

Failure probability of New Zealand pavements

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Abbreviations and acronyms

AADT	annual average daily traffic
AC	asphaltic cement
ESA	equivalent standard axles
HCV	heavy commercial vehicle
NPV	net present value
NRB	National Road Board
OGPA	open-graded porous asphalt
VPD	vehicles per day
v/l/d	vehicles per lane per day

NAASRA roughness metre:

A standard mechanical device used extensively in Australia and New Zealand since the 1970s for measuring road roughness. Records the upward vertical movement of the rear axle of a standard stationwagon, relative to the vehicle's body, as the vehicle travels at a standard speed along the road being tested. A cumulative upward vertical movement of 15.2mm corresponds to one NAASRA Roughness Count (1 NRM/km).

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Executive summary

New Zealand's current pavement design is based on the Austroads document, *Pavement design: a guide to structural designs of road pavements*, and is based on the 'elastic layer' theory.

Prior to this, the structural design of asphalt pavements in New Zealand had been based on:

- the original 1963 *Shell pavement design manual's* design charts for flexible pavements
- the New Zealand National Road Board's *State highway design and rehabilitation manual*
- the 1992 version of the Austroads Guide, which was adopted as a design methodology for New Zealand in 1996.

The risk involved in pavement design is that the pavement life will be shorter than its design life. While the literature reveals that statistical methods can be used to estimate the risk (or reliability) of a pavement design, the researchers do not appear to have demonstrated the rigour of their analysis by comparing their results with the performance of real pavements.

This research, which was carried out in 2008, studied how the interaction of all the variables and unknowns relating to pavement design combine to influence pavement performance – thus the research concentrated on the life of pavements on the state highway network of New Zealand.

Four highway road networks in different areas were selected for the analysis – Gisborne and Hawke's Bay, West Wanganui, Southland, and Auckland.

The analysis assumed that for at least the past 40 years, the roads had been designed according to the elastic-layer theory, based on either the National Road Board's *State highway design and rehabilitation manual* or the Austroads Guide (including the New Zealand supplement to that document). In this analysis, pavement failure was assumed to be associated with rutting or roughness. Failure associated with the net present value (NPV) of future maintenance costs was not considered, as this was not part of the pavement design methodologies that would have been used.

None of the four road networks that were analysed showed a strong relationship between age and rut depth or roughness. This is contrary to what would be expected if the assumptions of failure mode in the design methodology were actually occurring in the pavement. However some explanation can be given for this.

It is proposed that thin-surfaced granular pavements have a bimodal distribution of life. In the first one to two years, shallow shear and potholing can occur; after this period, the pavement settles down and the average life will approximate 45–50 years under moderate traffic. It is also concluded that although the pavements have not been failing early through rutting or roughness, the Austroads Guide's proposed risk of a 5% probability of not achieving the design life appears to be correct.

These conclusions apply to most of the New Zealand roading network where design traffic levels are less than 107 ESA (equivalent standard axles), but there is very limited data for pavements with higher traffic loadings.

Abstract

The risk involved in pavement design is that the pavement life will be shorter than the design life. While the literature reveals that statistical methods can be used to estimate the risk (or reliability) of a pavement design, the researchers do not appear to have demonstrated the rigour of their analysis by comparing their results with the performance of actual pavements.

This research project, carried out in 2008 on four state highway networks in New Zealand, studied how the interaction of all the variables relating to pavement life combine to influence pavement performance.

The probabilities of failures were investigated through the available RAAM data. The study examined the rutting and roughness performance of unbound granular pavement and full-depth asphalt pavement.

Based on these findings, it is proposed that thin-surfaced granular pavements have a bimodal distribution of life. The first peak is in the first one to two years, when shallow shear and potholing can occur. After this period, the pavement settles down and the average life will approximate 45–50 years under moderate traffic. It is also concluded that although the pavements have not been failing through rutting or roughness, the Austroads *Pavement design guides*' proposed risk of a 5% probability of not achieving the pavement's design life appears to be correct.

1 Introduction

1.1 Purpose of this research

The New Zealand Supplement to the *Austrroads pavement design guide* contains a methodology for allocating probabilities of failure of different pavement construction types. When these risks are included in an objective comparison of alternative pavement designs, then the apparently cheapest option of granular pavement with a chipseal surfacing may not be the correct option.

It is recommended in the Guide that the estimates be made using local knowledge of the past performance of pavements.

This research project aimed to complement the Guide in that it sought to develop a more robust assessment of the risk associated with various forms of pavement construction through analysis of past performance of granular, bound and structural asphalt pavements. The analysis covered both long-term performance and the probability of early failure (within the first few years).

1.2 Background to pavement design and performance

New Zealand's pavement design is currently based on the Austrroads document, *Pavement design: a guide to the structural design of road pavements* (Austrroads 2004a).

Earlier design manuals used for the structural design of asphalt pavements in New Zealand include the following:

- the original *Shell pavement design manual's* design charts for flexible pavements (first published in 1963 and updated in 1978)
- the New Zealand National Road Board's (NRB) *State highway design and rehabilitation manual* (1987)
- an earlier version of the Austrroads manual (1992), which was adopted as a design methodology for New Zealand in 1996.

Although there are some differences between the various analysis systems, the pavement design system presented in all of these manuals is based on the 'elastic layer' theory, which assumes that pavement life is a function of the traffic loading and the compressive strain at the top of the subgrade, and/or the tensile strain at the bottom of a bound layer. For the majority of New Zealand roads that are granular pavements with a thin chipseal surfacing, the failure mode assumed in the design is that associated with the compressive strain on the subgrade, leading to rutting or roughness on the surface.

The risk involved in pavement design is that the pavement life will be shorter than its design life. The Austrroads design assumes that regular maintenance is carried out on the surfacing and drainage so that the 'design' moisture conditions are maintained. The Guide also presumes that the materials used are durable and have adequate shear strength. Based on these assumptions, the Guide allows the designer to allocate a level of risk for the pavement life being achieved. For lower-risk options, the pavement thickness is increased. The Guide thus minimises the risk of pavement failure by recommending changes in layer thicknesses without changing the material properties.

In 2006, Bailey et al analysed rehabilitation treatments on New Zealand state highways and found that the pavements being rehabilitated had low levels of rutting (typically less than 10mm) and low levels of

roughness (less than 120 NAASRA¹). The average life of the pavements was 45 years. The main reason for the rehabilitation had been that the net present value (NPV) of future maintenance costs was such that it was more economical to rehabilitate the pavement, rather than continuing to maintain it. These future maintenance costs for pavements are estimated as part of the NZ Transport Agency's (NZTA) requirement for an economic evaluation of all proposed rehabilitation treatments – where the NPV of future maintenance costs are greater than the cost of rehabilitation, then the rehabilitation treatment can proceed.

In 2008, Gribble and Patrick extended the above research into the performance of pavements on the state highways and investigated the appropriateness of the Austroads design criteria for New Zealand roads. They concluded that:

The roughness model from HDM III indicates that for design traffic levels of 10^5 ESA² Austroads' subgrade strain criteria is highly conservative, while for design traffic levels of 10^7 ESA Austroads is not conservative enough. From another perspective the HDM model indicates that Austroads pavement thickness is excessive for low traffic of 10^5 ESA while the 10^7 ESA traffic levels require greater aggregate cover.

There are several categories of risks affecting pavement life. Youdale et al (2003) noted that the categories may include technical, financial, environmental, safety and political aspects.

Technical risk, such as method of design, the design input parameters, reliability of the design etc, are explained in the design criteria (ie *Austroads pavement design guide*, 2004a and the *New Zealand supplement to the document, pavement design*, Transit NZ 2007), but a few factors are not discussed in detail. These include:

- moisture sensitive-based materials
- the effect of drainage
- the shear strength of thin asphalt surfacing in high-stress areas
- material variability
- the risk of premature rutting that can occur on 'Greenfield' pavements
- construction and maintenance standards.

To investigate the effects of variations in the design inputs, researchers such as El-Basyouny and Jeong (2010) used Monte Carlo simulations to estimate the reliability of the design. These simulations are based on the assumption that the design methodology is robust and that changes in the input factors in the design will have a predictable effect on the pavement performance.

Although all the variables can be considered in such an analysis, the final proof of the design is the pavement's performance in the field.

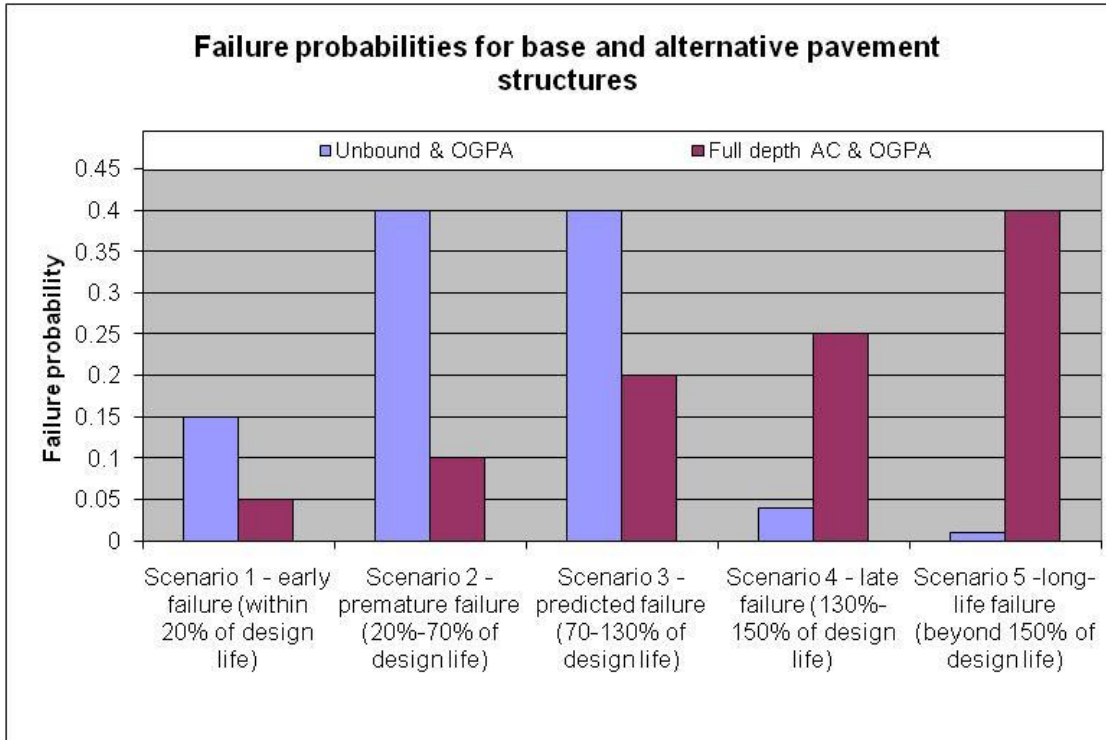
Every designer needs to consider the funding restriction for the construction and maintenance of a pavement. To identify the best design option, a comparison of the cost of the risk associated with each alternative option is essential. The *New Zealand supplement to the Austroads pavement design guide* (Transit NZ 2007) discusses the method to calculate this cost analysis and provides the necessary spreadsheet. In this spreadsheet, failure probabilities are assumed for different pavement types – example

1 A measure of road roughness (see the Abbreviations section)

2 ESA – equivalent standard axle

probabilities given in the supplement are shown here in figure 1.1. These failure probabilities have to be estimated for each project, based on consultation and examination of similar projects in the area.

Figure 1.1 Example failure probabilities for unbound granular base and asphaltic concrete alternative structure (data extracted from TNZ 2007)



As well as being related to pavement type, risk of failure is also a function of traffic volume. The relatively high number of early failures being reported on higher-trafficked roads (Alabaster, pers comm) appears to be because of this. Although it is not currently stated in the New Zealand Supplement (2007), updates will make it clear that probability analysis is applicable only to higher traffic-volume pavements (Alabaster, pers comm).

In determining failure probabilities, the Austroads Guide suggests that there should be a 95% probability of achieving the design life.

This research project has concentrated on thin-surfaced granular pavements, as these comprise over 95% of New Zealand’s state highway network.

2 Literature review

A number of researchers have noted that the vulnerability of unbound granular pavement performance is being heightened by increasing vehicle axle loads, limited material resources and loss of engineering design skills (Vuong and Hazell 2003, Wijeyakulasuriya et al 2004, Arnold 2007).

Kim (2006) investigated the uncertainties in design and grouped them into the following four categories:

1. *Spatial variability, which includes a real difference in the basic properties of materials from one point to another in what are assumed to be homogeneous layers and a fluctuation in the material and cross-sectional properties due to construction quality;*
2. *Imprecision in quantifying the parameters affecting pavement performance, such as random measurement error in determining the strength of subgrade soil and estimation of traffic volume in terms of average daily traffic (ADT) and the mean truck equivalency factor;*
3. *The model bias due to the assumption and idealization of a complex pavement analysis model with a simple mathematical expression; and*
4. *The statistical error due to the lack of fit of the regression equation.*

He noted that the first two categories relate to the pavement's materials and construction, and the last two to the design methodology. For example, subgrade strength is related to the moisture content and compaction state likely to pertain in the field. Possible errors in the estimation of subgrade properties are:

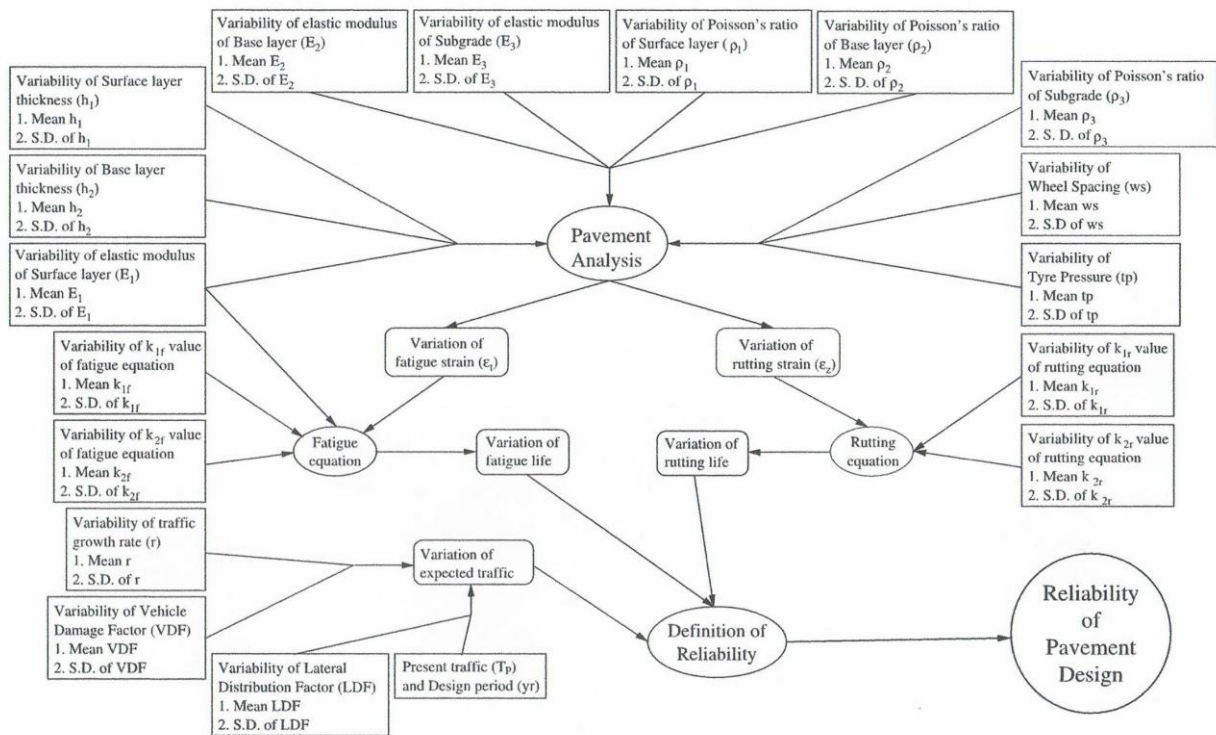
- knowledge of the soil type
- variability of the soil
- how that soil reacts to changes in moisture content
- equilibrium moisture content
- depth to water table
- relationship between modulus and CBR.

Maji and Das (2008) published research into the reliability of pavement design. They listed the following inputs required for mechanistic design, and the variability of each of them:

- layer modulus and Poisson's ratio
- layer thickness
- tyre contact pressure
- wheel spacing
- vehicle damage factor
- lateral distribution factor.

They developed a flow chart showing the interactions involved. This is reproduced in figure 2.1.

Figure 2.1 Pavement design interactions (Maji and Das 2008)



Kim, as well as Maji and Das, developed estimates of the variability of the inputs and then modelled the resulting output to estimate the reliability (or risk) associated with the design.

Designers with knowledge of local conditions may choose locally available materials that are outside the specification, but may work well for certain conditions and cut down the cost. The performance of these materials may change for different conditions. Creagh (2005) noted that the key failure modes identified in workshops and case studies were:

- rutting (severe, short-term)
- potholes caused by unsuitable material
- longitudinal or crocodile cracks
- loss of skid resistance.

These were all caused by deficiencies in pavement materials. His research suggested that failure that occurs very early in the pavement's life is associated with materials and construction, rather than the design method.

Pavement materials are specified in the NZTA specifications, which include the requirements for materials and construction of granular basecourse and subbase (NZTA B/3, B/4). Asphaltic materials are covered in NZTA M/10 and P/9.

The practice of pavement design in New Zealand is thus a combination of specifications for materials and construction standards and the use of the appropriate material properties from the Austroads Guide.

In summary, the failure of a pavement to meet its design life can be associated with:

- inappropriate material property assumptions

- errors in the design methodology
- inadequate pavement materials
- inadequate pavement construction
- underestimation of traffic volumes and loading
- inadequate maintenance.

The failure probabilities given in figure 1.1 are estimations that take all of these factors into account.

As the average life of a pavement on New Zealand's state highways is approximately 45 years (180% of the design life of 25 years), then the assumption in figure 1 that 55% of granular pavements fail at less than 70% of the design life should not apply to the average pavement.

The literature reveals that statistical methods can be used to estimate the risk (or reliability) of a pavement design. However, the researchers do not appear to have demonstrated the rigour of their analysis by comparing their results with the performance of real pavements.

This research studied how the interaction of all the variables, known and unknown, combine to influence pavement performance – thus the research has concentrated on the life of pavements on the state highway network.

3 Definition of pavement life

It is difficult to define the life of pavements because the 'actual' end of the life of a pavement is often not clear. A pavement can reach a condition where rutting or roughness levels are getting high, but its life can be extended with appropriate maintenance. As previously mentioned, if the NPV of the future maintenance cost is above the cost of rehabilitation, then rehabilitation is the least-cost option and the existing pavement can be considered to have reached the end of its life.

A pavement that is nearing the end of its life would therefore exhibit any of the following characteristics, or a combination of them:

- rutting levels nearing or greater than 20mm
- roughness levels nearing or greater than 120–150 NAASRA
- fatigue cracking
- higher-than-average maintenance costs.

Surfacing failures associated with loss of skid resistance, ravelling, are not considered as pavement failure.

The failure conditions given above are consistent with Austroads (2004b), which states that implicit in the 1992 design procedure was a terminal condition of:

- an average rut depth of about 20mm
- a terminal roughness of about three times the initial roughness.

The 2004 design procedure does not state the failure criteria.

In this research project, it is assumed that the presence of high failure rates of granular pavements in the first few years would be reflected in maintenance costs and failure in later years, due to the expected deterioration of the pavement, associated with its strength, resulting in rutting and roughness trends.

The influence of traffic loading is assumed to be part of the design system, so if the design methodology overestimated the life of pavements that are subjected to higher traffic volumes, this would be reflected in the different performance of pavements in different traffic situations.

4 RAMM data

The RAMM database contains data on the condition of the entire state highway system. Its data includes factors such as age, traffic, width of surfacings and pavement depth for both sealed and unsealed roads. Pavement-condition data, in terms of roughness and rutting, is collected annually by a high-speed laser-based system and typically divided into 20m sections. Therefore, for a kilometre stretch of highway, there would be 50 measurements of roughness and rut depth. In addition, maintenance-cost data, in terms of pavement as well as surfacing, is recorded.

The NRB introduced the 'mechanistic approach' (based on the Shell method) in 1969. Therefore, pavements constructed since then can be considered to have been designed using a very similar methodology to the current approach.

Historic data on pavement construction in New Zealand is obviously less reliable than more current data. The RAMM system was set up in the 1980s, and assumptions had to be made about historic construction. Thus the accuracy of the data before 1980 cannot be verified.

For this research project examining pavement performance, data was initially extracted from the database for three networks - Napier/Gisborne, West Wanganui and Southland. The data covered the maintenance costs for the years 2002, 2003, 2004 and 2005. The pavement-condition data for 2005 was used for our analysis. Data from Auckland, a higher traffic-volume network, was subsequently added. In total, the data for more than 4500 road sections was combined into a spreadsheet.

Maintenance-cost data for the first year of pavement life was not regarded as reliable, as the performance of a pavement in its first year is normally the responsibility of the contractor, and thus 'failures' that are repaired by the contractor do not show up in maintenance-cost statistics.

5 Analysis of the data

5.1 Introduction

5.1.1 Maintenance cost of a pavement's first four years

The first four years' maintenance costs on three road networks (ie Gisborne and Hawke's Bay, Southland, and West Wanganui) were analysed. The costs were divided into three different categories: pavement maintenance, surface maintenance, and the total of both. The cost units are 'dollar per square metre'. As noted earlier, in some cases the cost of the maintenance for each of the first four years after the rehabilitation may not be accurately represented because the contractor may have accepted responsibility for repairs at their own cost.

Maintenance data for the layers construction in the Hawke's Bay and Gisborne road network during the period 2002–2005 was obtained from RAMM. The pavement maintenance cost per square metre against age is shown in figure 5.1. This figure indicates that three sections out of 118 sections had pavement maintenance costs of more than \$2.6 per square metre (ie 2.5% of the total number of sections had a maintenance cost higher than \$2.6/m²). The surface maintenance cost per square metre against age, shown in figure 5.2 also indicates the same proportion (more than \$2.6/m²). The total maintenance costs are shown in figure 5.3. In terms of an average, 11 sites out of the 118 had an average total maintenance cost greater than \$1/m²/yr, ie 9.3%. In terms of rutting, only 15% of the total treated length of road had a rut depth greater than 5mm, and no sections had rut depths greater than 20mm or roughness levels greater than 120 NAASRA.

The traffic frequency distribution (figure 5.4) shows that 95% of the sections had less than 12,000 AADT³, and 50% of the sections had less than 2000 AADT.

³ AADT – annual average daily traffic

Figure 5.1 Pavement maintenance costs for the first four years for the Hawke's Bay/Gisborne network

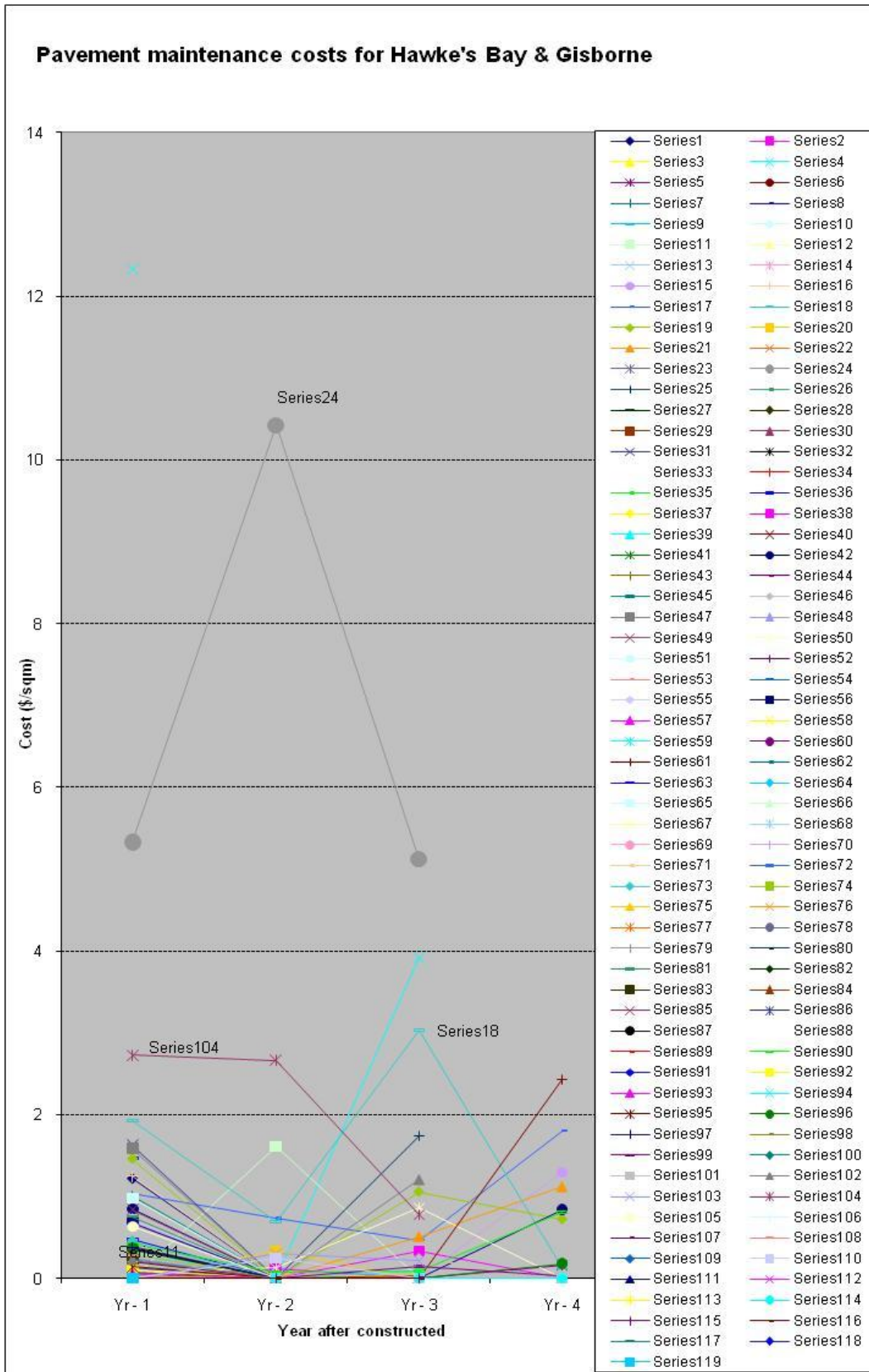


Figure 5.2 Surface maintenance costs for the Hawke's Bay/Gisborne network

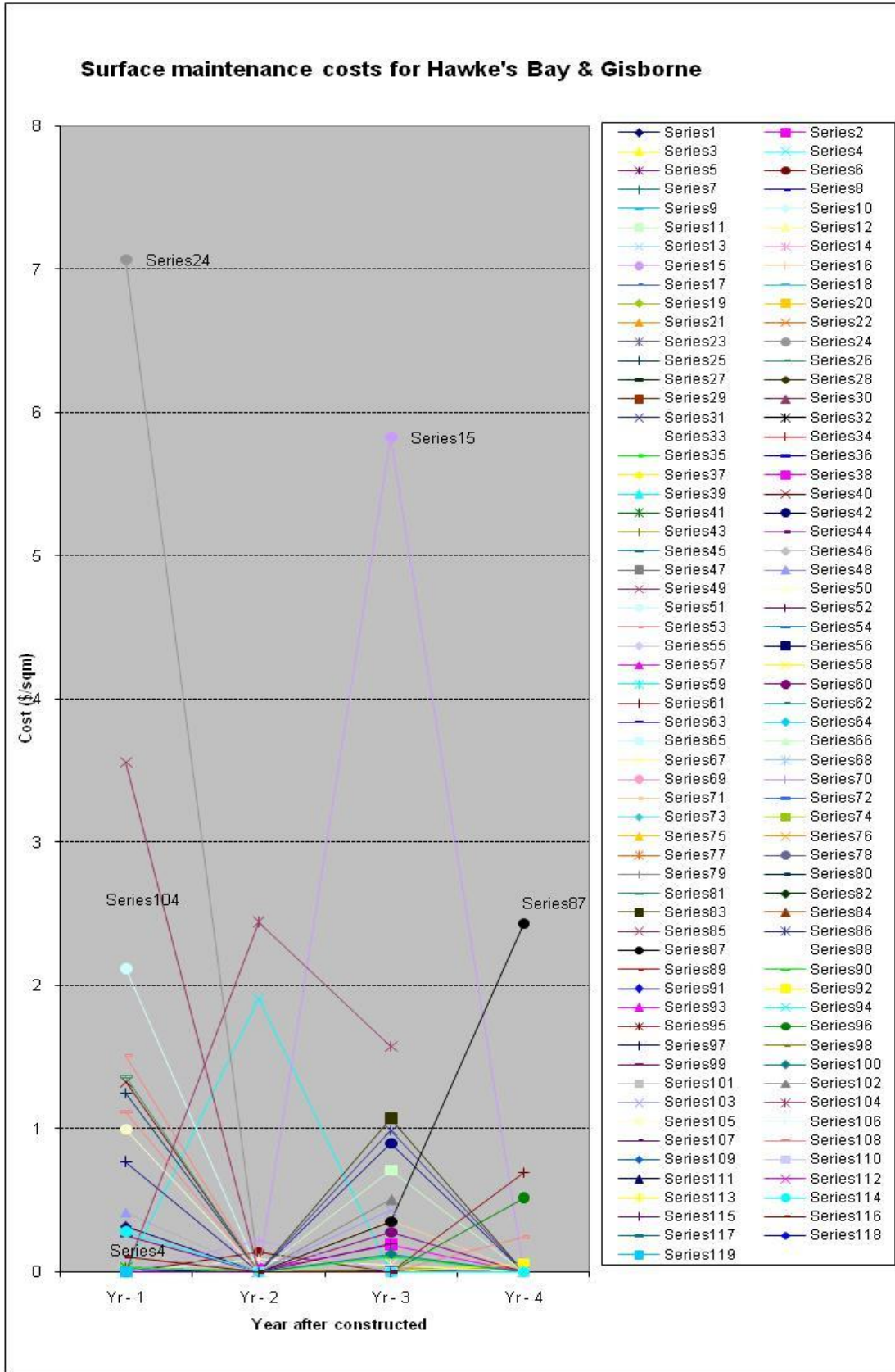


Figure 5.3 Total pavement and surfacing maintenance costs for the Hawke's Bay/Gisborne network

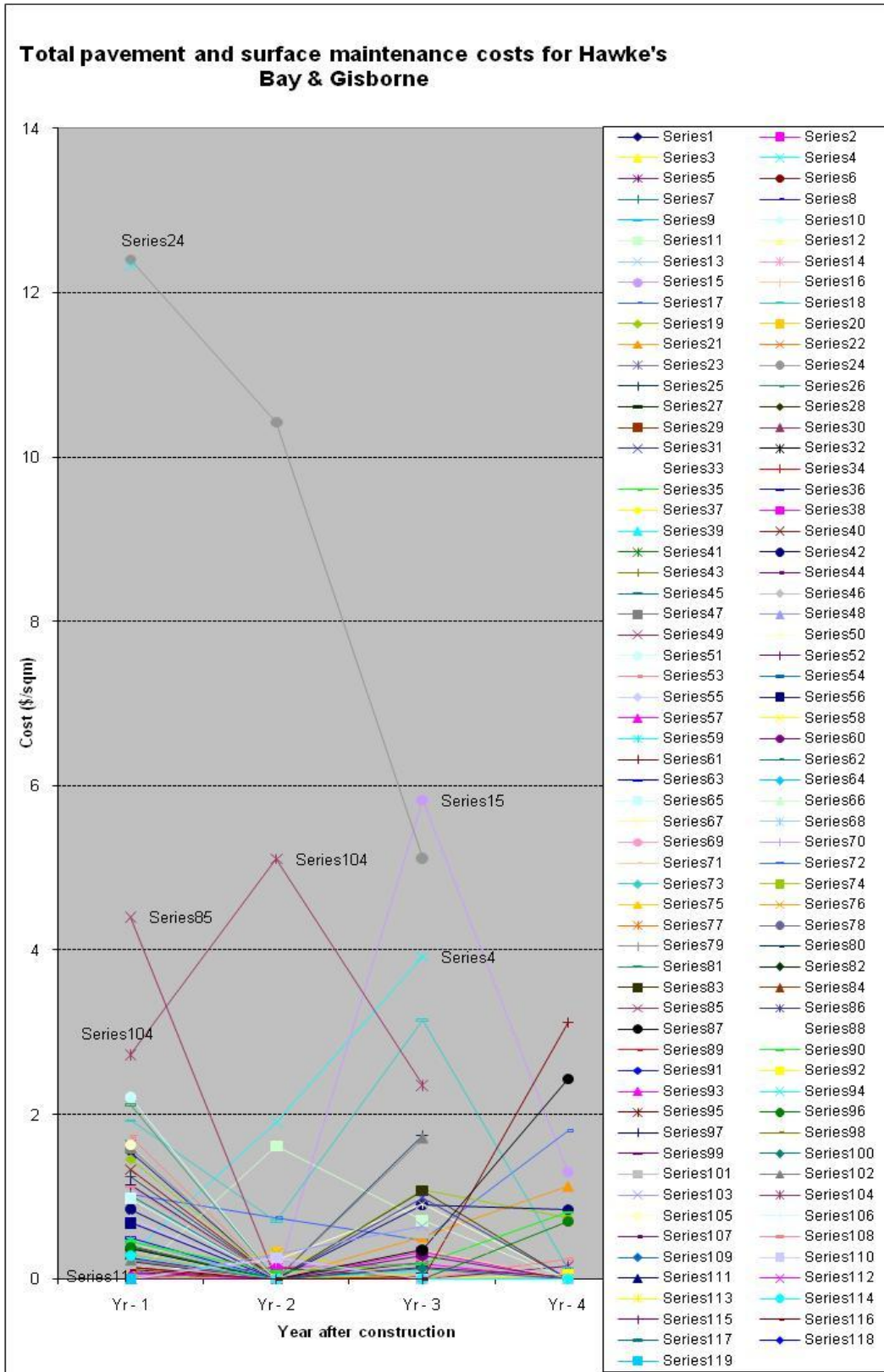
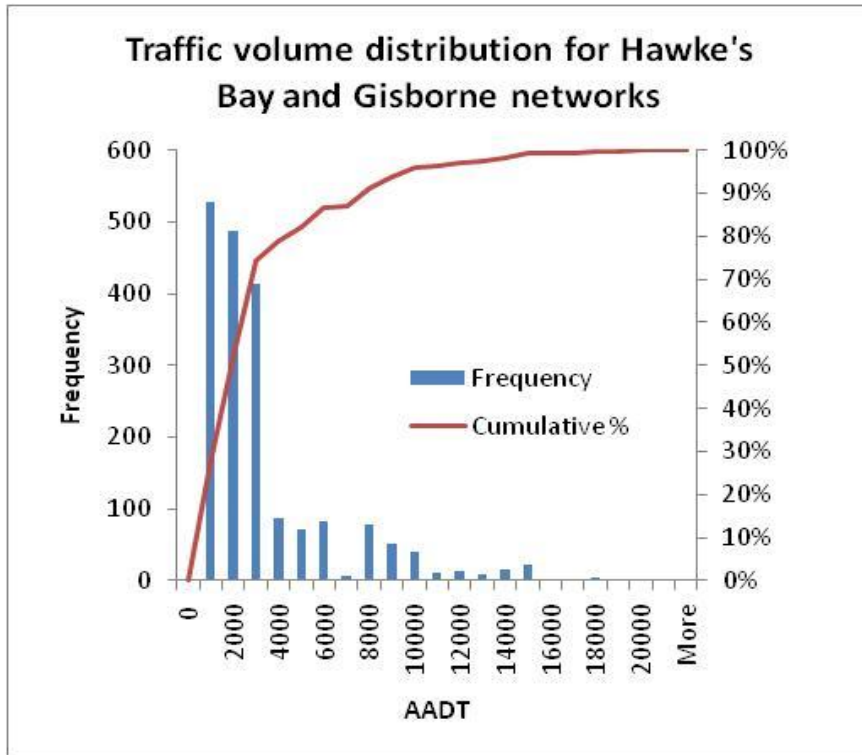


Figure 5.4 Traffic volume distribution for the Hawke's Bay/Gisborne network



The West Wanganui road network analysis was conducted in the same manner. The plotted graphs from this analysis are shown in appendices A, B and C. Although there were significant yearly variations, the number of sites that had average maintenance costs greater than $\$1/\text{m}^2/\text{yr}$ in the first four years was three out of the total 106 sites (2.8%). The traffic distribution for the treated sections of roads shows that 95% of the sections had less than 10,000 AADT, and 50% of the sections had less than 3000 AADT. Six percent of the total treated length of road had a rut depth greater than 5mm.

The Southland road network also had a very low proportion of sections repaired within the first four years. The plotted graphs from the analysis are shown in appendices D, E and F. These show that there was no significant increase in the pavement maintenance costs during the first four years after rehabilitation, but one section had a significant peak in maintenance costs in the second year. In this road network, the number of sites that had average maintenance costs in the first four years that were greater than $\$1/\text{m}^2/\text{yr}$ was two out of the total 48 sites (4.2%). The 95 percentile traffic volume in this network was approximately 4000 AADT.

The results for the three networks are summarised in table 5.1.

If a significant failure is assumed to be associated with higher maintenance costs, say greater than $\$1/\text{m}^2/\text{yr}$, then overall, 5.9% of the rehabilitation treatments required significant maintenance. However, the average rut depth for each area was less than 3.5mm and only one site had a rut depth greater than 10mm.

Table 5.1 Maintenance cost summary for first four years

	Napier/Gisborne	West Wanganui	Southland
No. of sites	118	106	48
Av. maintenance cost \$/m ²	0.45	0.16	0.16
No. sites >\$1/m ² /yr av. maintenance cost	11	3	2
Percentage	9.3	2.8	4.1
Maximum rut depth (mm)	9	9	11
Av. rut depth (mm)	2.4	2.8	3.4
95% traffic volume AADT	12,000	10,000	4000

5.2 Pavement performance of each network

In this research, pavement performance was analysed as a function of age rather than of traffic volume or traffic load. This is because all the roads studied had a design life of 25 years, and it could be expected that as the pavement age increased then the probability of failure would increase (see figure 1.1). By analysing the pavement performance in terms of its age, then a direct comparison with its design life could be made.

The research first examined:

- the age of the pavement layer of the road sections
- the corresponding rut depth and roughness for the three road networks (Hawke's Bay and Gisborne, Southland, and West Wanganui).

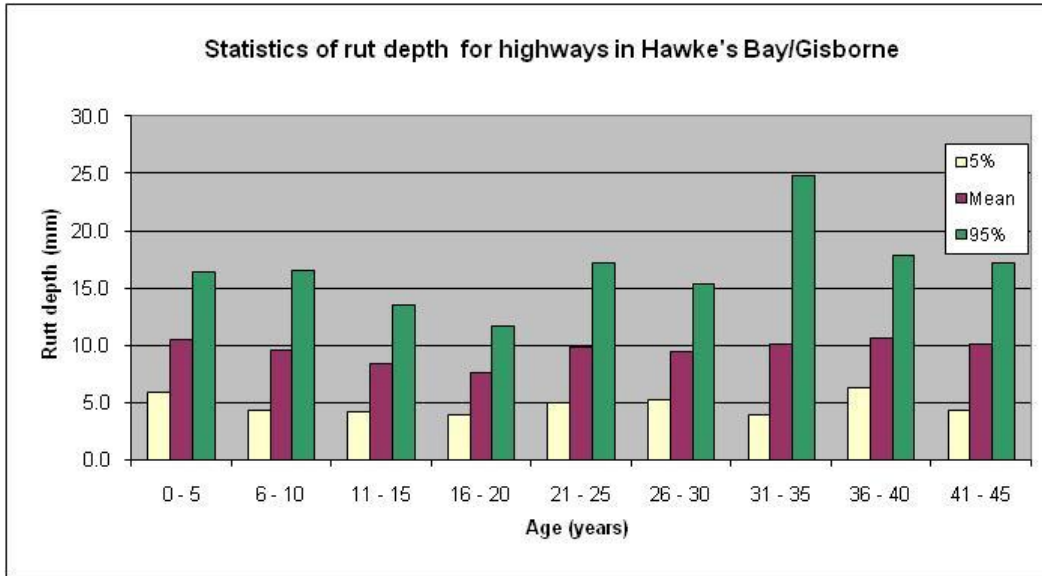
The three road networks were predominantly unbound pavements with chipseal surfacing, even though there were a few isolated sections (eg roundabouts) that had structural asphalt concrete with a thickness greater than 80mm. There were not enough structural asphalt sections to allow a meaningful analysis of its performance. The networks could be considered low volume, in that the average AADT was less than 3000.

In order to obtain data from a high-traffic network that included structural asphalt, data from Auckland was included. In Auckland, there were both unbound pavements and thin-surfaced pavements, as well as several structural asphalt concrete sections. For this reason, the Auckland network was analysed in two groups. The analysis results for each of these networks are discussed separately below.

5.2.1 Gisborne and Hawke's Bay road network performance

For this analysis, road sections were grouped into five-year bands (ie 0-5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-35, 36-40 and 41-45 years). Roughness and rut depth were examined, as these are the 'failure' mechanisms that are assumed in the design methodology for unbound granular pavements. The mean, standard deviation, and the 5 and 95 percentile values, were calculated for each age group. These statistics of the rut and roughness were plotted for each age group, as shown in figures 5.5 and 5.6.

Figure 5.5 Statistics of rut depth for highways in the Hawke’s Bay/Gisborne network

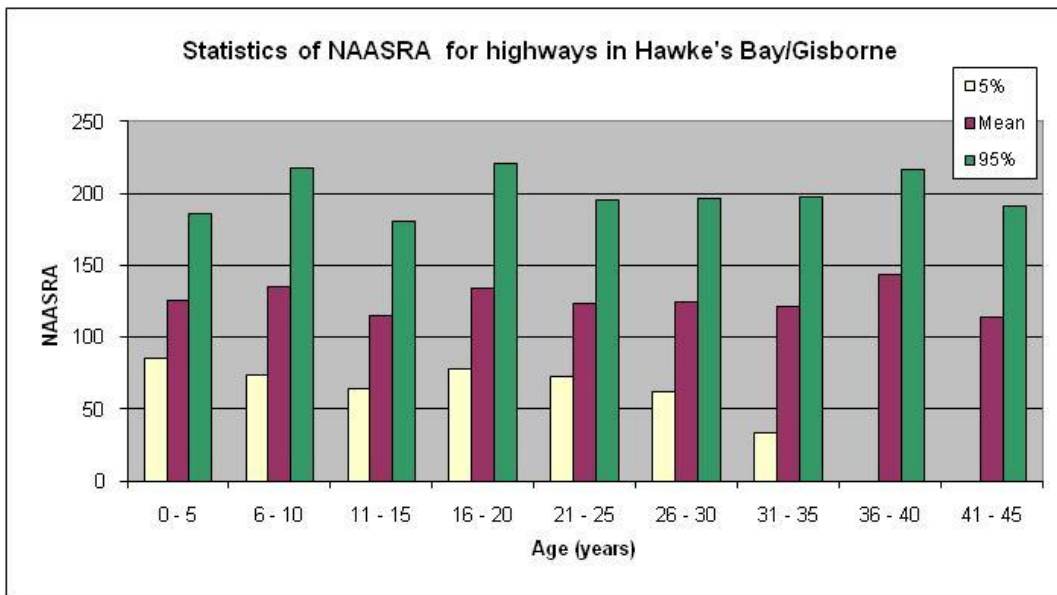


There was no significant increase in rut depth related to ageing, and a similar observation was made with respect to roughness with age (figure 5.6 below).

The mean traffic was 7.56E+05 ESA, the 95 percentile traffic was 2.29E+06 ESA, and the maximum was 5.09E+06 ESA.

The age group 21-25 years was investigated further to check any relationship between ESA and rut depth. The sections that had rut depth greater than the 95 percentile or less than the 5 percentile did not correlate with low or high traffic ESA volumes. In the age group of 0-5 years there was also no correlation between ESA and rut depth.

Figure 5.6 Statistics of roughness for the Hawke’s Bay/Gisborne network



5.2.2 West Wanganui road network performance

The West Wanganui network was examined in the same way. The rut depth and the roughness statistics are shown below in figures 5.7 and 5.8.

Figure 5.7 Statistics for rut depth for the West Wanganui network

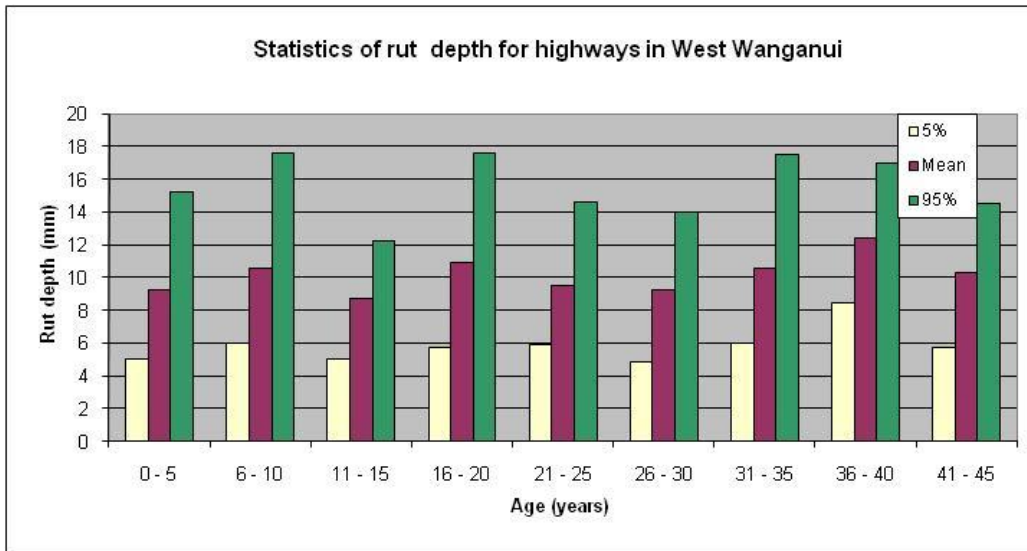
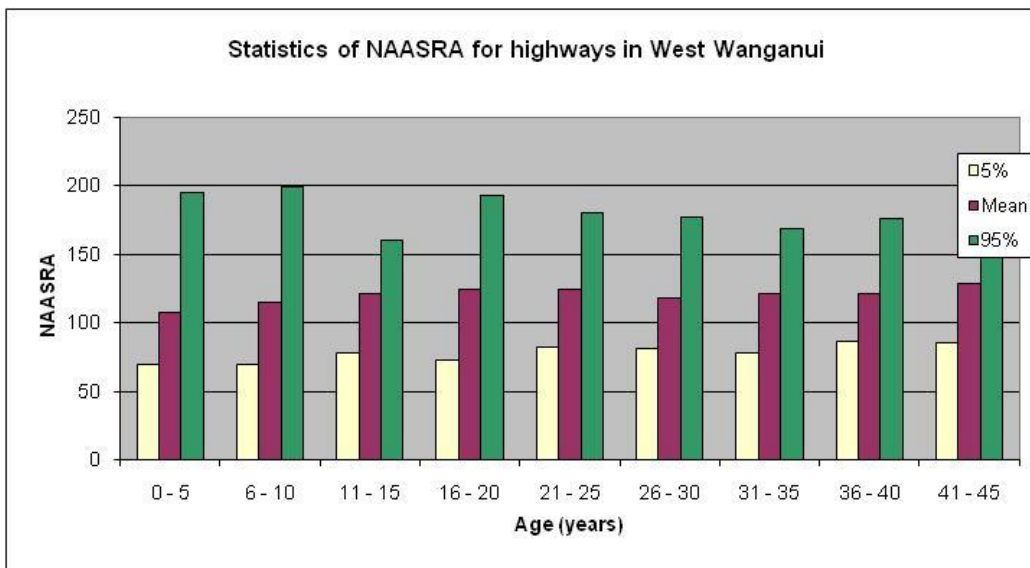


Figure 5.8 Statistics for roughness for the West Wanganui network



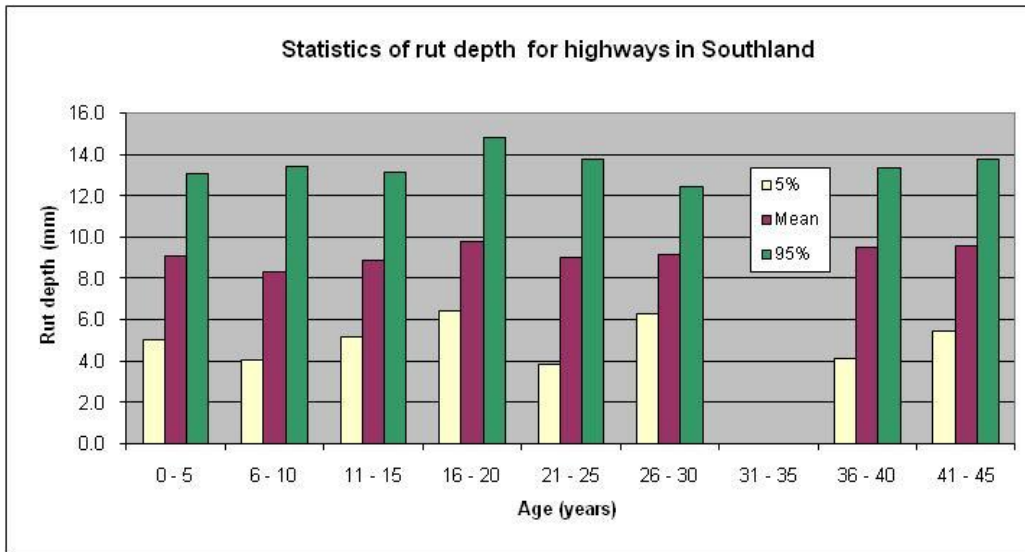
The West Wanganui road network data indicated a very similar trend to the Gisborne and Hawke’s Bay road network.

Figures 5.7 and 5.8 show that rut depth or roughness did not change with age, and even the 95 percentile is almost constant. Figure 5.7 shows that the average rut depth fluctuates around 10mm for ages up to 45 years.

The mean traffic was 9.13E+05, the 95 percentile traffic was 2.41E+06 ESA, and the maximum was 4.56E+06 ESA. Again, this was less than 1.0E+07 ESA. Details are given in appendix A.

5.2.3 Southland road network performance

Figure 5.9 Statistics of rut depth for the Southland road network



The rut statistics shown in figure 5.9 are from the data for the Southland road network. There was very little data for the age group of 31–35 years in this network. The average rut depth for the rest of the age group fluctuates around 9mm. Also, the 5 and 95 percentile rut depth values do not show any increasing or decreasing trend with age.

Figure 5.10 Statistics of roughness for the Southland road network

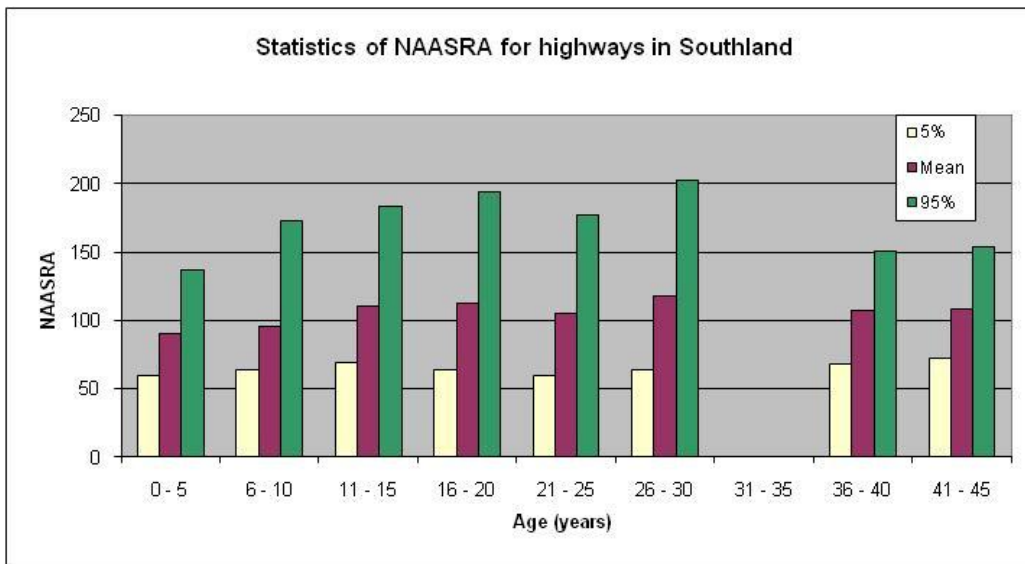


Figure 5.10 shows the roughness statistics for the highways in Southland. The average NAASRA counts increase up to the age of 20 years. The 5 percentile value does not show an increasing trend with age, but the 95 percentile and the mean both show an increasing trend up to the age of 30 years.

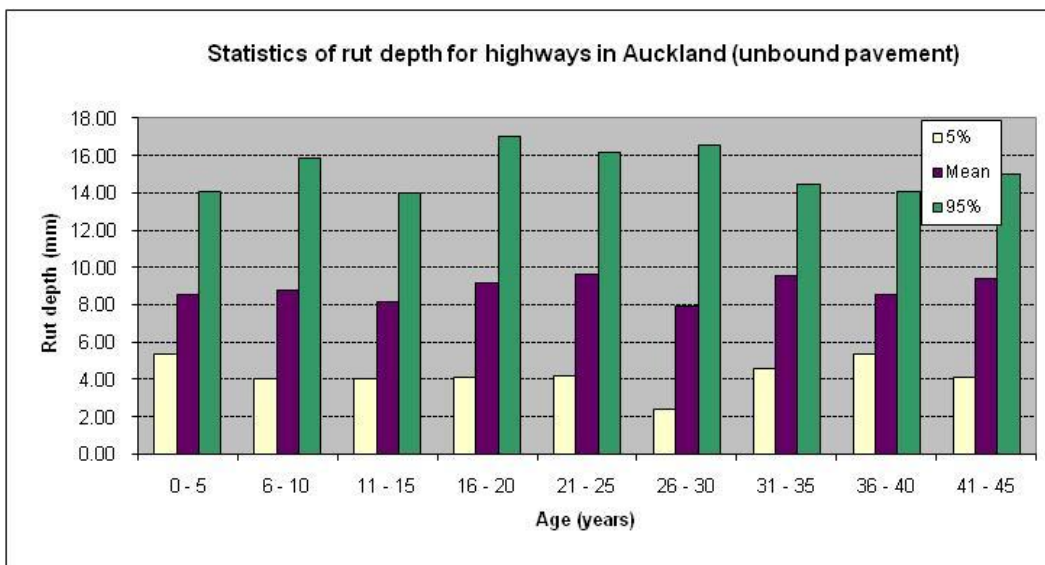
The mean traffic was $7.51\text{E}+05$ ESA, the 95 percentile traffic was $2.53\text{E}+06$ ESA, and the maximum was $4.68\text{E}+06$ ESA. Again, this was less than $1.0\text{E}+07$ ESA.

The rut depth that was greater than 14, 16, 18 and 20 for each age group are shown in appendix B, which also shows that the rut depth fluctuated but did not increase with age. The roughness plot in this appendix shows that the roughness increased slightly with age.

5.2.4 Auckland road network performance

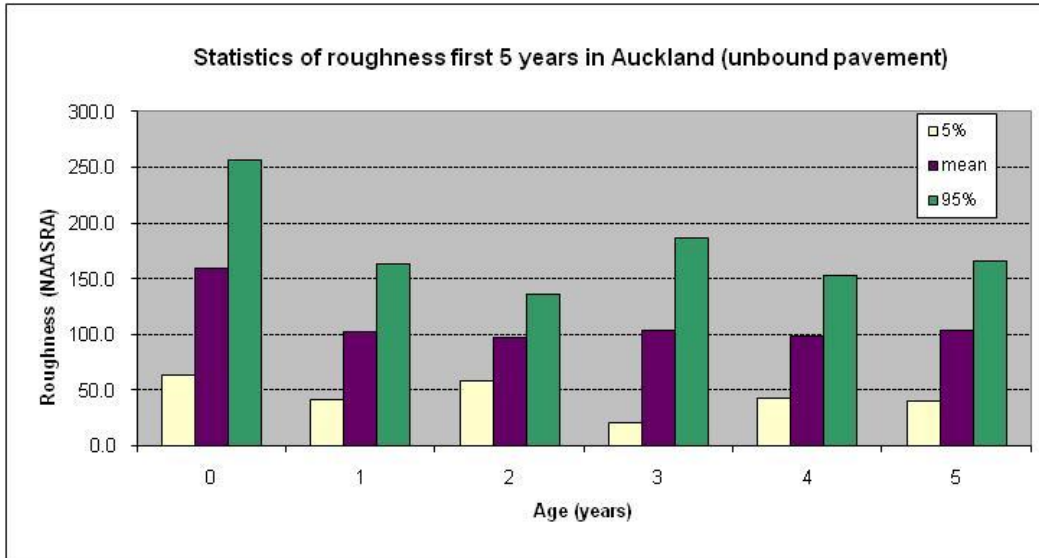
The Auckland road network had more sections of full-depth structural asphalt concrete than other road networks. Therefore, this network was divided into two groups: bound pavement and unbound pavement. In the unbound pavement, the surface was OGPA, asphalt, or chipseal, with the surfacing not more than 50mm thick. These two groups were analysed in the same way as the previous networks. The data for structural asphalt is discussed in section 5.4. The statistics of rut depth and roughness in the unbound pavement are shown here in figures 5.11 and 5.12.

Figure 5.11 Statistics of rut depth for unbound pavements in the Auckland network



The mean and 95 percentile rut profile in figure 5.12 appear to fluctuate with no significant trend with age. The roughness profile shown in this figure also appears to fluctuate with no increasing trend. The 95 percentile traffic was $4.8E+06$ and the maximum was $1.1E+07$ (ESA). The Auckland samples show the pavements having a higher traffic load than the previous three road networks, but still the 95 percentile design load was less than $5.0E+06$ (ESA).

Figure 5.12 Statistics of roughness for unbound pavements in the Auckland network



Appendix C shows the rut and roughness profile for each age group. The profile for rut depths 14mm and 16mm show an increasing trend up to 30 years of age, but the 18mm and 20mm profiles do not show an increasing trend. This might be because in this region, most of these roads are rehabilitated before reaching a rut depth of 18mm and 20mm. The mean and the 95 percentile roughness profiles also show an increasing trend with the pavement age.

The age group 0-5 years was analysed year by year to investigate the early-life behaviour of pavements on this higher-trafficked network. Figures 5.13 and 5.14 show the rut profile and roughness profile respectively.

Figure 5.13 Statistics of roughness in the first five years for unbound pavements in the Auckland network

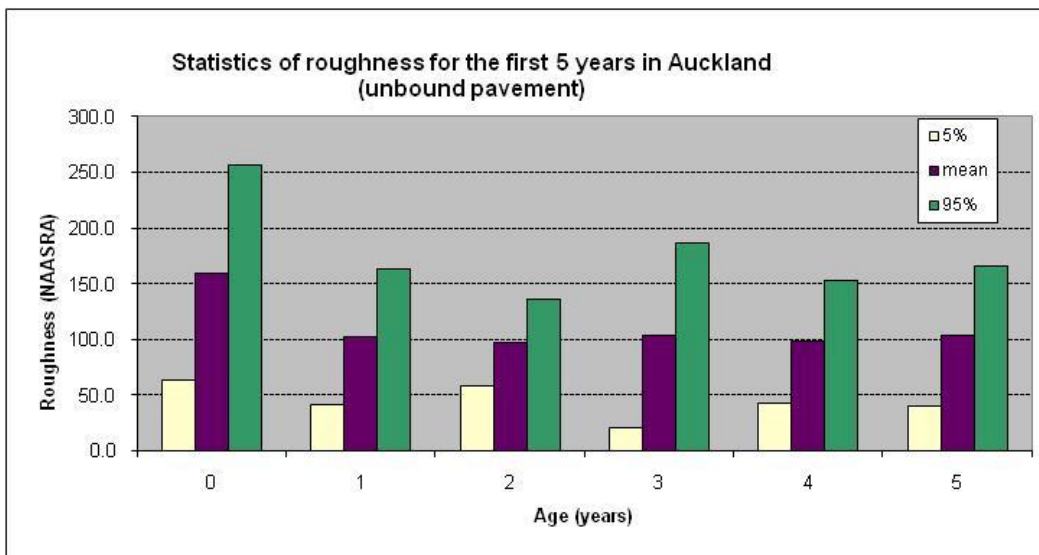
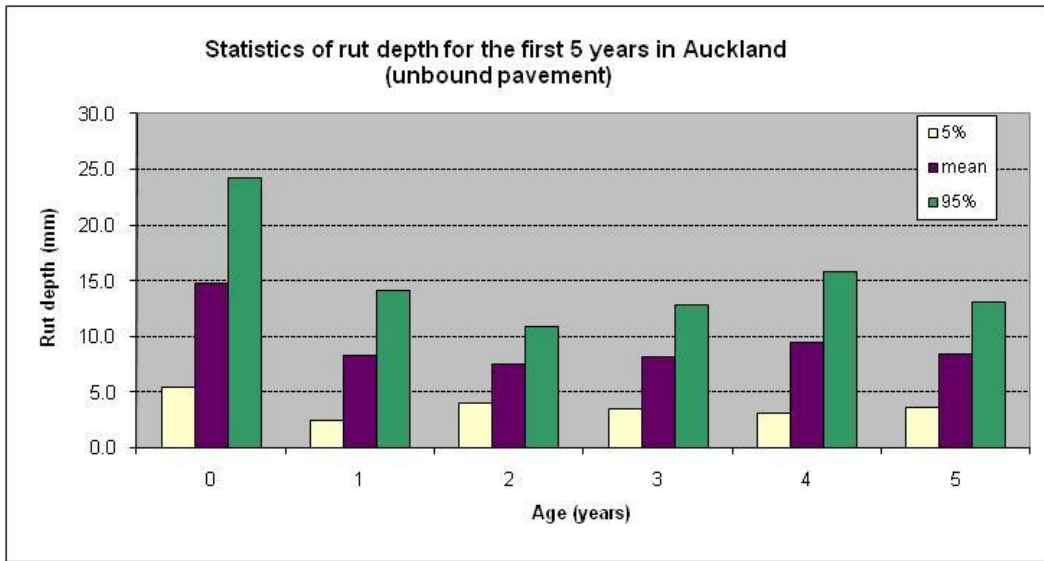


Figure 5.14 Statistics of rut depth in the first five years for unbound pavements in the Auckland network



The rut profile for the first year shows the average rut depth is 15mm, which could be due to an early failure that might have been repaired in the consequent year. The roughness values also show a similar trend.

The number of sections in the first year is low compared with subsequent years, and therefore the first-year data may not be representative. The following table shows the number of sections in each year.

Table 5.2 Number of samples in the first five years for unbound pavement in Auckland

Year	0	1	2	3	4	5
Number of samples	4	26	30	38	42	16

The average roughness of the year zero was above 150 (NAASRA), which could be associated with the low number of sections. It could also indicate problems associated with a pavement’s performance during the first year – by the second year, the contractor would have been obliged to have corrected the pavement shape.

5.3 Overall pavement failure rate

This analysis was performed by combining the data from the entire road network previously investigated, as detailed in section 4.3. The total number of road sections was more than 4800.

The NZTA *State highway asset management manual* (2000) specifies the intervention level of roughness as a function of different traffic volumes. This is reproduced in table 5.3. The corresponding rut depth maximum is 20mm for all traffic volumes.

Table 5.3 Intervention levels for roughness from the NZTA *State highway asset management manual* (2000)

Traffic level	NAASRA roughness intervention level counts/km
Motorway	100
>10,000vpd ^a	110
4000-10,000vpd	120
1000-4000vpd	130
<1000vpd	150

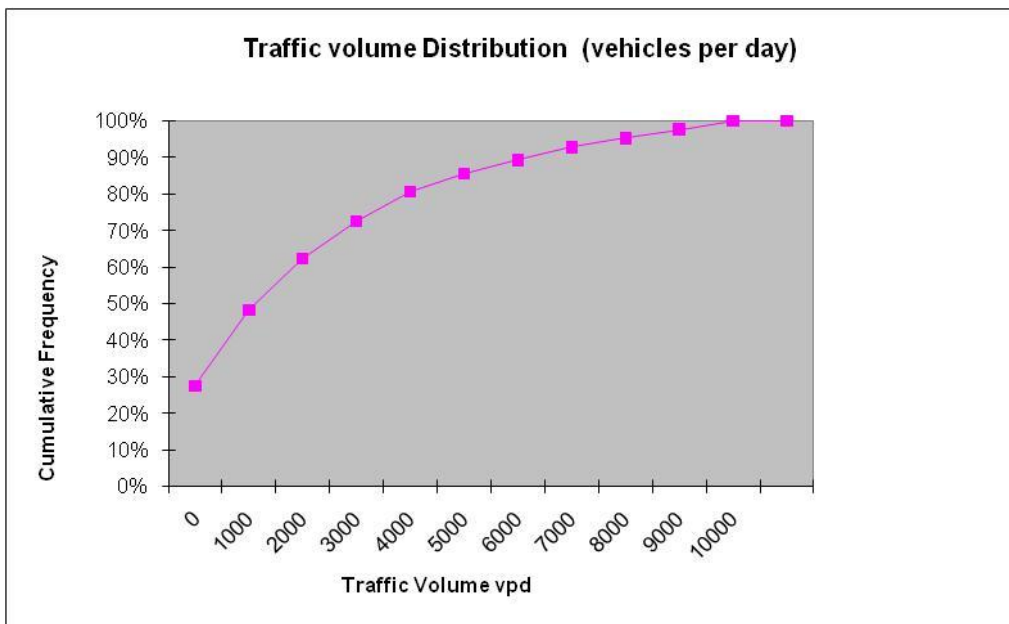
a) vpd - vehicles per day

Therefore the definition of failure in terms of shape for New Zealand’s state highways is dependent on traffic volume.

The distribution of traffic volume over the combined networks used in this study is shown in figure 5.15.

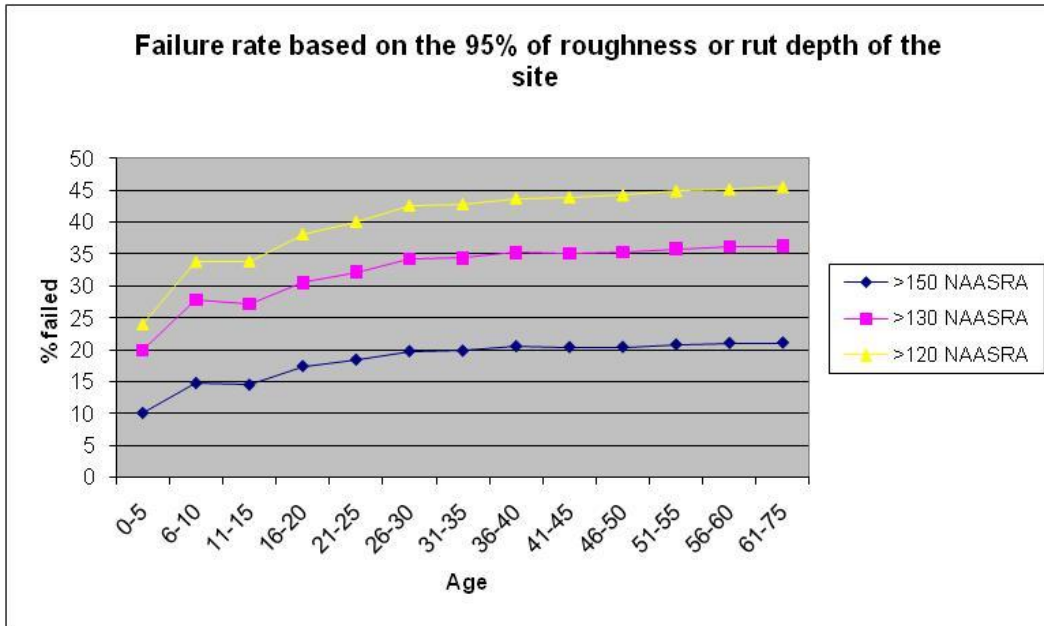
The mean was approximately 2000vpd and the 90 percentile was 7000vpd. Most of the sections analysed would therefore fit into the intervention bands of 120–130 NAASRA counts/km.

Figure 5.15 Distribution of traffic volumes of the sites used in this study



Taking failure as where there is more than a certain roughness level, or where the rut depth is greater than 20mm, the cumulative percentage of sites that were failing, based on the average condition of the site, is shown in figure 5.16. The failure rate appears to level off after approximately 20 years, and after that the rate of increase is low. Even for a roughness level of 120 NAASRA, the failure rate was less than 5%. This figure was in terms of cumulative failure rate for the unbound pavements which, for example, means that 3.9% of all pavement sections under 25 years of age failed a roughness criterion of 120 NAASRA counts.

Figure 5.16 Cumulative failure rate of unbound pavements for the combined network



In order to examine the effects of traffic level, the unbound granular pavement data was divided into four categories (AADT <5000, AADT 5000, <AADT <10,000, AADT 10,000, <AADT <20,000, and AADT >20,000). In all the pavements, the design life was assumed to be 25 years. In order to be consistent with the probability distribution discussed in the New Zealand Supplement to the Austroads guide, the age groups were divided into four categories (0-20%, 20-70%, 70-130% and 130-200% of design life).

A more severe definition of rutting failure was adopted. The pavement was considered to have failed if the rut depth was greater than 15mm and/or the pavement had a roughness greater than 120 NAASRA. The following two graphs show the profiles for rut and roughness.

Figure 5.17 Percentage of rut depth >15mm as a function of design life

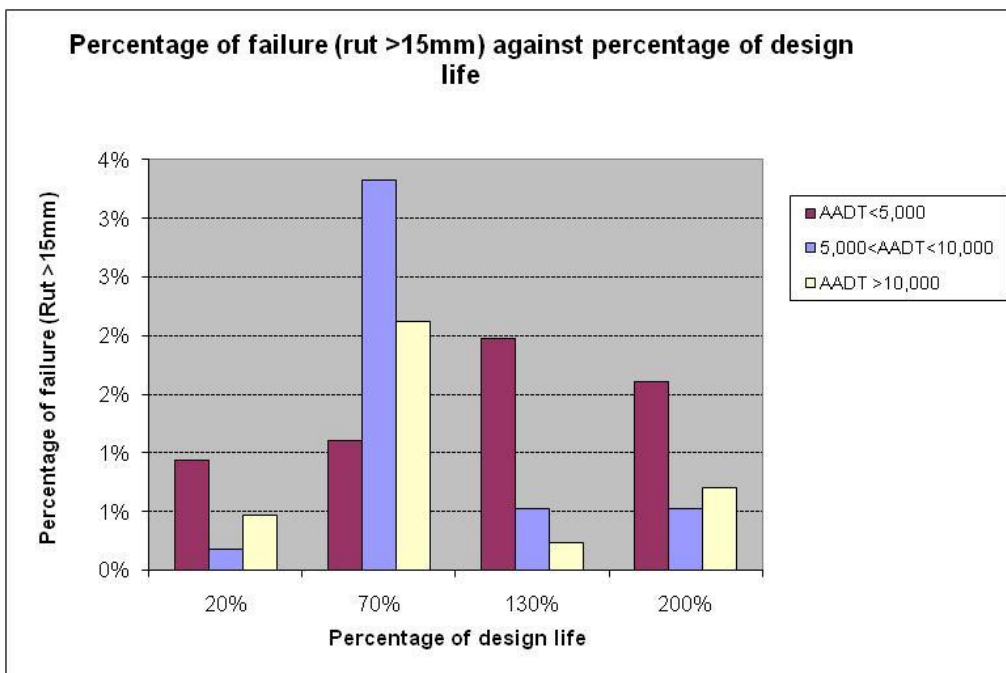
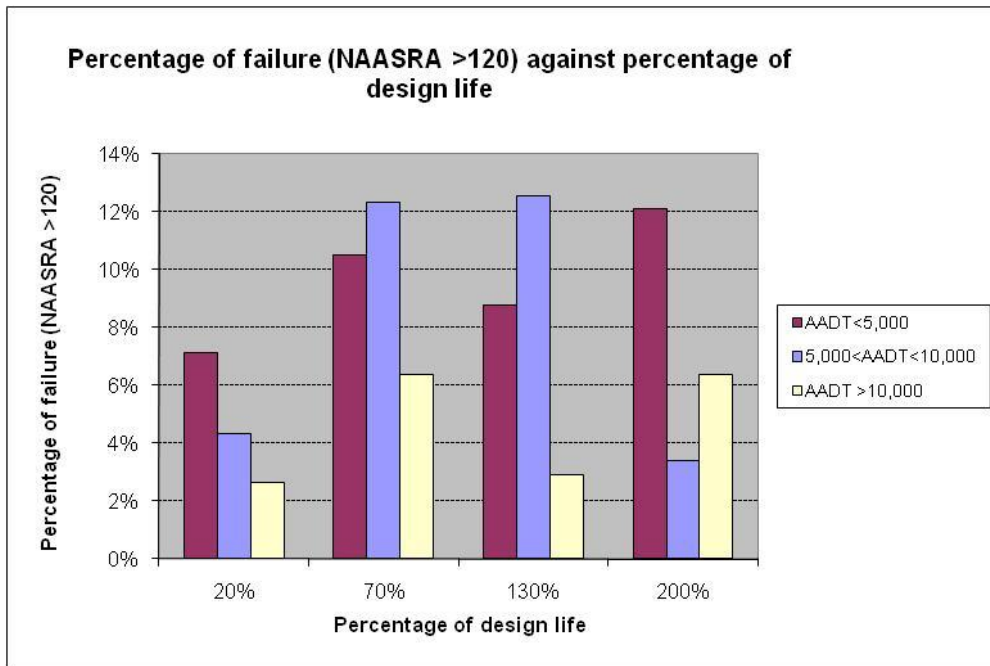


Figure 5.17 shows that there was no consistent trend of a higher failure rate with age. If the cumulative failure up to 70–130% of design life was taken, then there was an approximately 4% failure for the AADT <5000 and 5000–10,000 AADT ranges, and for the 10,000–20,000 AADT the rate was less than 4%.

These numbers indicate that the extent of rutting was not dependent on the traffic volume – ie when the traffic volume increased, the total of the proportion of rutting failure did not increase.

Figure 5.18 Percentage of roughness >120 NAASRA counts/km as a function of design life



If the failure for each traffic band is summed, then figure 5.18 shows:

- around 26% of road sections failed by roughness within 50 years for traffic volume less than 5000 AADT
- around 33% of road failed for traffic volume between 5000 and 10,000 AADT
- around 26% of road failed for traffic volume between 10,000 and 20,000 AADT
- around 5% failed for traffic volume greater than 20,000 AADT.

These percentages were higher than the rates for rutting failure, but the same conclusion could be made when considering traffic volumes related to failure rates. Thin-surfaced granular road sections with traffic greater than 20,000 AADT were investigated in more detail to ascertain the 5 percentile, mean, and 95 percentile profiles. The rut depth profile is shown in figure 5.19 and the roughness profile is shown in figure 5.20.

Figure 5.19 Rut statistics for unbound pavements with traffic volumes >20,000 AADT

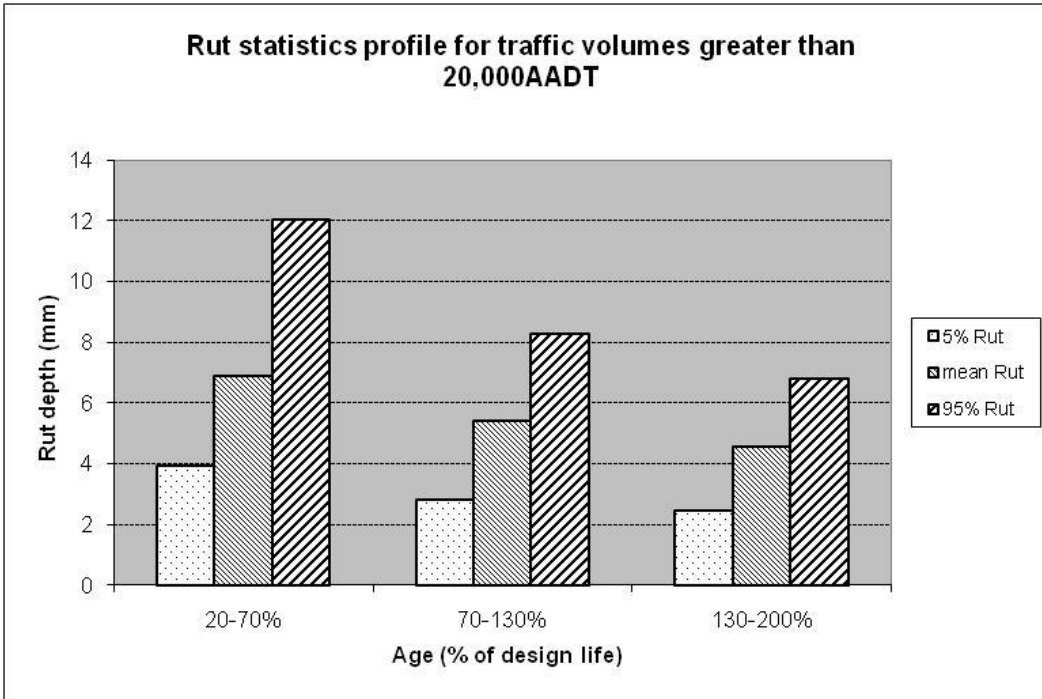
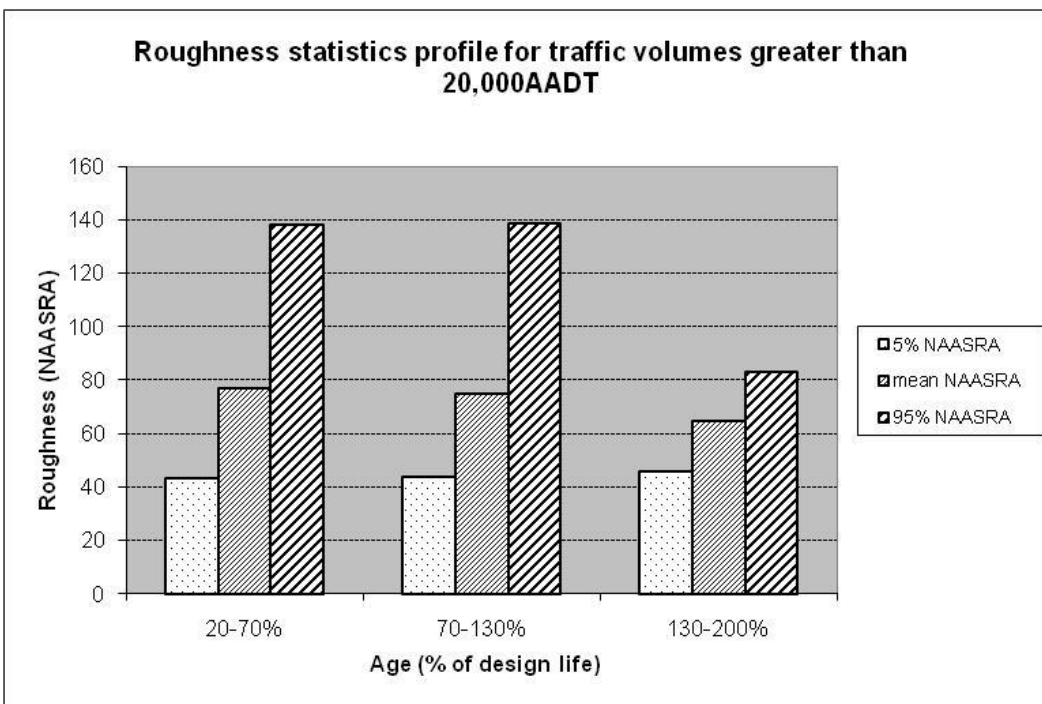


Figure 5.20 Roughness statistics for unbound pavements with traffic volumes >20,000 AADT



If anything, figures 5.19 and 5.20 show a decreasing trend with age.

The traffic volume for the data used for plotting these figures had a mean of 33,643 AADT.

5.4 Structural asphalt

The Auckland network has a significant length of structural asphalt, and this data was analysed in the same manner as in the previous sections. Figures 5.21 and 5.22 summarise the data. There is no obvious trend of increasing rut depth or roughness with age.

Figure 5.21 Rut depth statistics for Auckland structural asphalt

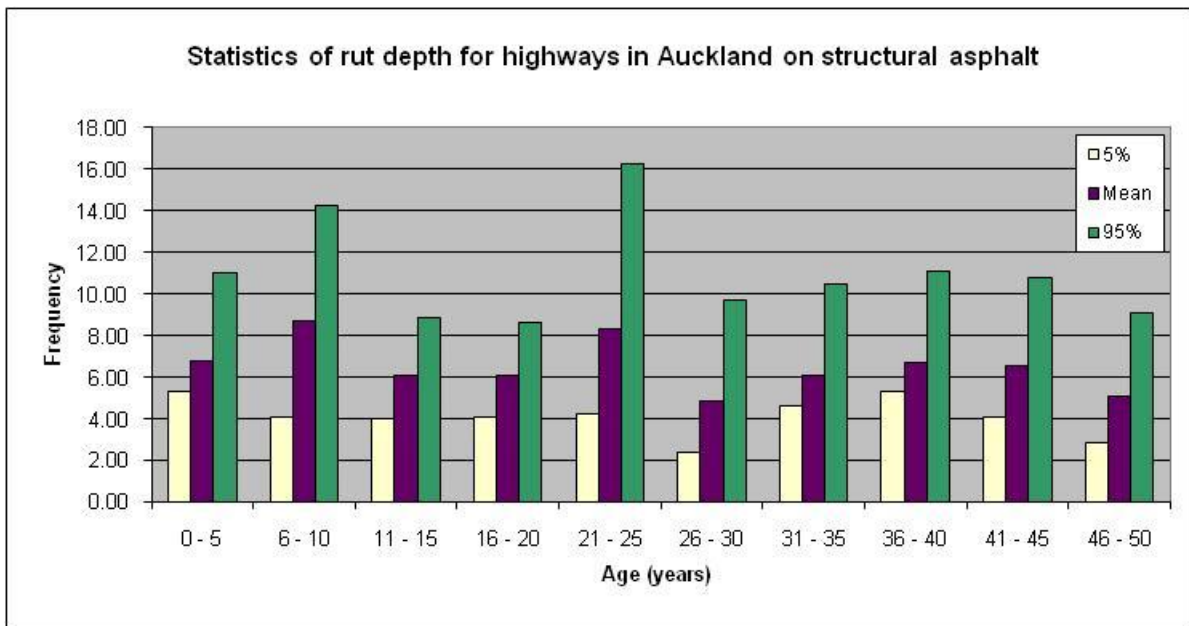
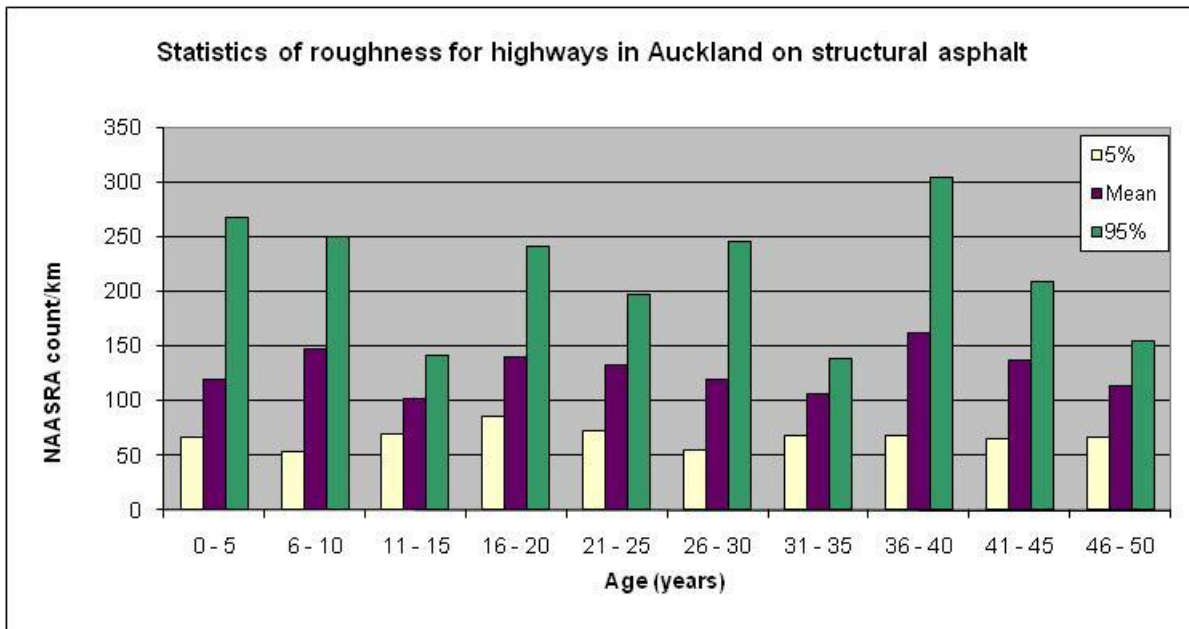


Figure 5.22 Roughness statistics for Auckland structural asphalt

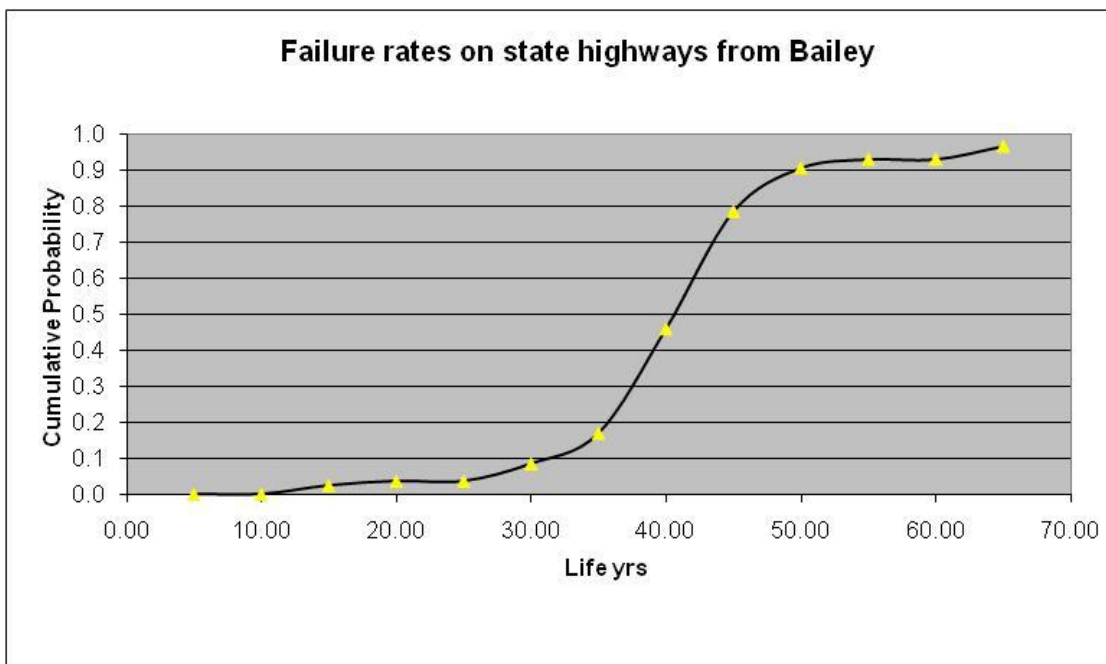


6 Discussion

It is normally assumed that failure within the first year of a pavement’s life is associated with a construction fault, but recent research into the permeability of first-coat seals (Patrick 2009) suggested that under higher traffic volumes, basecourse failure can occur through water being pushed through the seal faster than it can drain. This shows itself as potholes or shear failure in the surface.

Data was also available from the research of Bailey et al (2006), who investigated the relationship between the Austroads design methodology and pavement performance. The distribution of life of more than 60 pavements that had been rehabilitated is compared with the TNZ guidelines (2007) in figure 6.1.

Figure 6.1 Failure profiles (adapted from Bailey et al 2006)



The average life from Bailey et al’s data was 46 years. This compares well with the rehabilitation rate currently being achieved on the state highways. In 2005–06, a total of 259.5km of rehabilitation, smoothing or area-wide treatments were performed; in 2006–07 the total was 266.5km. The total state highway length was 10,895. The rate of structural treatment was therefore equivalent to a pavement life of 42 years for 2005–06, and 41 years for 2006–07.

It is therefore concluded that the distribution of pavement life on the state highway will have a mean of approximately 45 years.

Bailey et al’s data also indicated that the failure to meet a design life of 25 years was approximately 5% (even though the failure mode was not roughness or rutting). Coincidentally, this was consistent with the roughness failure rate of 4% of pavements with a threshold level of 120 NAASRA. It was also in agreement with the Austroads Guide’s assumption that granular pavements designed to the Guide’s specifications have a 5% probability of not achieving this life.

However, Bailey et al’s data did indicate that pavements were not surviving beyond a traffic level of 5×10^6 ESAs. For a 25-year design life, the 5×10^6 ESAs is approximately equivalent to 2500v/ld (5000 AADT) with 10% HCVs and 3% growth. The risks associated with higher traffic volumes on pavements need further consideration, as suggested by the New Zealand Supplement.

The typical pavement deterioration relationship is shown in figure 6.2. The mechanistic design assumes that each traffic load will damage the pavement, and in the case of rutting, a small increment of subgrade or base deformation will occur. This will continue until it reaches an unacceptable level of rutting or roughness, when the pavement is considered to have failed.

With New Zealand's proactive maintenance policy, the surface of a pavement on the state highway will be resealed approximately every 8-10 years. It is therefore hypothesised that as the resurfacing process also entails pre-seal repairs, these will assist in restoring the pavement shape, and therefore the pavement deterioration will appear more like that illustrated in figure 6.3.

The risk of a pavement not reaching its design life is therefore a function of the maintenance carried out on the pavement. It is proposed that on a well-maintained pavement, the risk of not achieving the design life is in the order found by Bailey et al, ie 5%.

Figure 6.2 Typical deterioration model

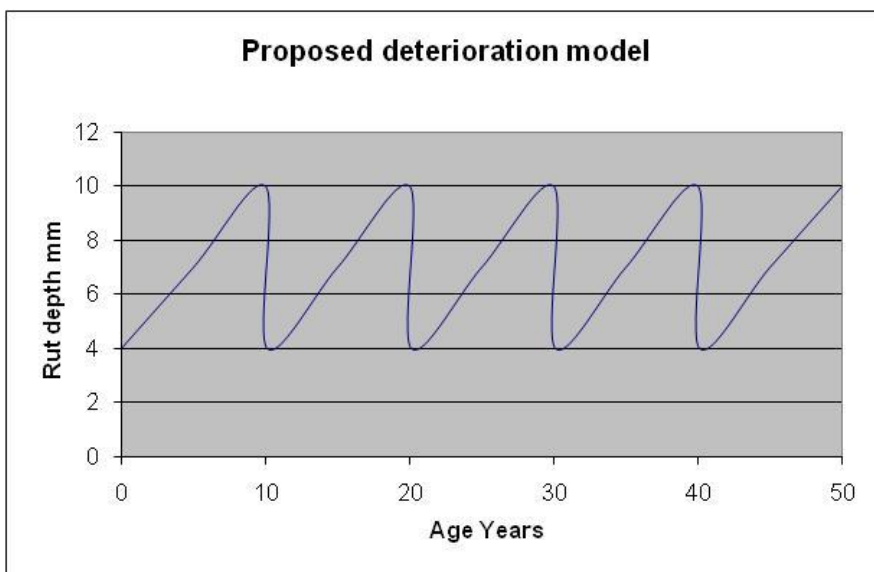
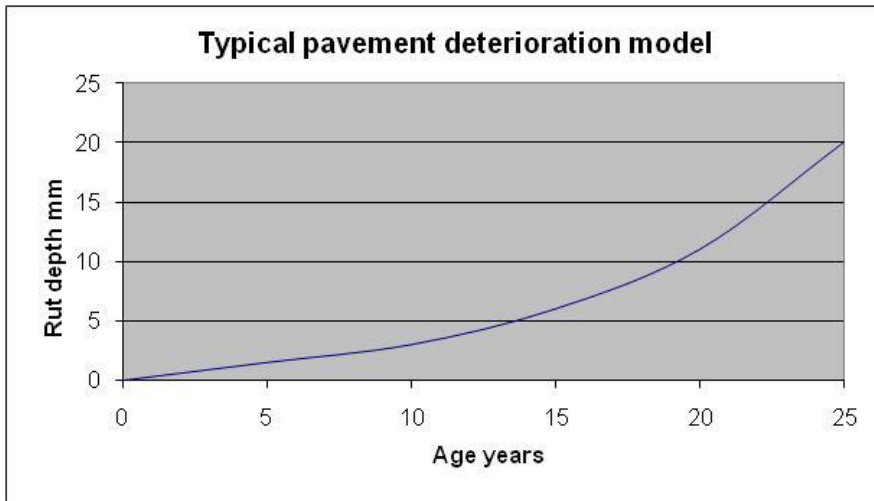


Figure 6.3 Proposed deterioration model

6.1 Early failure

As was noted in section 5.1, around 6% of pavement sections needed significant repair within four years of construction.

Only one section out of three had a high maintenance cost for both pavement and surfacing. Fifteen percent of the total treated length of road had a rut depth greater than 5mm. Rutting in the granular basecourse was identified as contributing to the total rut depth in a pavement. For roads with a higher traffic volume, a methodology has been developed by Arnold et al to estimate the rut depth in the granular layers (Arnold et al 2007).

This method is currently being phased in to the NZTA specifications and will assist in ensuring that the rutting performance of granular materials is controlled in the materials specification.

7 Conclusions

This project aimed to complement the New Zealand Supplement to the *Austrroads pavement design guide* by seeking to provide objective data to be able to assign a failure probability associated with various forms of pavement construction. This has been achieved through analysis of past performance of granular, bound and structural asphalt pavements. The analysis covered both the long-term performance and the probability of early failure (within the first few years).

The overall analysis in this research was based on four New Zealand road networks. The analysis assumed that for at least the past 40 years, the roads had been designed according to the elastic-layer theory, based on either the NRB *State highway design and rehabilitation manual* (1987) or the *Austrroads Pavement design guide* (2004a) along with the *New Zealand supplement* (TNZ 2007). In this analysis, pavement failure was assumed to be associated with rutting or roughness. Failure associated with the NPV of future maintenance costs was not considered, as this was not part of the pavement design methodologies that would have been used.

None of the four road networks that were analysed showed a strong relationship between age and rut depth or roughness. This is contrary to what would be expected if the assumptions in the design methodology were actually occurring in the pavement.

The design life of typical granular pavements is 25 years, and the evidence shows that New Zealand's road pavements are mostly averaging close to 50 years – ie 200% of their design life.

This is thought to be because surface treatments repairing minor rutting and roughness are performed regularly through a pavement's life, meaning that pavements do not deteriorate in the same fashion as proposed in classic deterioration models.

It is proposed that thin-surfaced granular pavements have a bimodal distribution of life. The first peak of failure is in the first one to two years, when shallow shear and potholing can occur. After this period, the pavement settles down and its life will approximate that shown by Bailey et al in figure 6.1.

Therefore, even though the majority of pavements are not actually ultimately 'failing' through rutting or roughness, the *Austrroads Pavement design guide's* proposed risk of 5% probability of not achieving the design life appears to be correct.

For pavements with a high traffic volume, there is not enough data to determine the size of the 'early failure' peak. The failure rate associated with thin-surfaced unbound pavements at higher traffic volumes needs further investigation.

8 References

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Appendices

Appendix A West Wanganui network

Figure A1 Pavement maintenance cost for West Wanganui rehabilitation

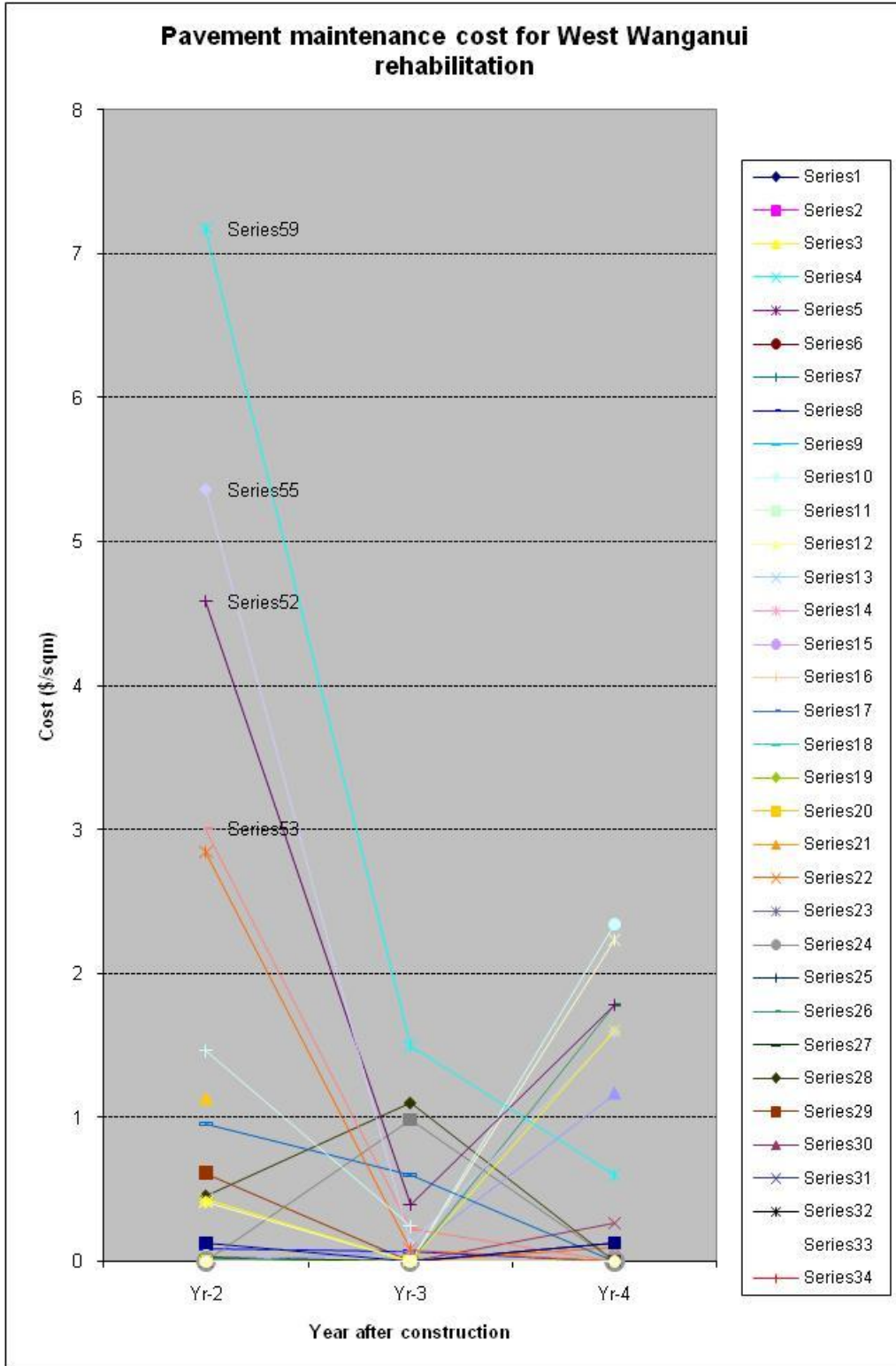


Figure A2 Surface maintenance cost for West Wanganui rehabilitation

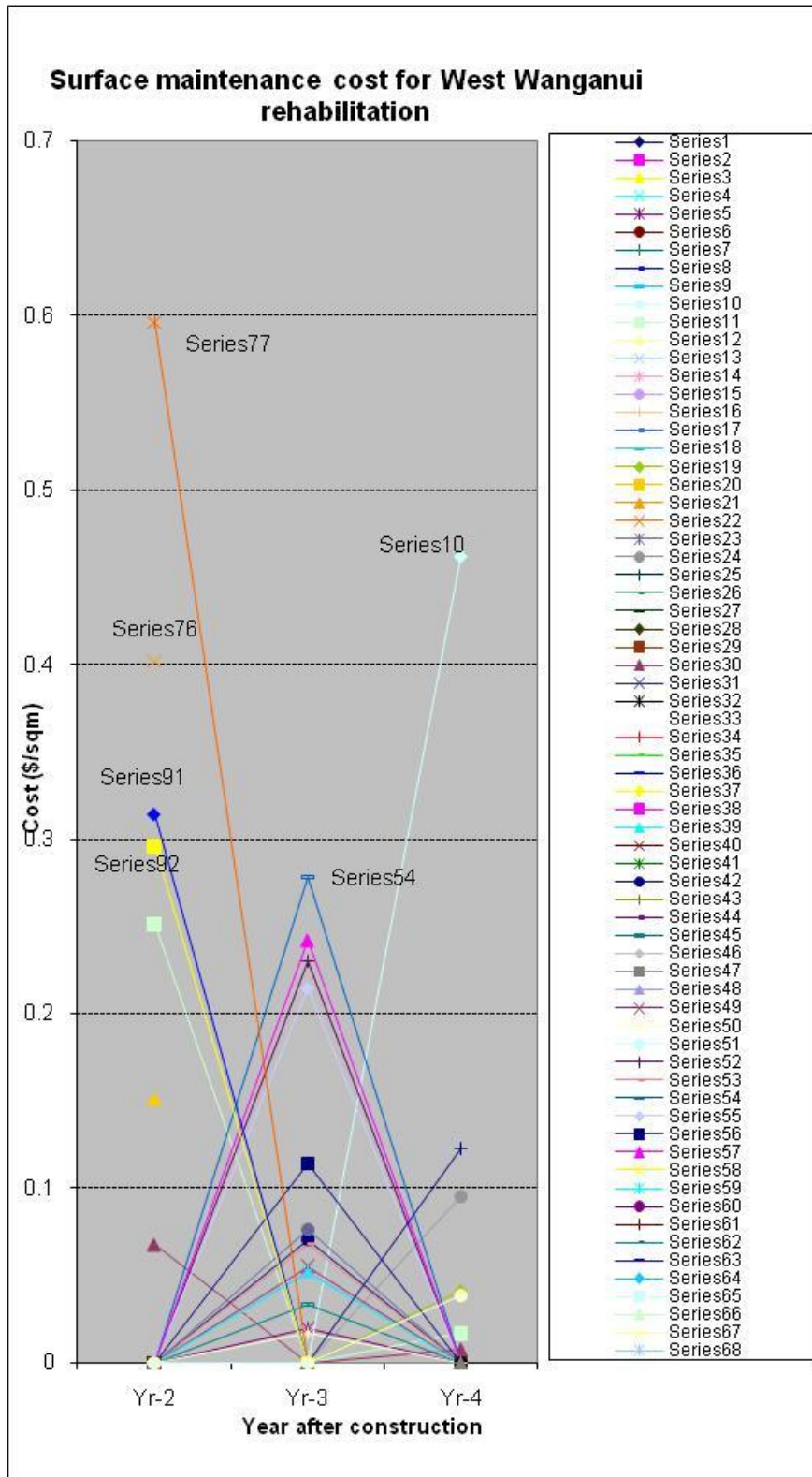


Figure A3 Traffic volume of analysed network in West Wanganui

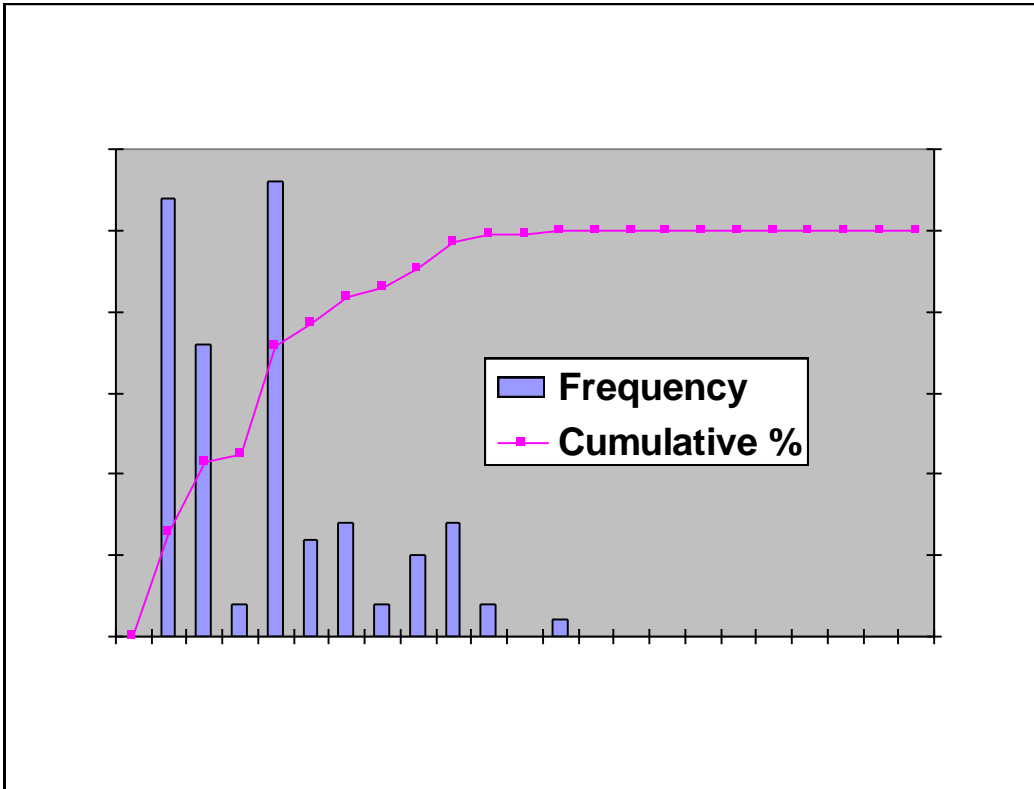
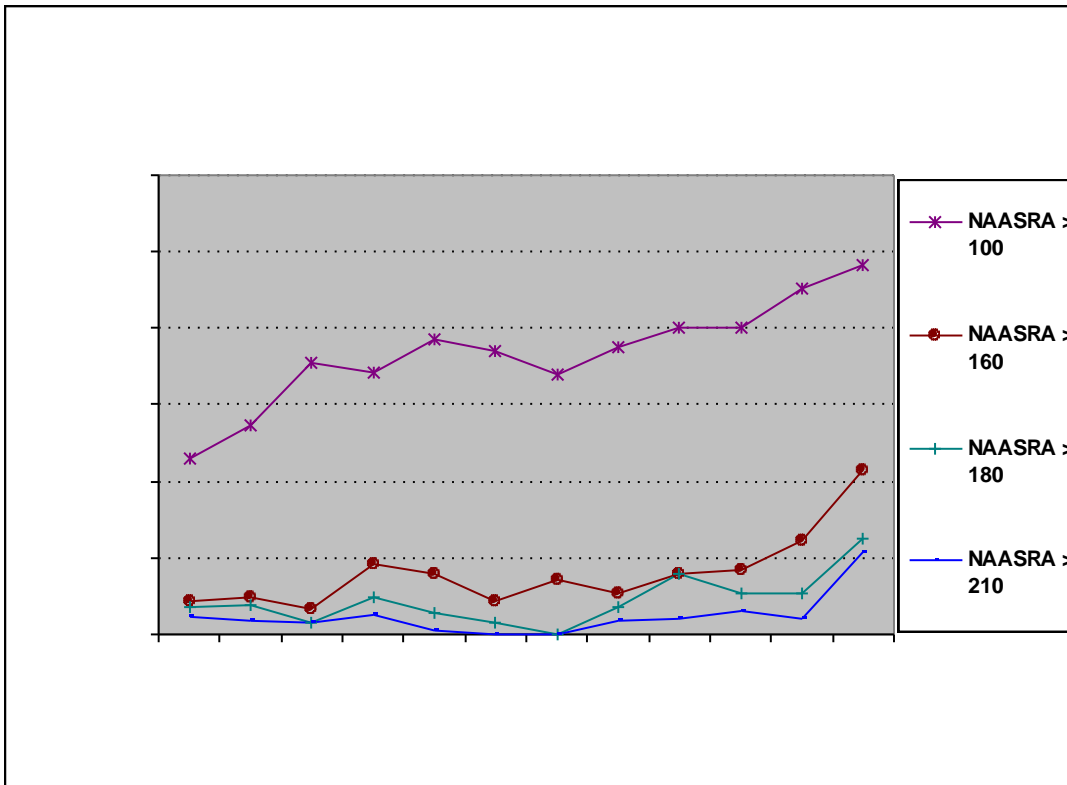


Figure A4 Roughness of each age group in West Wanganui highways



Appendix B Southland network

Figure B1 Pavement maintenance cost for Southland rehabilitation

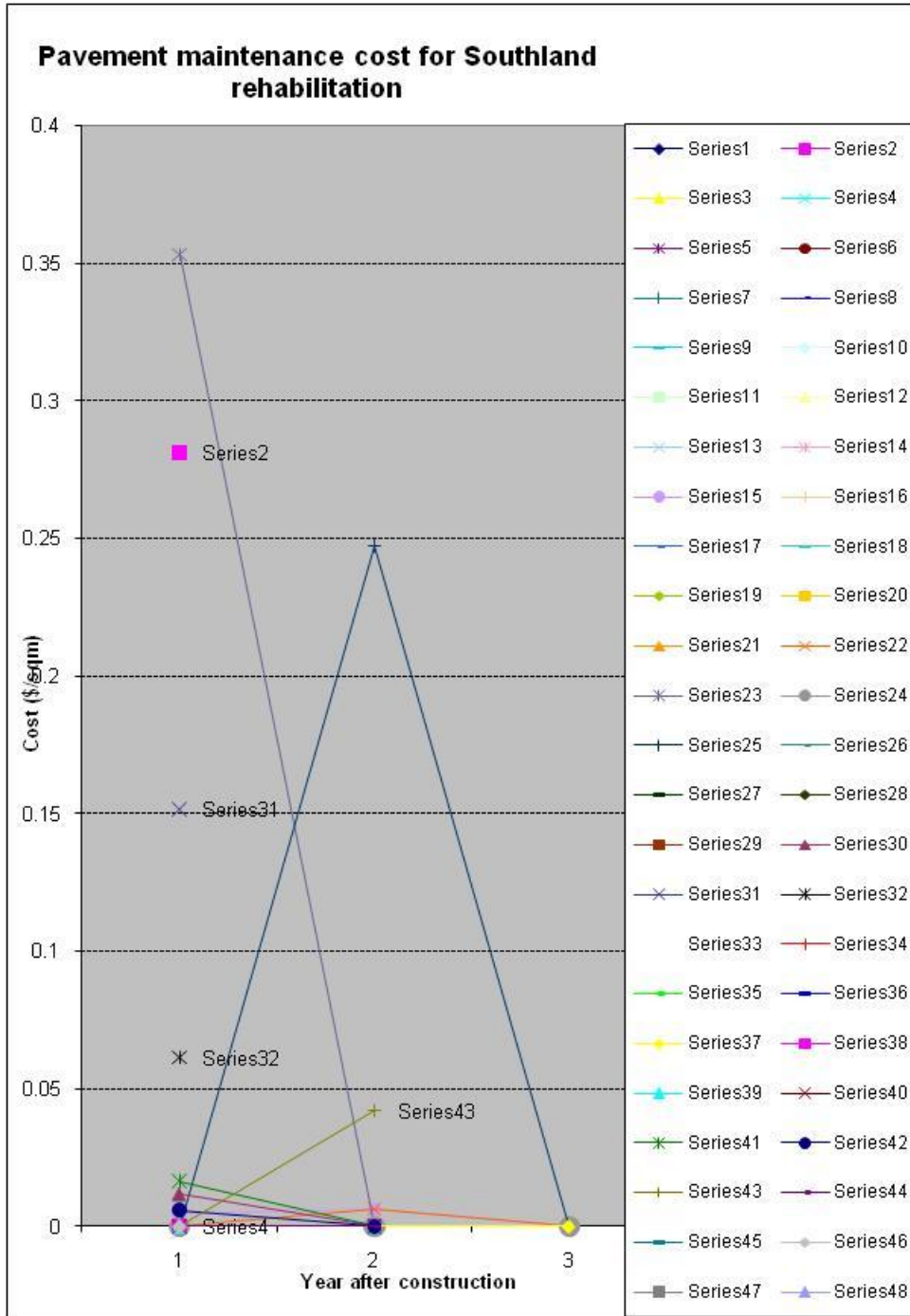


Figure B2 Surface maintenance cost for Southland rehabilitation

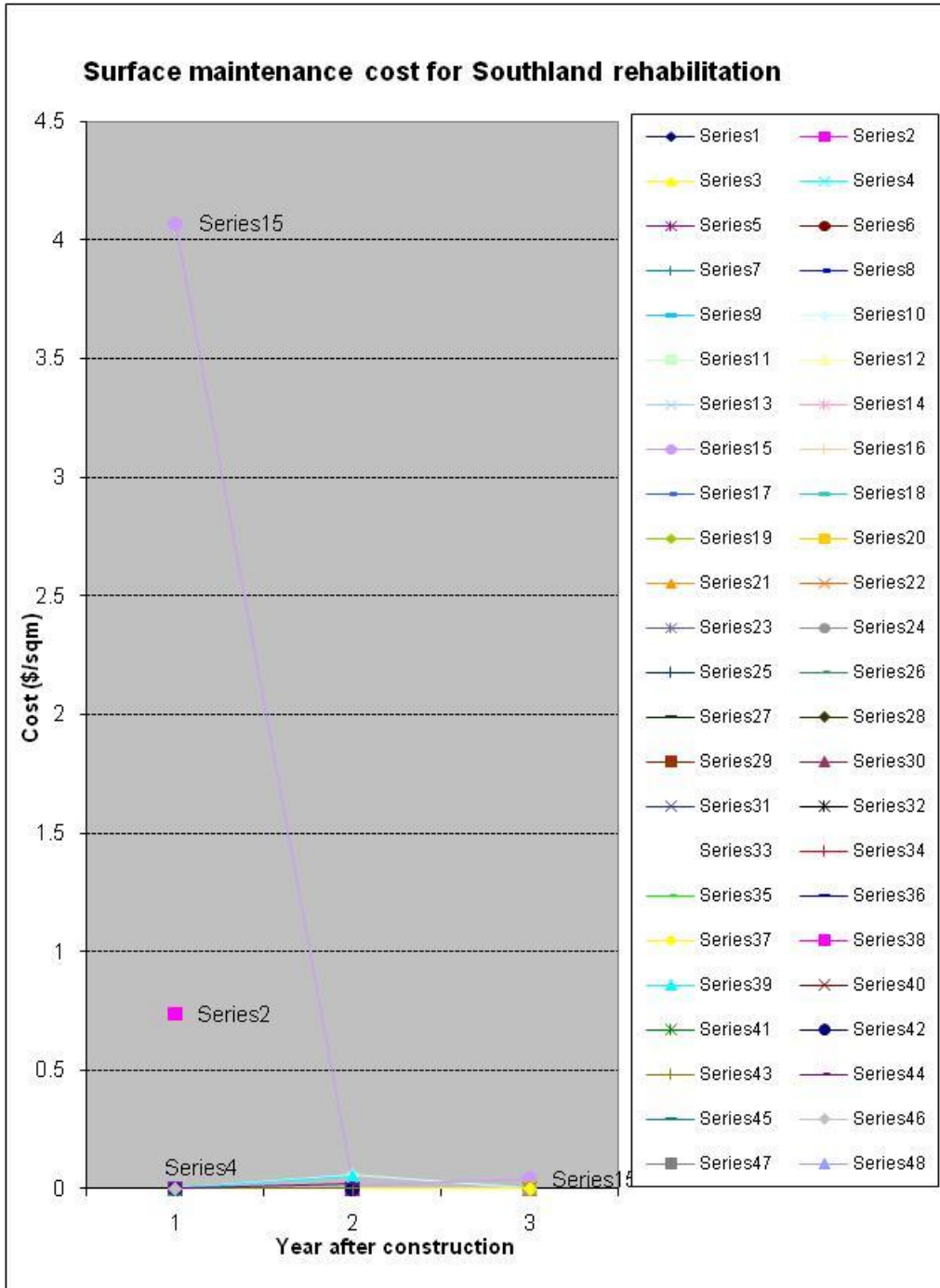


Figure B3 Traffic volume of analysed network in Southland

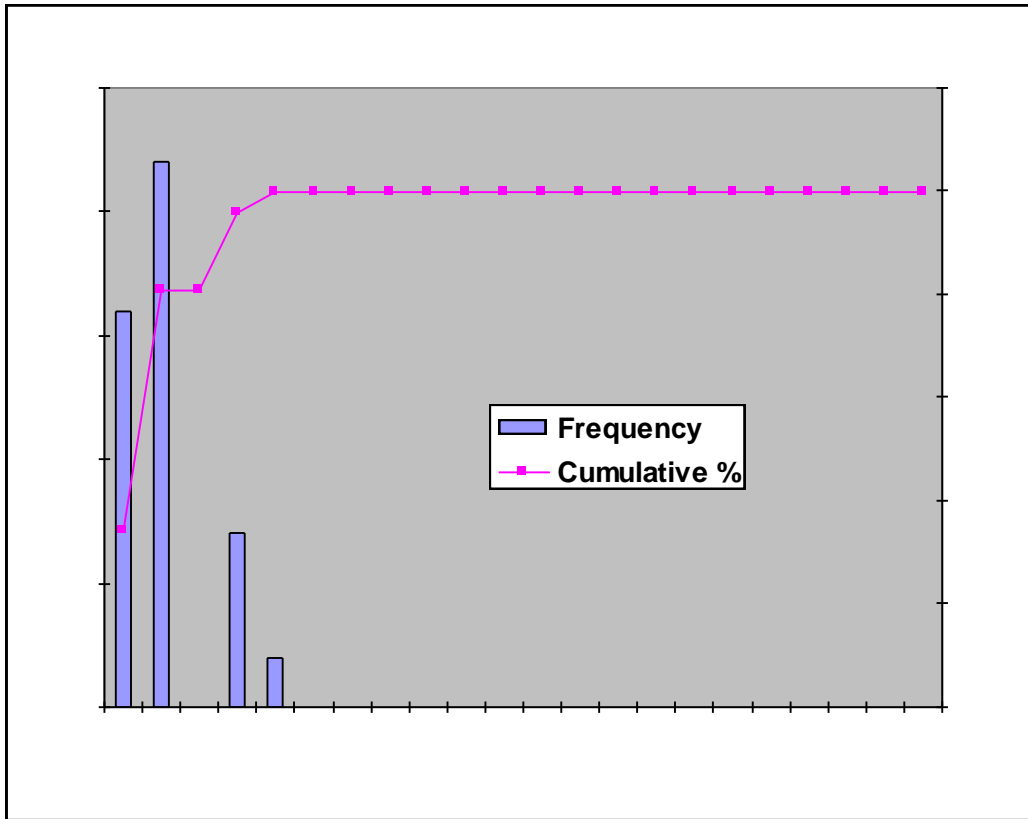


Figure B4 Roughness of each age group in Southland highways

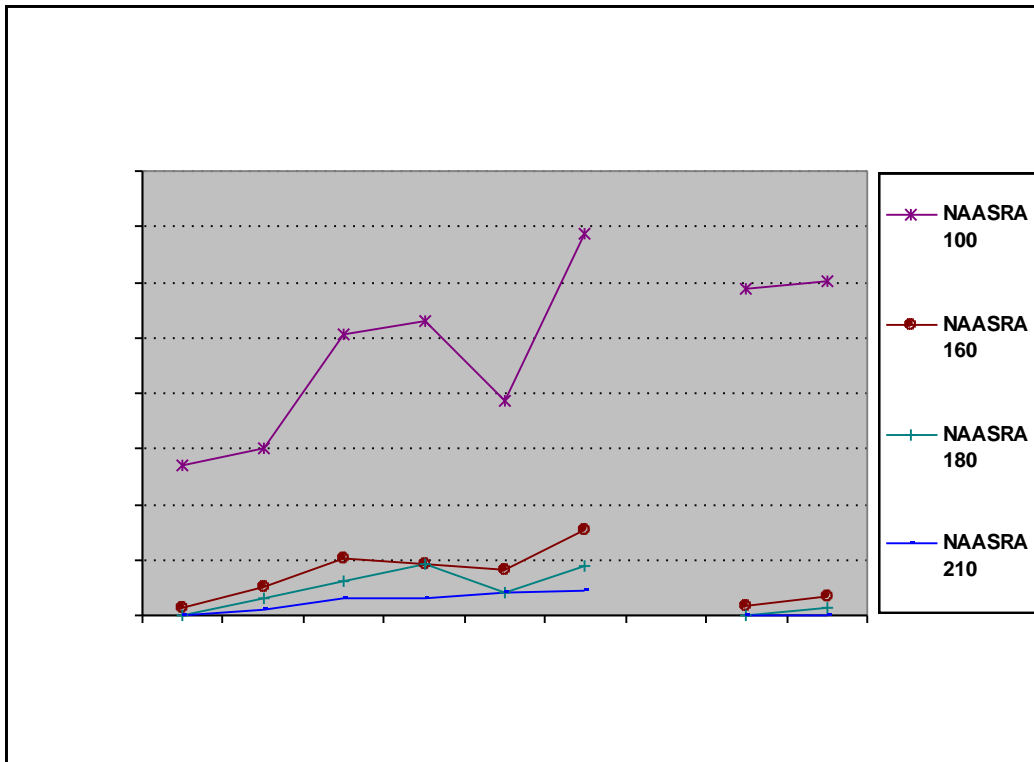
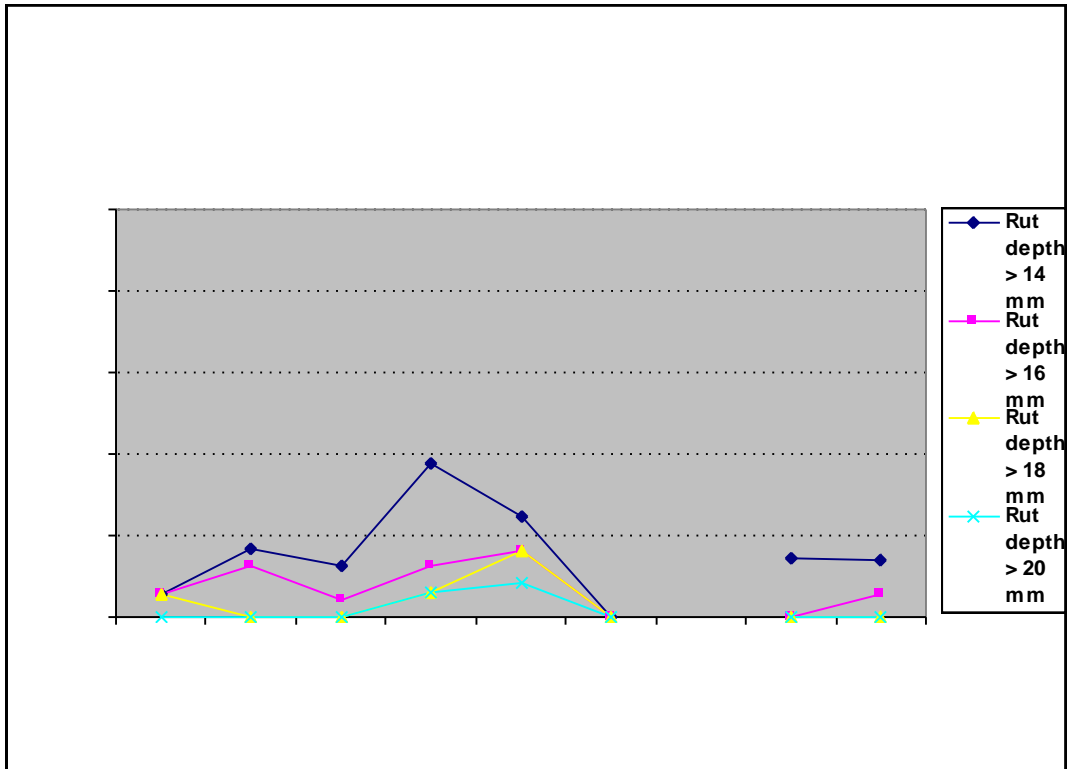


Figure B5 Rut depth of each age group in Southland highways



Appendix C Auckland network

Figure C1 Rut profile of Auckland highway (unbound)

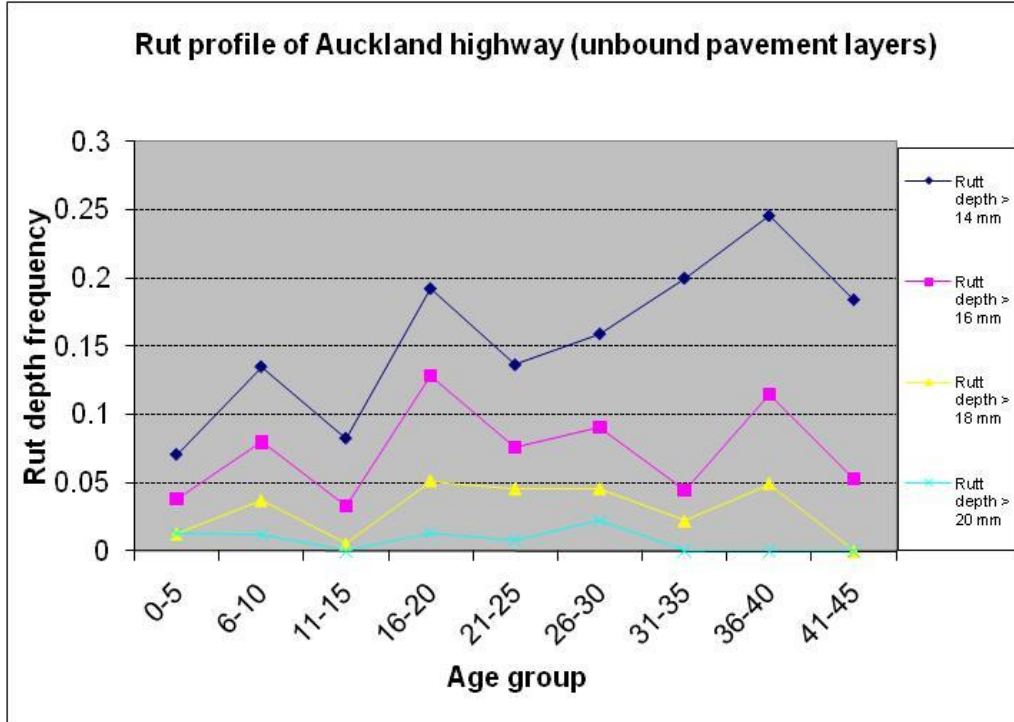


Figure C2 Roughness profile of Auckland highway (unbound)

