highway engineering , 4th edition, Cengage learning, United states

Gosford City Council , Transport Asset Management plan 2014 , , volume 1

Khan MU , Odoki. JB, 2008 , Establishing optimal pavement maintenance standards using HDM-4 Model for Bangladesh. Journal of Civil Engineering IEB pp 1-16 , 2010 institute of Engineers Bangladesh.

K.P George , A. S Rajagopal , L.K Lim , 1989, "Models for predicting Pavement deterioration " , Transportation Research record 1215, Department of Civil Engineering University of Mississippi .

Li, Q, Kumar, A & De Silva, S 2002, 'A hybrid deterministic-probabilistic approach for pavement deterioration modelling for local roads', International conference on application of advanced technology in transportation, 8th, 2002, Massachusetts, USA

The Local government municipal knowledge base, Road hierarachy < http://www.lgam.info/road-hierarchy> accessed 10/06/2017 .

Li, Z , 2005, A probabilistic and Adaptive approach to modelling performance of pavement infrastructure . PHD thesis , University of Texas,

Lytton, RL 1987, 'Concepts of pavement performance and modelling', North American conference on managing pavements, 2nd, vol. 2, Ministry of Transportation, Ontario, Canada, pp. 4-19.

Mallick R, Korchi T.EL, 2013 , “Pavement Engineering Principals and Practices second edition”, Taylor and Francis inc, US

Muhammad M. ,2010, Predicting deterioration for the Audi Arabia Urban Road Network, PHD Thesis University of Nottingham

Mills. L,Attoh – Okine N, Mcneil S. 2011“Developing Pavement Performance Models for Delaware “, Department of Civil Engineering and Environmental Engineering, University of Delaware

Randwick city council, Asset Manageent ,NSW 2004

RHD. 2017 HDM4 Overview . {ONLINE }Available
At: http://www.rhd.gov.bd/Documents/HDM/Overview/HDM.pdf

SMEC, 2015, “ SMEC Pavement management and Road Inventory system Uer’s Manual” , PDF, Version 5.5 .

S. Somasundarawaran , 2014 Transport Enginering , CIV3703, USQ, Toowoomba

Southern Grampians Shire Council, Road Infrastructure Asset management plan ,2013

Underwood R,1995 ,Road Engineering Practice Mcmillian Education Australia , South Melbourne .

Vandermeer. W, 2001 “Maintenance of pavenets ‘, Thesis Bachelor of Engineering , University of Wollongong .

Waverly City Council , Strategic Asset Management plan ,NSW , 2013

Appendix A – SPECIFICATION

Name: Janahan Karunaharan

Project: Asset predication modelling.

Supervisor: David Thorpe

Project aim: To investigate how local governments conduct their asset maintenance particularly in the areas of asset prediction modelling and gauge how effective it is.

Enrolment : ENG 4111 S1 ,EXT 2017

ENF 4111 S2, EXT 2017

Programme:

1) Research literature and background information.
    a) Asset management in terms of roads
    b) Local government roads.
    c) Road defects.
    d) Common Road designing processes.
    e) Prediction models of roads
    f) Pavement designs
    g) Ways of measuring effective asset maintenance.

2) After undergoing a literature review a methodology will be developed which will explain the testing and analysis procedures.

   Testing procedures.
3) The testing procedure will be of a qualitative style questionnaire, which will be distributed to government organisations and private companies. The prime focus of the questionnaire will be focused on asset life cycle. The questionnaire may be broken into categories which might focus on a particular type of road.

4) Data analysis

An Excel spread sheet will be formed in which the collated data will be fed into. The spread sheet will have a number of algorithms inbuilt. Each question will have a criteria in which the response will be marked on. In essence a qualitative scoring system will be developed in which a number of outputs such as graphs will be produced. Comparisons can be made between outputs generated.

5) From the outputs generated a comparison will be made between each local government's methods. In terms of their way of conducting their asset maintenance checks. A way to measure how 'robust' their methods will be explored i.e. their predication and validation models.

6) Recommendations and discussion about the project will then be made.

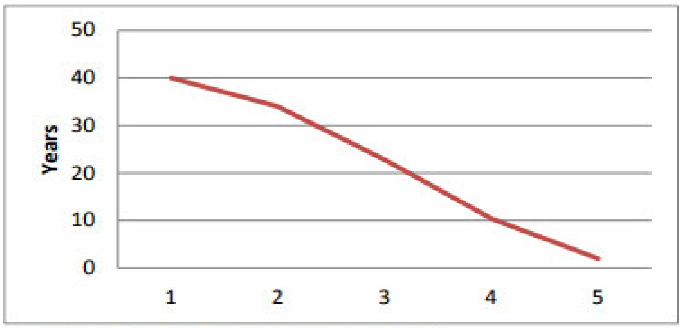
Appendix A – SPECIFICATION

7) The following chapters will comprise the dissertation. Introduction, Literature review, Methodology, Results, discussion and conclusion.

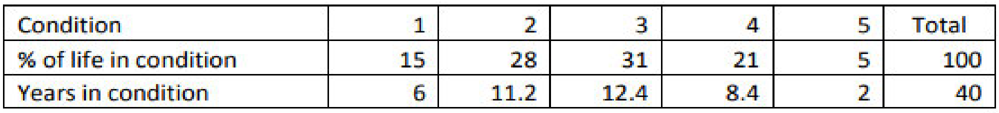
8) If time permits:
A universal prediction model will be developed in which will be able to be used by

Appendix B-Deriving Moloney Model

The following is an abstract from Coff's harbour city council which currently uses the moloney mode l. The figure is a representation of the entire network in terms of deterioration.



Remaining life (years) based on condition



Condition	1	2	3	4	5	Total
% of life in condition	15	28	31	21	5	100
Years in condition	6	11.2	12.4	8.4	2	40

Table 3.1 below shows the steps taken and the outcomes that have resulted when using the rating provided from the Coff's harbour asset management transportation publication.

Moloney's Rating	1	2	3	4	5	1 –Good, 5-failed
Reversed Moloney Rating and redefine	5	4	3	2	1	1-Failed 5-Good
Conversion to 1-10 scale applying criterion as established in	9.5	8	6	4	2.5	

literature review						
Accumulated % of life in condition	100	85 (100-15)	57 (85-28)	26 (57-31)	5 26-21	
Reversed Accumaled % of life in condition	5	26	57	85	100	
Adjusted Accumulated % of life in condition	0	30	60	85	100	

Time	**Index (Moloney)**	**Index (Moloney_Refined)**	**Index (Moloney_Final)**
0%	10.00	9.50	9.51
5%			9.29
10%			9.06
15%			8.81
20%			8.56
25%			8.28
30%	8.00	8.00	7.99
35%			7.69
40%			7.37
45%			7.04
50%			6.70
55%			6.34
60%	6.00	6.00	5.96
65%			5.58
70%			5.17
75%			4.76
80%			4.32
85%	4.00	3.80	3.88
90%			3.42
95%			2.94
100%	2.00	2.50	2.46

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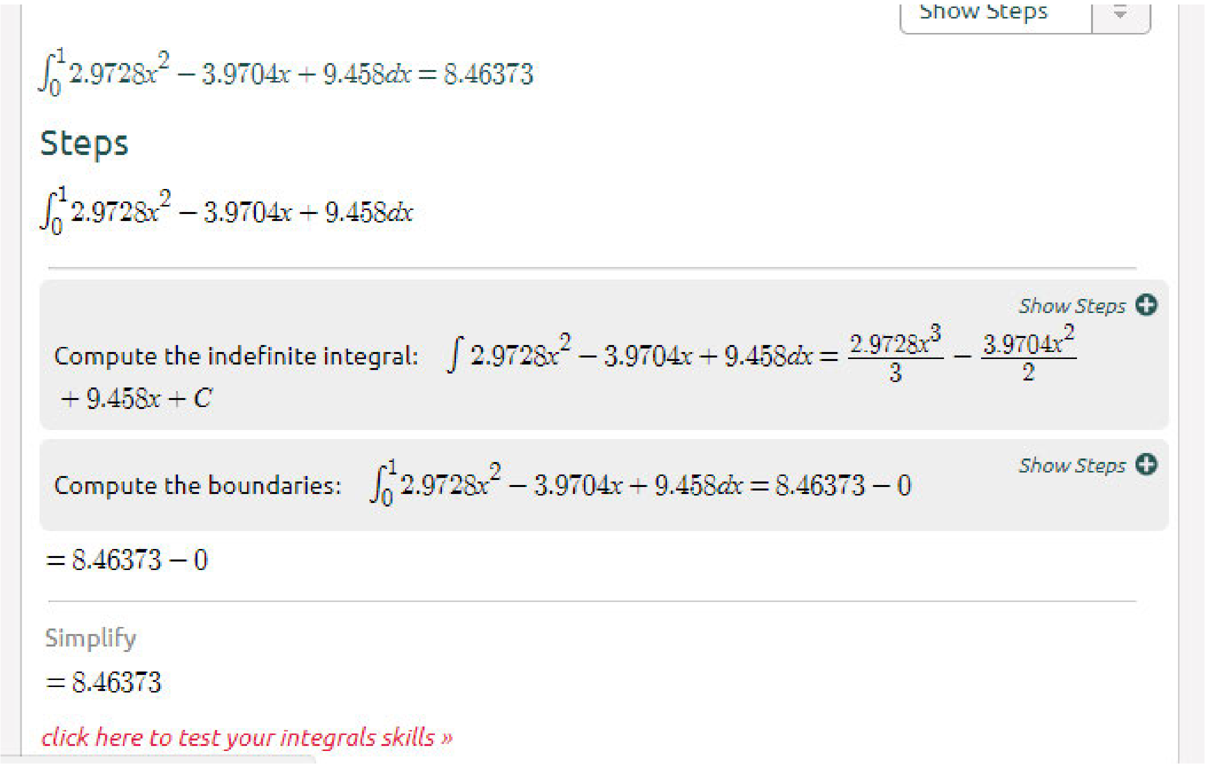
Appendix C – Calculus computations

SMEC Minor Calculous



$\int_0^1 2.9728x^2 - 3.9704x + 9.458dx = 8.46373$

Steps

$\int_0^1 2.9728x^2 - 3.9704x + 9.458dx$

Compute the indefinite integral: $\int 2.9728x^2 - 3.9704x + 9.458dx = \frac{2.9728x^3}{3} - \frac{3.9704x^2}{2} + 9.458x + C$

Compute the boundaries: $\int_0^1 2.9728x^2 - 3.9704x + 9.458dx = 8.46373 - 0$

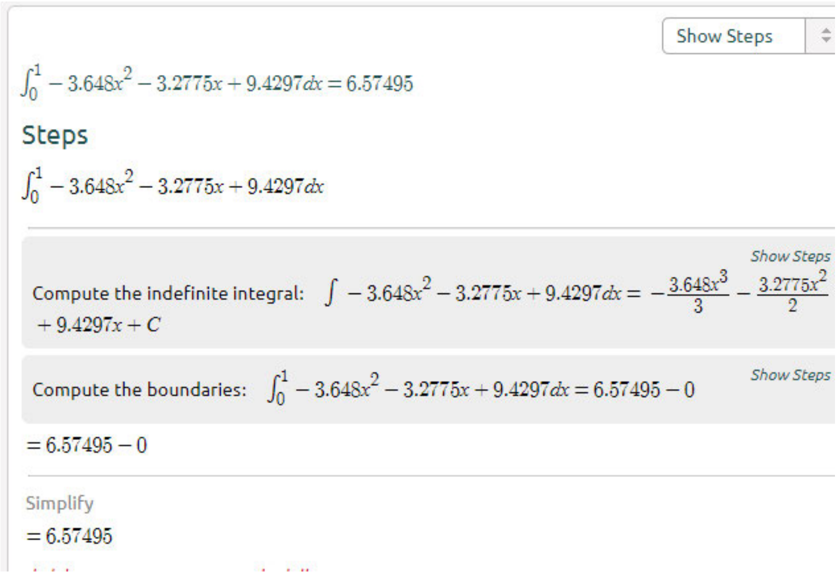
$= 8.46373 - 0$

Simplify

$= 8.46373$

click here to test your integrals skills »

Gosford Minor Roads



$\int_0^1 -3.648x^2-3.2775x+9.4297dx=6.57495$

Steps

$\int_0^1 -3.648x^2-3.2775x+9.4297dx$

Compute the indefinite integral: $\int -3.648x^2-3.2775x+9.4297dx=-\frac{3.648x^3}{3}-\frac{3.2775x^2}{2}+9.4297x+C$

Compute the boundaries: $\int_0^1 -3.648x^2-3.2775x+9.4297dx=6.57495-0$

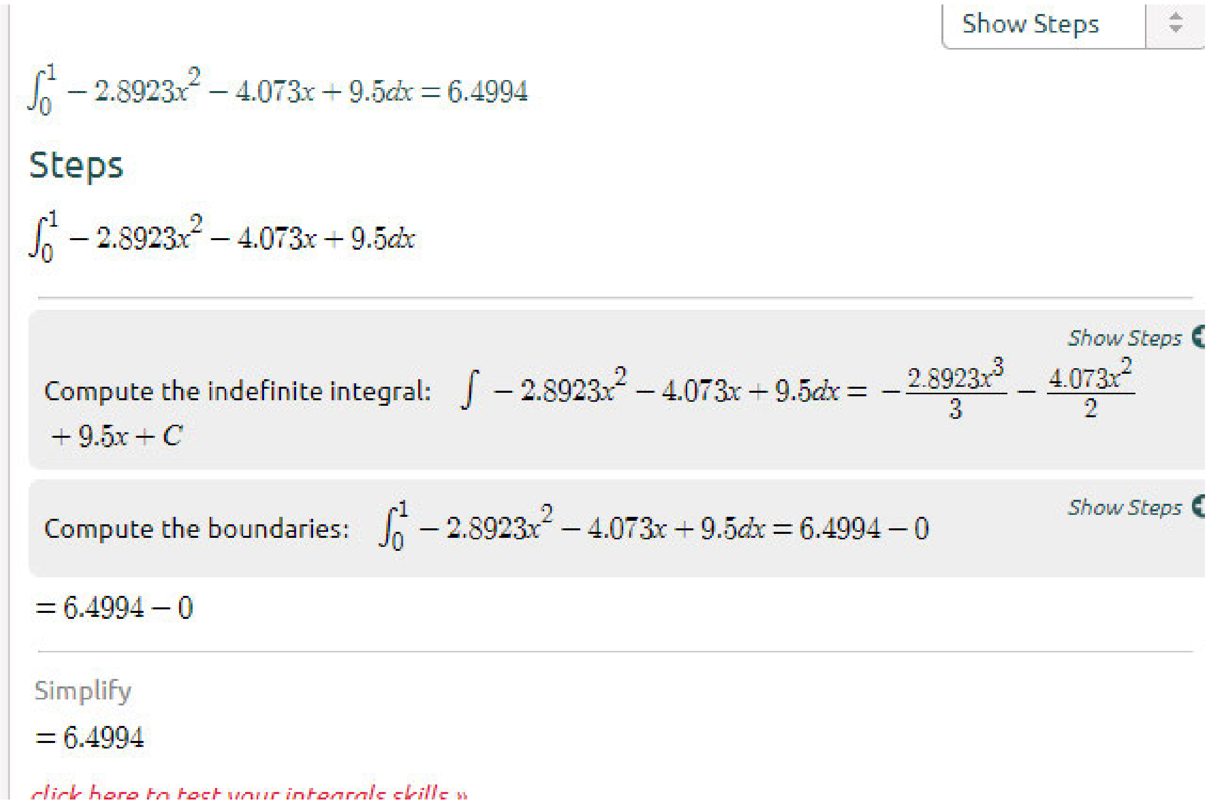
$=6.57495-0$

Simplify

$=6.57495$

Apendix C

Moloney



$\int_0^1 -2.8923x^2-4.073x+9.5dx=6.4994$

Steps

$\int_0^1 -2.8923x^2-4.073x+9.5dx$

Compute the indefinite integral: $\int -2.8923x^2-4.073x+9.5dx=-\frac{2.8923x^3}{3}-\frac{4.073x^2}{2}+9.5x+C$

Compute the boundaries: $\int_0^1 -2.8923x^2-4.073x+9.5dx=6.4994-0$

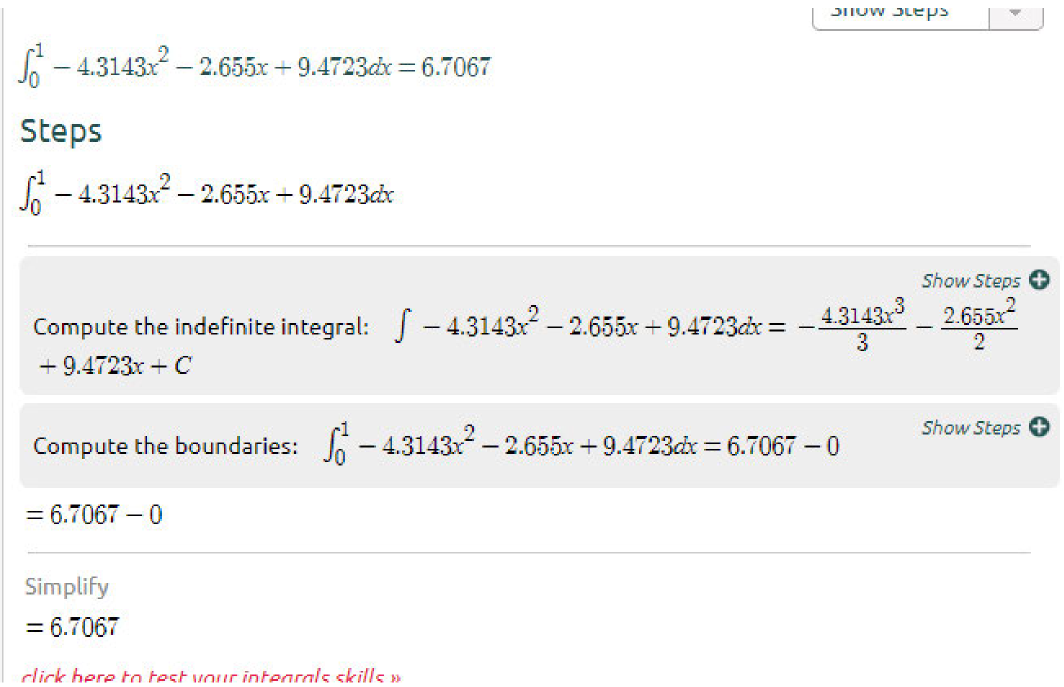
$=6.4994-0$

Simplify

$=6.4994$

click here to test your integrals skills »

Assetics Minor



$\int_0^1 -4.3143x^2 - 2.655x + 9.4723dx = 6.7067$

Steps

$\int_0^1 -4.3143x^2 - 2.655x + 9.4723dx$

Compute the indefinite integral: $\int -4.3143x^2 - 2.655x + 9.4723dx = -\frac{4.3143x^3}{3} - \frac{2.655x^2}{2} + 9.4723x + C$

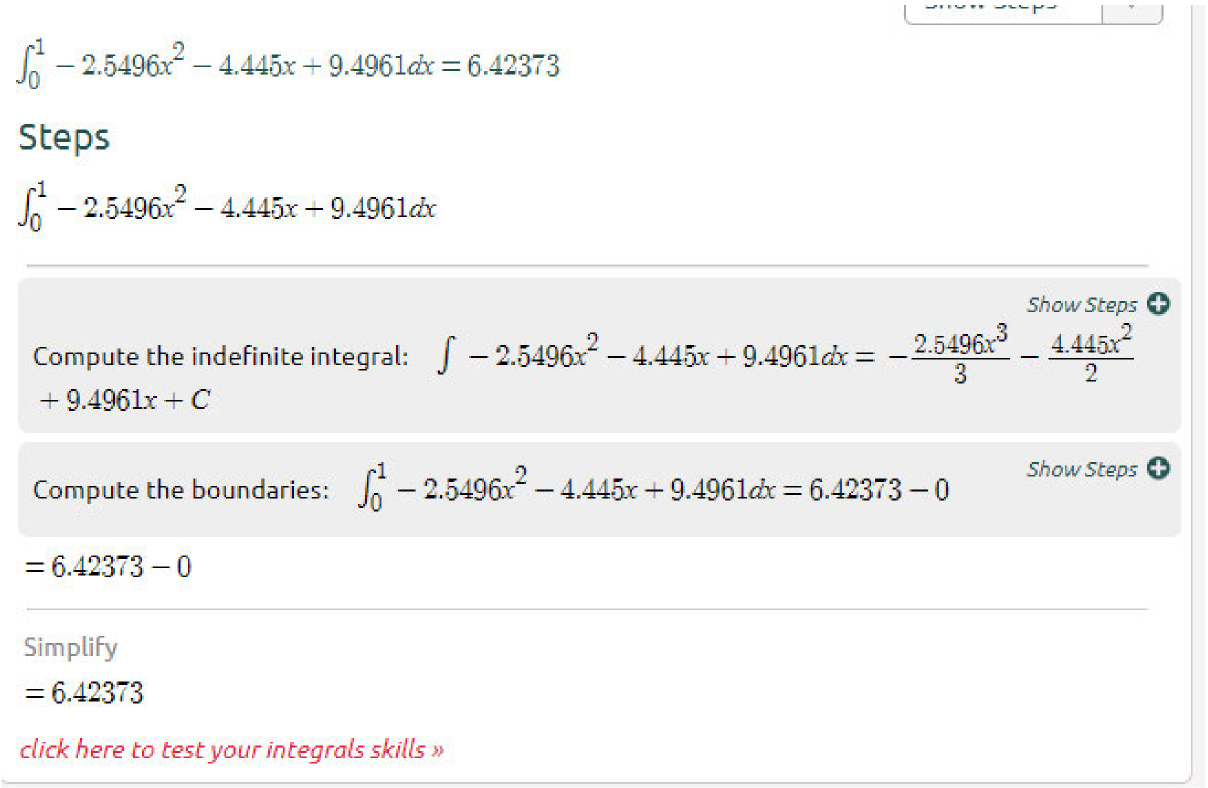
Compute the boundaries: $\int_0^1 -4.3143x^2 - 2.655x + 9.4723dx = 6.7067 - 0$

$= 6.7067 - 0$

Simplify

$= 6.7067$

Wyong Major



$\int_0^1 -2.5496x^2 - 4.445x + 9.4961dx = 6.42373$

Steps

$\int_0^1 -2.5496x^2 - 4.445x + 9.4961dx$

Compute the indefinite integral: $\int -2.5496x^2 - 4.445x + 9.4961dx = -\frac{2.5496x^3}{3} - \frac{4.445x^2}{2} + 9.4961x + C$

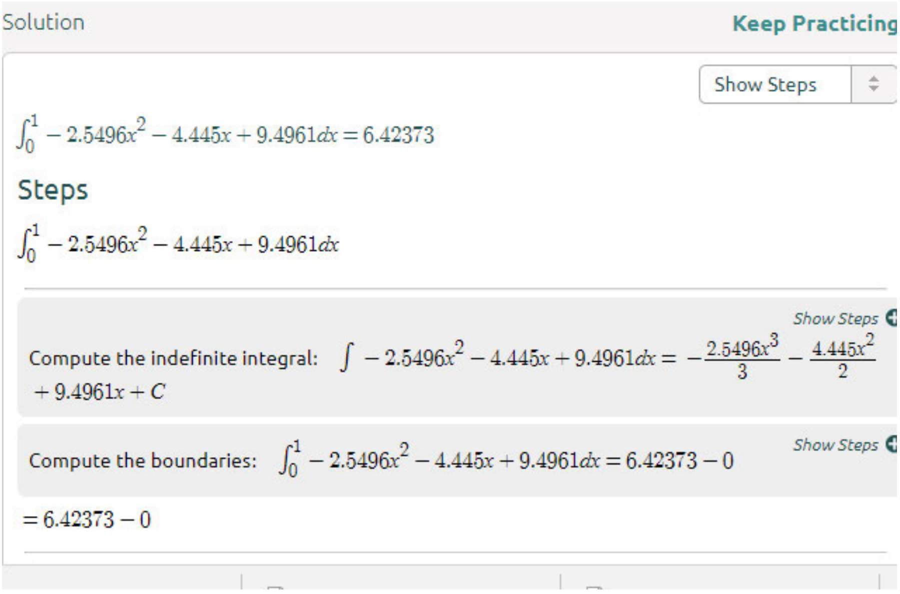
Compute the boundaries: $\int_0^1 -2.5496x^2 - 4.445x + 9.4961dx = 6.42373 - 0$

$= 6.42373 - 0$

Simplify

$= 6.42373$

Wyong Minor



$\int_0^1 -2.5496x^2 - 4.445x + 9.4961dx = 6.42373$

Steps

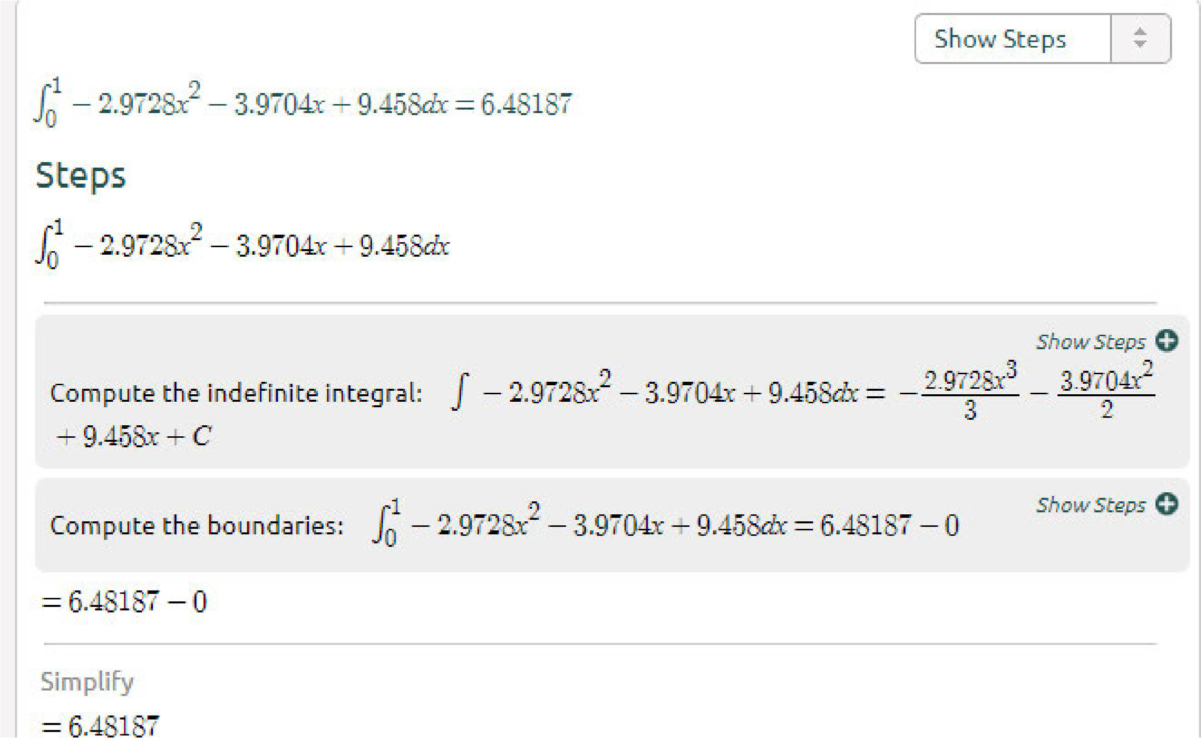
$\int_0^1 -2.5496x^2 - 4.445x + 9.4961dx$

Compute the indefinite integral: $\int -2.5496x^2 - 4.445x + 9.4961dx = -\frac{2.5496x^3}{3} - \frac{4.445x^2}{2} + 9.4961x + C$

Compute the boundaries: $\int_0^1 -2.5496x^2 - 4.445x + 9.4961dx = 6.42373 - 0$

$= 6.42373 - 0$

SMEC minor



$\int_0^1 -2.9728x^2 - 3.9704x + 9.458dx = 6.48187$

Steps

$\int_0^1 -2.9728x^2 - 3.9704x + 9.458dx$

Compute the indefinite integral: $\int -2.9728x^2 - 3.9704x + 9.458dx = -\frac{2.9728x^3}{3} - \frac{3.9704x^2}{2} + 9.458x + C$

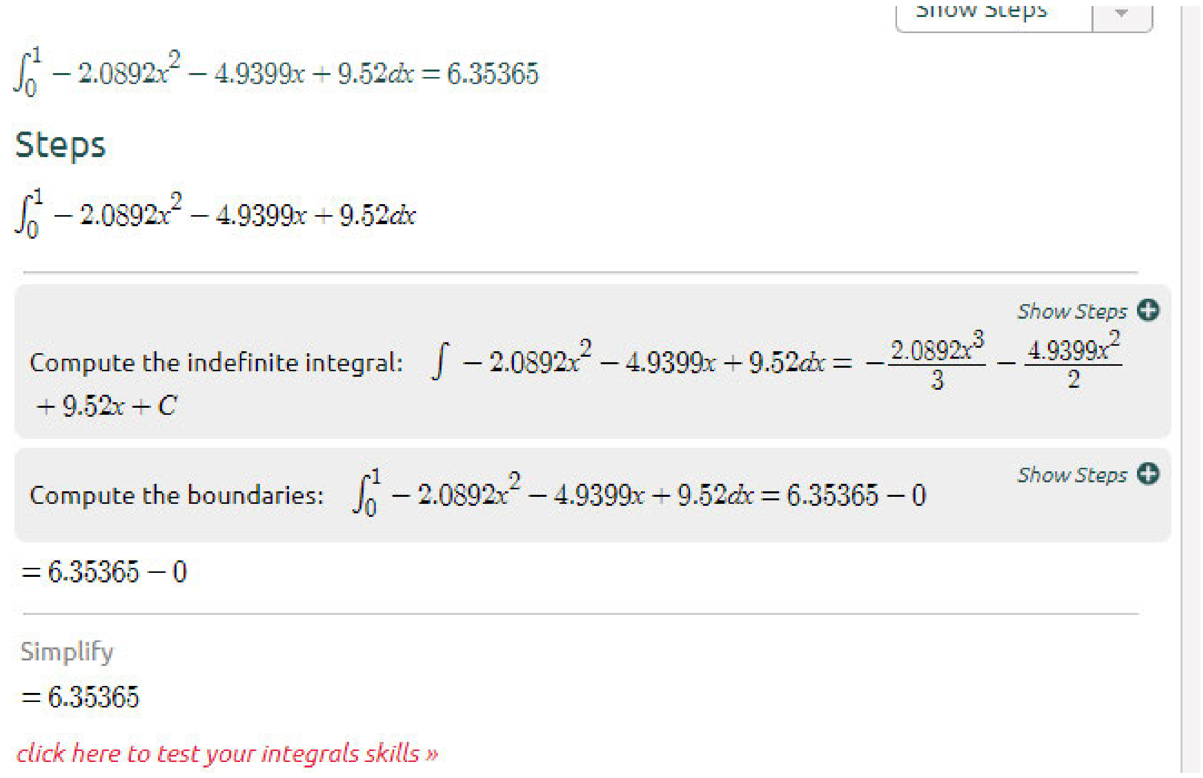
Compute the boundaries: $\int_0^1 -2.9728x^2 - 3.9704x + 9.458dx = 6.48187 - 0$

$= 6.48187 - 0$

Simplify

$= 6.48187$

SMEC major



$\int_0^1 -2.0892x^2-4.9399x+9.52dx=6.35365$

Steps

$\int_0^1 -2.0892x^2-4.9399x+9.52dx$

Compute the indefinite integral: $\int -2.0892x^2-4.9399x+9.52dx=-\frac{2.0892x^3}{3}-\frac{4.9399x^2}{2}+9.52x+C$

Compute the boundaries: $\int_0^1 -2.0892x^2-4.9399x+9.52dx=6.35365-0$

$=6.35365-0$

Simplify

$=6.35365$

click here to test your integrals skills »