Factors influencing the decision to rehabilitate a pavement

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JE Patrick
Dr Haran Arampamoorthy
Opus, Central Laboratories, Lower Hutt, New Zealand

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NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

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Abbreviations and acronyms

AADT:	annual average daily traffic
AC:	asphaltic cement
AWPT:	area-wide pavement treatment
ESA:	equivalent standard axles
FWP:	forward works programme
HCV:	heavy commercial vehicle
IRI:	International Roughness Index
NPV:	net present value
NZTA:	NZ Transport Agency
OGPA:	open graded porous asphalt
PSV:	polished stone value
RAMM:	road asset maintenance management
RP:	route position
SCRIM:	Sideways force coefficient routine investigation machine
SH:	State Highway
v/l/d:	vehicles per lane per day
VPD:	vehicles per day
NAASRA roughness meter	A standard mechanical device used extensively in Australia and New Zealand since the 1970s for measuring road roughness. It 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 (1NRM/km).

Contents

Executive summary

The decision to rehabilitate a section of pavement is critically dependent on the forecast maintenance costs. The methods historically used to forecast maintenance costs are based on costs escalating towards the end of a pavement's life. However, a recent study has suggested that this does not happen and an earlier study indicated that pavements are being rehabilitated while still appearing to have significant remaining life.

The objective of this research (undertaken 2008–2011) was the development of an improved method of modelling the decision to rehabilitate a typical New Zealand thin-surfaced unbound granular pavement. This was driven by previous research that had found a poor correlation between the data recorded in the road asset maintenance management (RAMM) database and the decision to rehabilitate. It had been hoped that by talking to local engineers and examining pavements proposed for rehabilitation, distress not currently recorded may be identified. This would have then driven the development of better models and may also have expanded the detail collected in the visual surveys. The research found, however, that the drivers are not obvious and that the decision maybe being based on factors such as the engineers' assessment of the risk of rapid failure.

The conclusions from this research are:

- According to a visual engineering inspection, many pavement sections require rehabilitation.
- In many cases, a significant quantum of deferred maintenance needs to be performed for the do-minimum option. This maintenance is not necessarily obvious from the data in RAMM or visual observations of the high-speed data videos.
- The methods used to determine future maintenance costs vary widely. This ranges from including the deferred maintenance cost into one year and extrapolating from this cost, to ignoring the deferred maintenance cost in the analysis.
- The timeframe for assessing maintenance cost history is variable.
- The net present value (NPV) calculation can be very sensitive to assumptions made on future maintenance and seal lives. This includes assuming that higher priced polymer-modified seals need to be used.
- Rutting and flushing at 88% and 80% of the surveyed pavements are the two most commonly quoted distress mechanisms. These do not appear in a proposed rehabilitation algorithm.
- Digouts are a factor mentioned in 55% of justifications.
- The inspection length associated with the visual pavement inspection did not reflect the treatment section length in 40% of sites.
- The influence of non-engineering factors, such as concerns over 'consuming the asset' and fears of rapid pavement failure, need to be investigated.
- The difference in condition between the typical pavements in a network and those chosen for rehabilitation can often be minor and thus very difficult to quantify.
- Better guidelines should be developed to assist and standardise the decision process. These guidelines need to be based on a risk and consequence approach, which, it is believed, will better reflect the engineers' approach.

Recommendations

If more emphasis in the justification was placed on the present pavement condition then this would lead to more consistent decisions. Through the use of an expert group, analysis of the Long-Term Pavement Performance trials, Canterbury Accelerated Pavement Testing Indoor Facility trials, dTIMS modelling etc, an acceptable definition of the degree of pavement distress and the rate of increase of this distress that triggers pavement rehabilitation could be developed. The expert group would need to consist of owner, consultant and contractor representatives to ensure that a balance was struck between the funders and the doers.

The definition would need to consider the effects of resealing in both improving the pavement performance and also masking distress. This would ensure that, for example, a surface condition such as flushing was not by itself a justification for rehabilitation, but unstable seal layers could be used.

It is envisaged that maintenance cost differences throughout the country could be normalised through analysing a section in terms of percentage increase from the mean for the network and also the rehabilitation cost as a percentage of the mean maintenance cost.

This approach would take into account both the engineering judgement associated with the inherent strength of the pavement, and also the economic and risk tension between maintenance and rehabilitation. The assessment of an NPV would not be the final step in the decision making but be a part of a maintenance-rehabilitation cost ratio.

It is also recommended that the use of inspection lengths be reconsidered. As the inspection length associated with the visual pavement inspection did not reflect the treatment section length in 40% of sites surveyed in this study, it is recommended that an investigation into a method of obtaining a more representative sample be explored. This could be in determining the position of the inspection length or taking subsamples or other means.

‘Standardising’ the methodology of determining the need for rehabilitation is necessary. It is recommended that the structure of such a methodology could consist of the following modules:

- **Data analysis:** In this first step, the RAMM data would be screened to highlight sections. It is envisaged that the expert group would develop a selection algorithm that would include factors such as
  - the shape of the section (roughness or rutting) being above certain thresholds or changing rapidly
  - the maintenance activities being significantly above a predetermined percentage of the average for the network
  - the condition in terms of shoving, edge breaks, potholes and digouts being above predetermined limits
  - the risk profile of the network associated with traffic volumes, subgrade moisture susceptibility, safety etc.
- The highlighted sections would be inspected, the data summarised and the cost of rehabilitation estimated.
- The results would be peer reviewed and maybe presented to a group that considered and objectively debated the total forwards work programme for the network. This could mean that the members of the review group are not directly associated with the network.

Abstract

The objective of this research, undertaken in 2008–2011, was the development of an improved method of modelling the decision to rehabilitate a typical New Zealand thin-surfaced unbound granular pavement. This was driven by previous research that had found a poor correlation between the recorded data and the decision to rehabilitate. It had been hoped that by talking to local engineers and examining pavements proposed for rehabilitation that distress not currently recorded might be identified. This would have then driven the development of better models and may also have expanded the detail collected in the visual surveys. The research found that the drivers are not obvious and that the decision may be based on factors other than those of an engineering nature.

It is recommended that a more consistent decision making process be developed that places more emphasis on the present pavement condition rather than the present emphasis on the net present value of future maintenance costs.

1 Introduction

1.1 Purpose of the research

The decision to rehabilitate a section of pavement is critically dependent on the forecast maintenance costs. The methods historically used to forecast maintenance costs are based on costs escalating towards the end of a pavement's life. However, a recent study by Gribble et al (2008) has suggested that this does not happen and an earlier study by Bailey et al (2006) indicated that pavements are being rehabilitated while still appearing to have significant remaining life. Therefore, it is possible that New Zealand pavements are being rehabilitated unnecessarily.

Rehabilitation treatments were performed on approximately 170 lane-km of state highways and 740 lane-km of local roads in the year ending 30 June 2006. Assuming an average cost of $250,000 per kilometre, this equates to an expenditure of almost $230 million. If 10% of the proposed rehabilitation can be deferred by one year, the potential cost savings are $2.3 million in the first year. Ongoing savings could potentially be similar, as the average life of the network is increased without loss of service or an increase in maintenance costs. On the other hand, with the increasing traffic on the network and the introduction of heavier vehicles, the quantity of rehabilitation may be too little and the asset may be being 'consumed'. Therefore, robust decision making tools are needed to guide the choice and quantity of rehabilitation that is being performed.

As part of a Land Transport New Zealand study, Gribble et al (2008) produced an improved rehabilitation model which has been incorporated into the dTIMS pavement modelling package. Gribble et al also tried to develop a maintenance cost model, but the best that could be obtained still only explained 18% of the variance in maintenance costs. Gribble et al suggest that this poor fit is likely to be a result of some factors that influence pavement maintenance costs not currently being recorded in the road asset maintenance management (RAMM) database. Gribble et al also suggested that the factors that influence the decision to rehabilitate a treatment length are not being recorded in RAMM or, if they are recorded, they are not being recognised as significant.

The research reported here is an extension of the previous work to improve the rehabilitation decision models, and was undertaken in 2008–2011. In order to achieve this, network managers for a number of NZ Transport Agency (NZTA) roading networks throughout the country were interviewed and an examination of a representative number of treatment lengths in each network was conducted. The hope was that this would enable the important factors associated with maintenance costs and pavement rehabilitation to be identified. It was suspected that, in addition to the local environment, local practice would have a strong influence on the maintenance costs and the diagnosis of rehabilitation requirements. The in-depth analysis was expected to assist in identifying these important factors for incorporation into the existing models.

The aim of the research was to refine the models developed by Gribble et al (2008), thus allowing better forecasting of pavement maintenance costs. The rehabilitation prediction model would also potentially be improved by a better understanding of the factors involved. Both models would allow more effective management of pavement assets to obtain optimum life.

1.2 Current model

The rehabilitation model developed by Gribble et al (2008) is based on logit regression techniques. They used the data from four networks combined into a single database and examined it for any tendencies. Logit regression techniques were used to model the likelihood of pavement rehabilitation. Logistic regression differs from linear regression models in that the outcome variable is binary or dichotomous, in this case to rehabilitate or to not rehabilitate. The generated models had the form shown in equations 1.1-1.2.

$$Pred = \sum Coeff_i \times Variable_i + Constant\,, \qquad \text{(Equation 1)}$$

$$Prob = \frac{1}{1+e^{-Pred}}\,, \qquad \text{(Equation 2)}$$

where the variable *Pred* is the predicator and *Prob* gives the output as a probability fraction. A pavement is considered as requiring rehabilitation if the value of the *Prob* output is greater than a threshold probability defined by the modeller, thereby producing a binary output result.

The combined roading data from four networks was modelled with the separated maintenance costs combined into a single parameter. The resultant model had the form shown in equation 1.3.

$$\begin{gathered} Pred = 0.568\ln MC_{Total} + 0.465\ln Traffic + 1.60UR + 0.065\ln EdgeBreak + 0.047\ln Allig + \\ 0.3Roughness + 0.021\ln Shoving - 14.963 \end{gathered} \qquad \text{(Equation 3)}$$

The variables in equation 1.3 are defined in table 1.1. Variables that were included in the analysis but were not found to be significant were rutting, pavement age, potholes and scabbing. Shoving was included in the relationship by the authors even though it was not statistically significant.

The pavement data from Napier, Gisborne, Southland and West Wanganui was used to develop the region-specific models given in equations 1.4, 1.5, 1.6 and 1.7 respectively.

$$Pred = 1.084\ln MC + 0.050\ln EdgeBreak - 12.270 \qquad \text{(Equation 1.4)}$$

$$\begin{gathered} Pred = 0.141\ln Shoving + 0.640IRI + 0.587\ln MC_{Total} + 0.646\ln Traffic + \\ 0.069\ln EdgeBreak + 1.732UR - 18.654 \end{gathered} \qquad \text{(Equation 1.5)}$$

$$Pred + 0.501\ln MC_{Total} + 0.088\ln EdgeBreak + 0.08\ln Potholes - 6.421 \qquad \text{(Equation 1.6)}$$

$$\begin{gathered} Pred = 1.016\ln Traffic + 1.016IRI + 0.328\ln MC_{Total} + 0.089\ln Allig + \\ 0.077\ln Shoving + 0.091EdgeBreak + 1.45UR - 18.968 \end{gathered} \qquad \text{(Equation 1.7)}$$

It can be seen that the drivers are not the same in each region. From a mechanistic point of view, the significance of edge break as a significant predictor is puzzling. Two of the models do not have traffic or roughness as a significant variable, and none has rutting.

Table 1.1 Variable definitions

Variable	Symbol	Unit	Format
Roughness	IRI	International Roughness Index (IRI)	Average Roughness in IRI (m/km) over six years
Shoving	$Shoving$	m	Normalised data averaged over six years
Alligator cracking	$Allig$	m	Normalised data averaged over six years
Edge break	$EdgeBreak$	m	Normalised data averaged over six years
Pavement maintenance cost	MC_P	Dollars	Cumulative maintenance cost per kilometre over six years for pavement cost group
Surfacing maintenance cost	MC_{Su}	Dollars	Cumulative maintenance cost per kilometre over six years for surfacing cost group
Shoulder maintenance cost	MC_{Sh}	Dollars	Cumulative maintenance cost per kilometre over six years for shoulder cost group
Maintenance cost	MC or MC_{Total}	Dollars	Cumulative maintenance cost per kilometre over six years for shoulder cost group, ie $MC = MC_P + MC_{Su} + MC_{Sh}$
Traffic levels	$Traffic$	Annual average daily traffic (AADT)	As estimated in year 2005 for both rehabilitated and unrehabilitated treatment lengths
Urban or rural environment	UR	Integer	Integer of either 1 for urban roads or 2 for rural roads

The range of the data that was analysed is given in table 1.2.

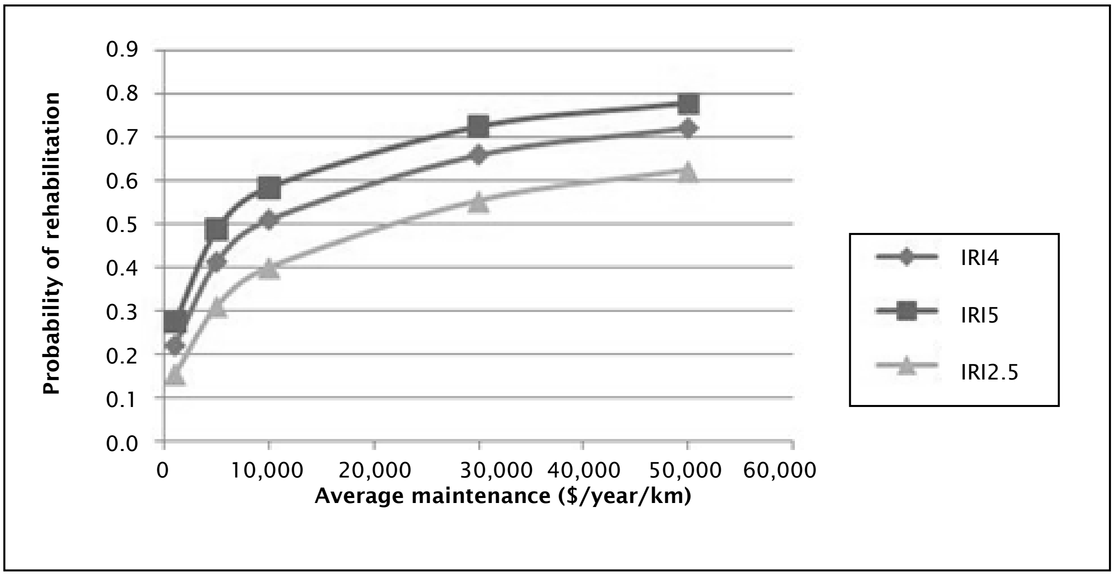
Table 1.2 Range of data analysed

	Roughness (IRI)	Shoving (m)	MC ($)	Traffic (AADT)	Alligator cracking (m)	Edge break (m)
Average	3	10.3	19.7×10^3	3020	29.1	23.7
Maximum	6.7	1667	600×10^3	24,450	2770	710
Minimum	1.2	0.001*	1*	125	0.001*	0.001*
Median	2.9	0.001*	10.5×10^3	1,840	0.001*	4.3

*While these values are properly zero, to remove the problem of taking the log of zero, they have been set to a value close to zero that has minimal influence on the calculated probability.

The sensitivity of the relationship to maintenance costs and roughness (IRI) is shown in figures 1.1 for a traffic volume of 5000AADT. It can be seen that maintenance cost is a major driver when the cost is relatively high. The maintenance cost is the average annual cost over a six-year period. The change in IRI has a linear effect, while maintenance cost is the major driver with a logarithmic effect. The effects of shoving, edge break and cracking all have only a minor effect.

Figure 1.1 Effect of maintenance cost and roughness (IRI) on predicted probability of rehabilitation



1.3 Maintenance costs

A predictive model of the maintenance costs was also attempted but a reliable model could not be developed by using the variables available in the RAMM database.

2 Justifying rehabilitation

2.1 Factors

The major factor in the decision to rehabilitate most of the state highway system is the net present value (NPV) of future maintenance costs (Bailey et al 2006; Gribble et al 2008). The future maintenance costs also include those required immediately to repair the pavement and the projected costs over a 25-year period.

Maintenance costs also include the costs of resealing. If the surface has ‘unstable seal layers’ then the resealing cycle can become significantly shorter than the ‘standard’, resulting in a significant cost impact.

A review of the rehabilitation decision making process in three regions was conducted and a summary of the process is given in the remainder of this chapter.

2.2 Identification process: potential sites for rehabilitation

Identification of potential sites for rehabilitation is carried out during formulation of the annual plan. Using historical data (forwards work programme (FWP), RAMM rating and local knowledge), potential sites are identified for the following three years, and a drive-over of the network is carried out to confirm the suitability and potential economic viability of each site for the forthcoming year. Sites that are deemed to have the potential to pass economic evaluation are then formally inspected, and an assessment is made on the extent of backlog repairs required to bring the site up to a suitable standard. This figure is then used during the economic evaluation process and the remaining sites are reprioritised in accordance with their current condition.

2.3 Economic assessment: NPV analysis

Determining whether a site is viable for rehabilitation is based on a simple cost comparison of continuing maintenance versus the cost to rehabilitate using a method called NPV analysis.

The procedure is outlined in the *Economic evaluation manual* of the NZTA (2010) and uses current, future and historical maintenance costs to give a total value of maintenance for the particular section of highway over the following 25-year period. This value is then compared against a similar calculation for the cost of rehabilitating and maintaining the pavement over the same period to give the NPV (cost differential); a positive value indicates that the section of highway is viable for treatment.

From the examples reviewed, costs for reseals, heavy maintenance and rehabilitation appear to be common to both sides of the analysis table at the various discount rates, though the inclusion of deferred maintenance is unique to the maintenance cost calculation and therefore plays a significant role in the analysis. Deferred maintenance or backlog repairs are a one-off cost with a zero discount rate which is not replicated when calculating the 25-year costs after rehabilitation, which thus has the potential to play a key role in the overall cost comparison. The methodology and use of discounted rates to evaluate the cost from year 0 to year 25 have not been examined in depth as part of this research and it is assumed that the procedure is being followed correctly.

Additionally, annual pavement and surfacing costs plays a pivotal role in the analysis, and their calculation appears to lack consistency, eg maintenance values have been averaged over different numbers of preceding years.

Depending on the range of maintenance costs in the preceding number of years, the average cost could be high and the scope could be selective if a site that just fails the economic evaluation is deemed desirable for rehabilitation (eg if two of the previous three years have a zero maintenance value, the average could be taken from the previous four years to effectively increase its value, favouring the cost of rehabilitation).

2.4 Engineering measures: tools used to assess pavement condition

Tools such as RAMM rating and other historical data are used during the initial identification of a site for rehabilitation. Data such as roughness, texture, rutting, shoving and measurements by the sideways force coefficient routine investigation machine (SCRIM) are considered, and these can be assessed in terms of the network's statement of intent or against the national average. However, in terms of the decision to rehabilitate, these are used only as 'indicators' of a pavement's condition, and no limits have been defined by which a site is deemed unacceptable (and thus requiring rehabilitation).

2.5 Evaluation of backlog repairs: the site walkover

The extent of backlog repairs required to bring a section of highway back to a suitable standard is evaluated during a site walkover. The process consists of a walkover of the site, generally by two people, one walking the site, and the other driving a car and operating a distance recorder and taking notes. Walkovers are done in an increasing chainage measuring each defect as it is encountered (in both lanes) and determining an appropriate method of repair in each case. The defects are recorded in terms of their route position, road side, length, width and fault type, and the proposed repair type, area, rate and cost are then calculated and totalled to give a value of backlog repairs for each individual section of highway.

Although the RAMM rating is used initially to identify a site as discussed above, limiting engineering measures are taken during the site inspection process itself. For example, individual ruts may be identified as being ≥10mm, but the overall extent of rutting is not measured during site inspection. It is possible, therefore, that perception may have some influence on the extent of backlog repairs identified, and that there may be some degree of variability from one inspector to another in assessing the level of maintenance required to bring a site back to a suitable standard.

3 Economic justification

3.1 Example 1

Three examples from different regions have been selected to demonstrate the methodology being used in the determination of the NPV.

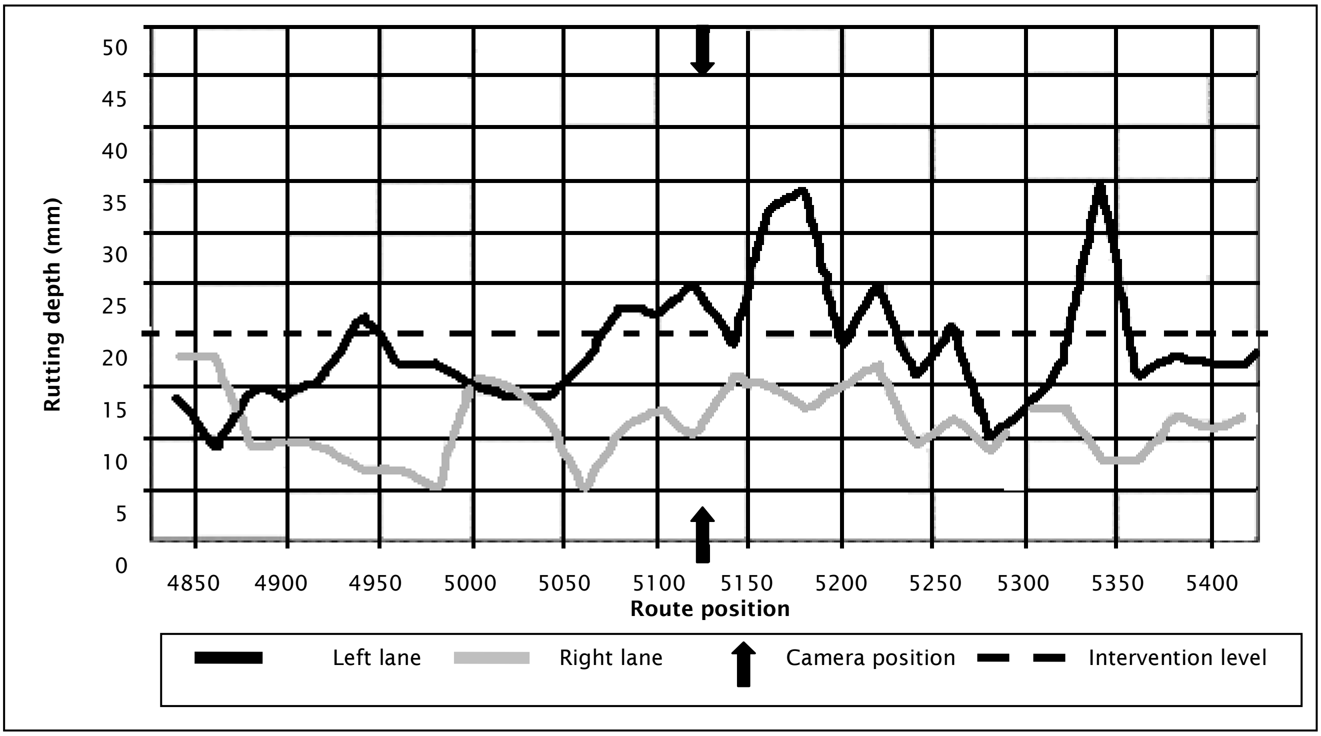
This first example is taken from a pavement proposed for rehabilitation that consisted of a chipseal over a granular basecourse. The site is 910m long and 11.4m wide.

The comments associated with the proposal suggested the following:

- The predominant problem is wheeltrack rutting.
- The existing pavement was constructed in 1940 with two shape corrections in 1977 and 1989. The section appears to have a weak subgrade as observed during the inspection. The option of recycling the pavement may be considered.
- The AADT is 7860.

The extent of the rutting can be seen in figure 3.1, where the majority of the length of the left lane has a rut depth greater than 15mm. The road has three lanes and the middle lane was not surveyed.

Figure 3.1 High-speed data rut measurements



Survey data collection date: 9 January 2009

The economic justification in terms of NPV is shown in table 3.1. In this example, a discount rate of 10% has been used. The estimated yearly routine maintenance costs for the do-minimum and the rehabilitation option (table 3.2) are similar. The do-minimum option has two major costs. The first is the maintenance required immediately and the second is the assumption that rehabilitation will be required in year 8.

The NPV resulting from the analysis is \$504,227 – \$486,967 = \$17,260.

The immediate maintenance requirement of \$185,362 was based on the need for extensive digouts. The engineer estimated 2782m^2 of digout repairs would be required to fix the rutting. This is equivalent to 26% of the total pavement area. If the estimate had been 2500m^2 (24% of the area) then the positive NPV would have been lost.

The sensitivity of the analysis can also be seen if the rehabilitation planned for year 8 was delayed until year 9; the NPV for the do-minimum would then have been \$483,650. This would again have resulted in a negative NPV of \$483,650 – 486,967 = –\$3317 and the rehabilitation would not have been justified.

Table 3.1 Do-minimum NPV calculation for example1

Year	SPPWF*	Major treatment		Maintenance	Sum	Present value
0	1			185,362	185,362	185,362
1	0.909	Reseal	73,255	1264	74,519	67,745
2	0.826			1359	1359	1123
3	0.751			1461	1461	1098
4	0.683			1570	1570	1072
5	0.621			1688	1688	1048
6	0.564			1815	1815	1025
7	0.513			1851	1851	950
8	0.467	Rehabilitation	418,600	2097	420,697	196,258
9	0.424	Reseal	73,255	910	74,165	31,453
10	0.386			978	978	377
11	0.350			1052	1052	369
12	0.319			1130	1130	360
13	0.290			1215	1215	352
14	0.263			1306	1306	344
15	0.239			1404	1404	336
16	0.218			1510	1510	329
17	0.198			1523	1523	301
18	0.180	Pre-reseal repairs	5900	1745	7644	1375
19	0.164	Reseal	73,255	910	74,165	12,127
20	0.149			978	978	145
21	0.135			1052	1052	142
22	0.123			1130	1130	139
23	0.112			1215	1215	136
24	0.102			1306	1306	133
25	0.092			1404	1404	130
TOTAL						**504,227**

* SPPWF = single payment present worth factor

Table 3.2 NPV calculation for the rehabilitation option for example 1

Year	SPPWF	Major treatment		Maintenance	Sum	Present value
0	1			1264	1264	1264
1	0.909	Rehabilitation	418,600	0	418,600	380,545
2	0.826	Reseal	73,255	910	74,165	61,293
3	0.751			978	978	735
4	0.683			1052	1052	719
5	0.621			1130	1130	702
6	0.564			1215	1215	686
7	0.513			1306	1306	670
8	0.467			1404	1404	655
9	0.424			1510	1510	640
10	0.386			1623	1623	626
11	0.350	Pre-reseal repairs	5000	1745	6745	2364
12	0.319	Reseal	73,255	910	74,165	23,631
13	0.290			978	978	283
14	0.263			1052	1052	277
15	0.239			1130	1130	271
16	0.218			1215	1215	264
17	0.198			1306	1306	258
18	0.180			1404	1404	253
19	0.164			1510	1510	247
20	0.149			1623	1623	241
21	0.135	Pre-reseal repairs	5000	1745	6745	911
22	0.123	Reseal	73,255	910	74,165	9111
23	0.112			978	978	109
24	0.102			1052	1052	107
25	0.092			1130	1130	104
TOTAL						**486,967**

3.2 Example 2

The second example is taken from another region of New Zealand.

The pavement is 230m long and 9.2 m wide with an AADT of 2350. The analysis was performed with an 8% discount rate. The pavement has a length of approximately 50m where rutting is deeper than 20mm.

The engineer's assessment included the following:

- The NPV calculation is based upon heavy maintenance prior to the initial resurfacing in year 1(1000m^2 or 20% of the total area) and medium maintenance (600m^2 or 12% of the total area) prior to resurfacing for years 7 and 14 for the do-minimum option.
- The option cost also allows for 800m^2 of pavement repairs prior to the completion of the option overlay for the site. This effectively balances out the heavy maintenance allowance in the option costs and reinforces the need for the selected treatment option.
- The do-minimum resurfacing cycle is driven by shortened seal lives caused by pavement faults, frost and ice control, polishing and drainage.
- The option cost also allows for drainage improvements in the option cost to a value of $64,900. This amount has also been allowed for in the associated works category.
- Existing historical maintenance costs have been used for the predicted model; these have also been reset following periodic resurfacing.
- The site is currently below SCRIM threshold level levels, with treatment needed next year as a priority.
- Associated guardrail works have also been allowed for in the safety retrofit programme for 2010/11 as a priority to complete all identified works in the same year – value $170,000.
- Resurfacing lives are affected by SCRIM, polishing and frost grit at this site; hence the design lives that are shorter than would normally be expected.

The calculation of the NPV is given in tables 3.3 and 3.4. It can be seen that the positive NPV has been obtained in this example through the extensive preseal repairs required before each seal compared with no preseal repairs assumed for resealing in the rehabilitation option. The do-minimum also assumed an increasing pavement maintenance cost that will be significantly greater than the rehabilitation option.

The increasing pavement maintenance cost has been obtained through extrapolating linearly from the maintenance cost history and adding a 10% annual increase for expected cost increases. The data used is shown in figure 3.2, where it can be seen that the maintenance performed in 2006 has resulted in a step in the total maintenance costs and this has resulted in a significant change in slope.

The original proposal obtained a do-minimum present value of $256,091, with the rehabilitation option of $234,976, giving a positive NPV of $21,115. If the compounding increase in pavement maintenance costs was set to zero from 10% (the cost of resealing was not assumed to increase) then the result would have been an NPV of –$5,077.

The extensive heavy preseal repairs, totalling $78,000 in years 1 and 16, represent repairs to over 50% of the area. These appear excessive and have a significant impact on obtaining a positive NPV.

Although the analysis included surface and shoulder maintenance costs, these are relatively small and do not have a significant effect on the result.

Figure 3.2 Cumulative pavement maintenance costs for example 2

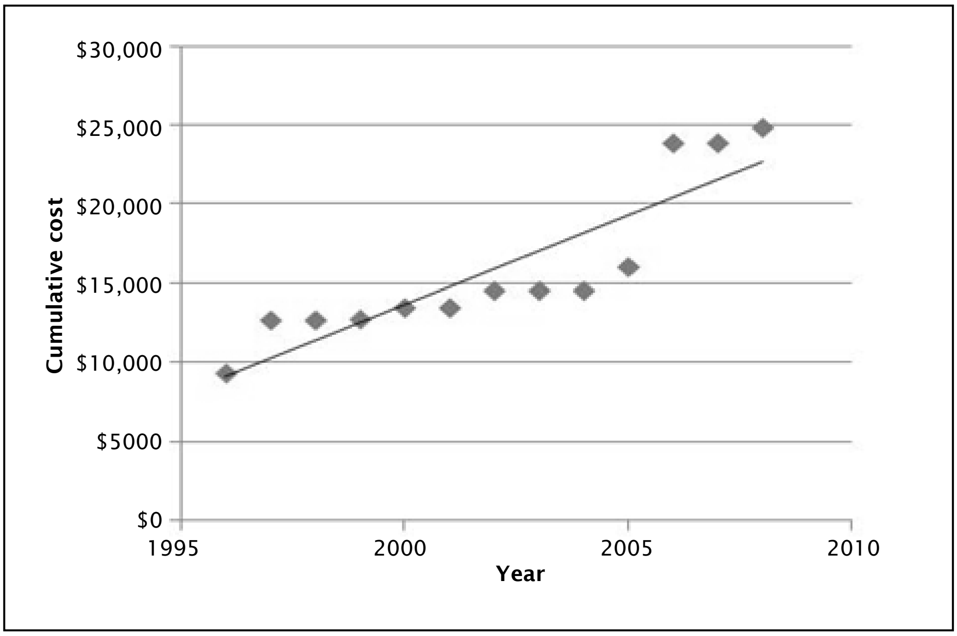


Table 3.3 NPV calculation for the do-minimum option for example 2

Year	SPPWF	Major treatment		Pavement maintenance	Surface maintenance	Shoulder maintenance	Sum	Present value
0	1.000			1346	32	14	1392	1392
1	0.926	Pre-reseal repairs	78,000	1481	69	16	79,566	73,672
2	0.857	Reseal	21,160	1629	114	17	22,920	19,650
3	0.794			1792	166	19	1978	1570
4	0.735			1971	69	21	2061	1515
5	0.681			2168	114	23	2305	1569
6	0.630	Pre-reseal repairs	52,000	2385	166	25	54,577	34,393
7	0.583	Reseal	21,160	2624	229	28	24,040	14,027
8	0.540			2886	302	31	3218	1739
9	0.500			3175	387	34	3595	1799
10	0.463			3492	486	37	4016	1860
11	0.429	Pre-reseal repairs	52,000	3842	69	41	55,951	23,997
12	0.397	Reseal	21,160	4226	114	45	25,544	10,144
13	0.368			4648	166	49	4864	1788
14	0.340			5113	229	54	5396	1837
15	0.315			5625	302	60	5986	1887
16	0.292	Pre-reseal repairs	78,000	6187	387	66	84,639	24,705
17	0.270	Reseal	21,160	6806	486	72	28,524	7709
18	0.250			7486	602	79	8167	2044
19	0.232			8235	69	87	8391	1944
20	0.215			9058	114	96	9268	1988
21	0.199	Pre-reseal repairs	52,000	9964	166	106	62,236	12,364
22	0.184	Reseal	21,160	10,961	229	116	32,465	5972
23	0.170			12,057	302	128	12,364	2127
24	0.158			13,262	387	141	13,790	2175
25	0.146			14,589	486	155	15,230	2224
Total								**256,091**

Table 3.4 NPV calculation for the rehabilitation option for example 2

Year	SPPWF	Major treatment		Pavement maintenance	Surface maintenance	Shoulder maintenance	Sum	Present value
0	1.000			1346	34	23	1404	1404
1	0.926	Rehabilitation	207,368	230	69	25	207,692	192,308
2	0.857			372	114	28	513	440,
3	0.794	Reseal	21,160	230	69	25	21,482	17,053
4	0.735			372	114	25	511	376
5	0.681			540	166	28	734	500
6	0.630			738	229	31	997	629
7	0.583			971	302	34	1306	762
8	0.540			1242	387	37	1666	900
9	0.500			1558	486	41	2085	1043
10	0.463			1925	602	45	2571	1191
11	0.429	Reseal	21,160	230	69	23	21,482	9213
12	0.397			372	114	28	513	204
13	0.368			540	166	31	737	271
14	0.340			738	229	34	1001	341
15	0.315			971	302	37	1309	413
16	0.292			1242	387	41	1670	487
17	0.270			1558	486	45	2089	565
18	0.250			1925	602	49	2575	645
19	0.232	Reseal	21,160	230	69	141	21,600	5005
20	0.215			372	114	25	511	110
21	0.199			540	166	28	734	146
22	0.184			738	229	31	997	183
23	0.170			971	302	34	1306	222
24	0.158			1242	387	37	1666	263
25	0.146			1558	486	41	2085	304
Total								234,976

3.3 Example 3

The third example is taken from yet another region. The site is 650m long and 8.5m wide.

The engineer’s report explained that the site has had an extensive repair history dating back to 1997. Almost 1000m^2 of structural repairs have been carried out on this section within the past five years. The site was last sealed with a grade 3 chip. The first 1200m was last sealed in January 1994, with the remaining length being sealed in February 2001. Available records indicate that the pavement was last reconstructed between 1979 and 1981. The site featured in the 2007/08 high-speed data survey, with 14 ten-metre sections identified as having SCRIM deficiencies. Six of these 10m sections were identified as priority A.

A detailed inspection of the site has identified a number of repairs that require urgent attention (around 1600m^2). The do-minimum is to treat pavement failures and reseal the entire site as conditions permit. Because of the size and quantity of the repairs that are required immediately, a waterproofing seal was provided for. As the pavement ages, repairs are also expected to appear at an increasing rate.

If the do-minimum is to continue with a cycle of resealing and heavy maintenance, the reseal frequency and the number of repairs can be expected to increase with time, and the surface may then start to become more and more unstable, with frequent water cutting required to remove excess bitumen.

The option in this case is to construct a granular overlay over the entire site to restore strength back into the pavement.

The NPV calculations are summarised in tables 3.5 and 3.6. These show, using the engineer's assumptions, that the NPV is $52,469. The significant difference in the reseal cost is because the do-minimum option assumes that the binder used is a polymer-modified emulsion rather than the normal bitumen used in the rehabilitation option. Using normal bitumen reduces the NPV to $30,000 from $52,469.

It has also been assumed that no extra pre-reseal repairs will be required in the rehabilitation option compared with nearly $12,000 in the do-minimum option

The routine maintenance cost assumptions are illustrated in figure 3.3. It has been assumed that the do-minimum option will result in $6,000/year more to maintain than the rehabilitation option. If the assumed maintenance cost were $1000/year more for the do-minimum rather than $6000/year more, then the NPV would have been –$904, ie negative.

Figure 3.3 Maintenance cost assumption

Table 3.5 Do-nothing NPV calculation for example 3

Year	SPPWF	Major treatment		Pavement maintenance	Sum	Present value
0	1.000				0	0
1	0.909		23,437	6283	29,720	27,519
2	0.826	Reseal	47,515	6787	54,302	46,555
3	0.751			7292	7292	5789
4	0.683			7796	7796	5730
5	0.621			8301	8301	5650
6	0.564			8805	8805	5549
7	0.513	Pre-reseal repairs	11,718	9310	21,028	12,270
8	0.467	Reseal	42,376	9814	52,190	28,197
9	0.424			10,319	10,319	5162
10	0.386			10,823	10,823	5013
11	0.350			11,328	11,328	4558
12	0.319			11,832	11,832	4699
13	0.290			12,337	12,337	4536
14	0.263	Pre-reseal repairs	11,718	12,841	24,559	8361
15	0.239	Reseal	47,515	13,346	60,861	19,186
16	0.218			13,850	13,850	4043
17	0.198			14,355	14,355	3880
18	0.180			14,860	14,860	3719
19	0.164			15,364	15,364	3560
20	0.149			15,868	15,868	3404
21	0.135	Pre-reseal repairs	11,718	16,373	28,091	5580
22	0.123	Reseal	42,376	16,878	59,254	10,899
23	0.112			17,382	17,382	2960
24	0.102			17,887	17,887	2821
25	0.092			18,391	18,391	2685
Total				308,422		232,625

Table 3.6 NPV calculation for the rehabilitation option for example 3

Year	SPPWF	Major treatment		Pavement maintenance	Sum	Present value
0	1.000				0	0
1	0.909	Rehabilitation	114,920	0	114,920	106,407
2	0.826			734	734	629
3	0.751			1238	1238	983
4	0.683	Reseal	23,426	1743	25,169	18,500
5	0.621			2247	2247	1529
6	0.564			2752	2752	1734
7	0.513			3256	3256	1900
8	0.467			3759	3759	2031
9	0.424			4264	4264	2133
10	0.386			4769	4769	2209
11	0.350			5274	5274	2262
12	0.319			5779	5779	2295
13	0.290			6282	6282	2310
14	0.263			6753	6753	2299
15	0.239			7220	7220	2276
16	0.218	Reseal	20,442	7684	28,126	8210
17	0.198			8155	8155	2204
18	0.180			8619	8619	2157
19	0.164			9089	9089	2106
20	0.149			9555	9555	2050
21	0.135			10,022	10, 022	1991
22	0.123			10,487	10,487	1929
23	0.112			10,956	10,956	1866
24	0.102	Reseal	29,227	11,420	40,647	6410
25	0.092			11,889	11,889	1736
Total				**153,947**		**180,156**

3.4 Discussion

These examples of rehabilitation justification are typical of those prepared throughout New Zealand, although example 1, which is related to extensive rutting, is relatively uncommon. The significant area of repairs and the immediate maintenance costs are a common feature.

The main assumptions that are used in the justification are:

- deferred maintenance – the level of maintenance activity that is needed immediately
- expected seal lives
- seal type (use of polymers)
- pre-reseal repair costs
- estimation of future maintenance costs (either straight line or exponential)
- Cost increase (%).

All these give the engineer a lot of scope to develop a positive NPV.

4 Inspections

4.1 Introduction

The analysis given in the previous chapter suggests that for a pavement to be rehabilitated, the area of repairs that would be required for the do-minimum option would be relatively significant. However, the research performed by Gribble et al (2008) did not find a robust relationship between the RAMM pavement distress and the rehabilitation decision.

Areas that had been identified for rehabilitation in four networks were investigated to determine if other factors not recorded by RAMM were prompting the engineer to consider that rehabilitation was the most appropriate treatment. In each region, discussions were held with the network maintenance engineer.

4.2 Region A

4.2.1 Site A1

Site A1 (route position (RP) 4880–5790) is located in a rural environment with an approximate AADT of 5000 vehicles per day (vpd). The pavement was constructed in 1951 and the area immediately preceding it was shape-corrected in 1994.

The most signification pavement failure in this section was significant rutting in the true right-hand outer wheeltrack. Approximately 80% of this length was rutted, with isolated areas of shoving. The majority of this section had been identified for digout by the assessor. The remainder of the pavement was covered with a large number of old repairs, with varying age and condition, some of which were flushed. Small areas of rutting were visible, but none of these was significant. The majority of these areas had been identified for ripping and remaking by the assessor.

The site also had high shoulders for the majority of both sides. The ride quality through this section was very poor.

In discussions with the route manager on site, one possible reason for the increased rutting in one lane at this site was the number of loaded milk tankers heading to the local Fonterra plant.

4.2.2 Site A2

Site 2 is located in a rural environment with an approximate AADT of 9000vpd. The road was constructed in 1959 and had a 70mm overlay in 1998. This site had a small amount of rutting, with no shoving, and a minimal amount of flushing. The site had a small number of relatively old looking patch repairs; however, these where generally in good condition (figures 4.1 and 4.2). The shoulders and drainage were good and the ride quality through the site was very good. This site did not appear to require an area-wide treatment.

It was commented by the area manager that (probably because of the way the subgrades in the area perform) that pavements on the network do not typically deteriorate linearly over time but instead last up to a certain point then fail quite quickly. The manager also commented that certain areas seemed to continue to fail regardless of the type of repair carried out on them.

Figure 4.1 View of site 2, showing evidence of flushing and other areas of poor condition

Figure 4.2 Alternate view of site 2, facing the opposite direction

4.3 Region B

4.3.1 Overview

From discussions with the engineer, the following points were noted:

- The region has significant rutting and roughness issues. The network also has separate (significant) issues with subsidence, which were evident throughout the routes inspected, and probably contributed to the roughness counts for the region.
- Some locations have major issues with unstable subgrades, and high water tables or swampy soil conditions.
- A lot of surface scabbing could be seen throughout all of the routes inspected.
- The level of maintenance repairs seemed to be poor. A number of sites had inappropriate repairs (a lot of cold mix and repairs on repairs seem to have been used). This would contribute to high maintenance costs.

- It was noticeable that the state of repairs and the condition that the highways were in – which were identified for area-wide treatment in this region – were significantly worse than what was observed in other regions.

Discussions were held with the engineer on whether subsidence contributed to area wide-site selection and it was decided that it did not. Maintenance/repair of subsidence sites is typically reactionary (ie subsidence occurs gradually over time), so it is desirable to repair pavements once failure is competed rather than on an ongoing basis. Unless the site is repaired, it will just slip further and need to be repaired once more, though some proactive stabilisation was being undertaken through piling. For this reason, in general, no direct correlation could be found between subsidence sites and sites identified for area-wide treatment (ie there was no overlap of subsidence and area-wide pavement treatment (AWPT) sites on the FWP).

Site inspections details are given in the subsections below.

4.3.2 Site B1

Site B1 had a six-year-old seal. The main issues identified at this site were:

- edge break (minor)
- flushing (moderate)
- patchwork repairs (moderate)
- rutting (significant overall and in both lanes) with some shoving
- scabbing/chip loss
- minor cracking
- SCRIM/polishing (minor)
- failed repairs
- noticeable roughness issues.

Figure 4.3 View of site B1, showing patchwork repairs and flushing

24/06/2009

Figure 4.4 View of site B1, showing an extended area of flushing

4.3.3 Site B2

Site B2 (RP 8680–8860) had a one-year-old seal. The main issues identified at this site were:

- rutting (minor)
- shape loss (minor)
- patchwork repairs (minor, isolated)
- scabbing/chip loss (minor)
- cracking (minor).

Figure 4.5 View of site B2, showing chip loss at the edge of the pavement

Figure 4.6 View of site B2, showing a close-up view of scabbing/chip loss

4.3.4 Site B3

Site B3, which is a historic subsidence site, had a seal that was less than a year old. The main issues identified at this site were:

- shoving
- rutting (minor, both lanes)
- shape loss (severe on curve on negative grade)
- patchwork repairs (minor, isolated)
- scabbing/chip loss (minor)
- cracking (minor).

Figure 4.7 View of site B3, showing rutting

Figure 4.8 Alternate view of site B3

24/06/2009

4.3.5 Site B4

Site B4 appears to be an old piece of road which has drainage and subgrade issues. It was noticeable that the existing repairs were in poor condition. The main issues identified at this site were:

- potholing
- flushing
- failing repairs
- patchwork repairs
- scabbing (chip loss)
- rutting.

Figure 4.9 View of site B4, showing extensive flushing

24/06/2009

Figure 4.10 View of site B4, showing an example of patchwork repairs

4.3.6 Site B5

Site B5 also appears to be an old piece of road which has drainage (high shoulders) and subgrade issues, and the existing repairs were in poor condition. The main issues identified at this site were:

- flushing (a lot through old repairs)
- patchwork repairs (isolated but large)
- scabbing (chip loss)
- rutting (quite large) plus shoving
- shape loss (severe)
- potholing (a number of blowouts).

Figure 4.11 View of site B5, showing flushing and shape loss

Figure 4.12 Alternate view of site B5, showing flushing and patchwork repairs

4.3.7 Site B6

Site B6 (RP 3300–4370) had a five-year-old seal. The main issues identified at this site were:

- flushing (significant)
- patchwork repairs, which looked like a combination seal to fix a history of rutting
- cracking
- rutting
- shape loss (moderate).

It was noticeable that a small chip was used to fill previous ruts, leading to the suggestion that this may have contributed to some of the cracking. The pavement looked generally tired and possibly had subgrade/drainage issues.

Figure 4.13 View of site B6, showing overall condition.

Figure 4.14 Alternative view of site B6, showing flushing

4.3.8 Site B7

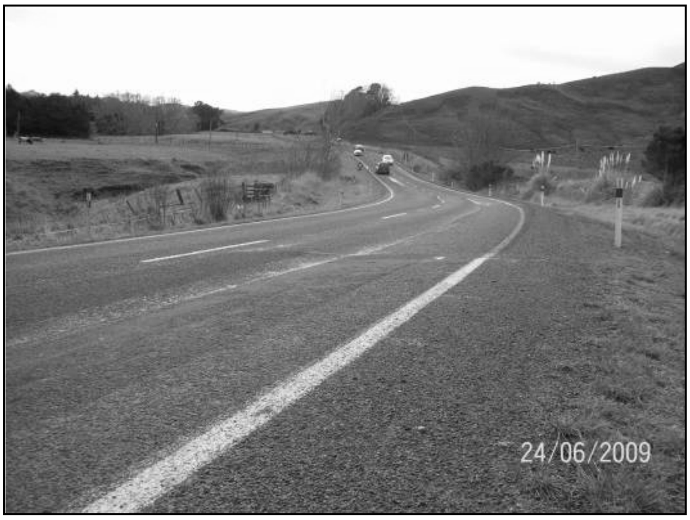
Quite a large amount of backlog repairs seemed to be required on this (and other) sites prior to undertaking an area-wide treatment. The site also seemed to have little or no roadside drainage (it had some longitudinal grade, but had high shoulders and was through a cutting with no table drains).

The main issues identified at this site were:

- flushing, which was significant, al though it appeared that some water-blasting had taken place recently
- quite a number of patchwork repairs, some of which were failing, with fines pumping up through the seal
- scabbing, with quite a lot of chip loss
- significant rutting with some shoving
- significant shape loss (mostly on curve)
- noticeable roughness issues.

Figure 4.15 View of site B7, showing a failed patchwork repair

Figure 4.16 View of site B7, showing extensive rutting



4.3.9 Site B8

The main issues at site B6 were:

- flushing
- existing failing repairs, which were particularly significant, with repairs on repairs
- scabbing, with the seal also lifting off in places
- significant rutting with some shoving
- cracking
- noticeable roughness issues.

Figure 4.17 View of site B8, showing flushing and patchwork repairs

Figure 4.18 View of site B8, showing a range of problems contributing to pavement roughness

4.3.10 Site B9

Site B9 had a five-year-old seal. The subgrade was probably better in this area than other sites in this region, as the road was located close to the coast and the subgrade may be sand. The main issues identified at this site were:

- flushing (recent water blasting had also taken place)
- scabbing (significant)
- rutting (isolated) with some minor shoving
- some shape loss (minor, mostly at curve)
- cracking
- existing patch repairs, which were holding up well.

Figure 4.19 View of site B9, showing scabbing

Figure 4.20 View of site B9, showing scabbing

4.3.11 Site B10

This site had a two-year-old seal. The main issues identified at this site were:

- flushing (minor)
- rutting (isolated and minor)
- cracking.

Figure 4.21 View of site B10, showing an area of flushing

Figure 4.22 View of site B10, showing flushing

4.4 Region C

4.4.1 Overview

From discussions with the engineer, the following issues were noted:

- The region has significant flushing issues (they have an annual water-blasting programme costing over $1 million).This relates to problems with old seal layers where the existing seal layer could be 50–60mm thick. This is something that has built up over time and is probably compounded by the high application rates used at the time of construction. Flushing features on the majority of the sites that were inspected.
- The network has a SCRIM issue, namely problems with the polished stone values (PSVs) of their wearing course chip. This means that quite a bit of scabbing is undertaken each year, though it was noted that a new material had been trialled in recent years which achieves higher PSVs.
- Regarding the geology, the typical pavements in the region are formed on silty subgrades which can result in stability problems, particularly in cases where drainage may be an issue.
- Some sites are restricted in the type of remedial measures that can be used. For example, surfacing cannot be water-blasted to treat flushing at some locations, as the seal would literally fall apart.
- The penultimate reseal on a site (ie the last reseal prior to going to fully recycling or overlaying of the pavement) will typically last four years. This is usually the case if the site has underlying seal issues.
- Drainage problems are apparent at some sites where subsoil drains cannot be installed because of restrictions created by topography and/or existing services in berms (this comment may have related to one or two particular sites rather than something that was a general issue for the area).

The sites visited were those on the FWP for the coming year and also some potential sites that were scheduled for the following three years. These are described in the next subsections.

4.4.2 Site C1

The main issues encountered at this site were:

- flushing
- patchwork repairs
- scabbing (chip loss)
- a number of repairs on repairs
- some loss of shape
- minor cracking.

Figure 4.23 View of site C1, showing patchwork repairs and flushing

Figure 4.24 View of site C1, showing minor flushing

4.4.3 Site C2

The main issues identified at this site were:

- edge break/shear failure
- patchwork repairs (quite a few in places)
- some scabbing (relatively minor)
- some loss of shape and rutting
- flushing (significant in places).

Figure 4.25 View of site C2, showing patchwork repairs and flushing

Figure 4.26 View of site C2, showing more patchwork repairs and extensive flushing

4.4.4 Site C3

The main issues noted at this site were:

- significant shape loss
- significant wheeltrack rutting
- a number of patchwork repairs
- some relatively minor cracking
- significant flushing.

The engineer suggested that this location possibly had drainage issues – note the high shoulders visible in figures 4.27 and 4.28.

Figure 4.27 View of site C3, showing flushing and the high road shoulders

Figure 4.28 View of site C3, showing the high shoulders and an area of extensive flushing

4.4.5 Site C4

This site had a two-year-old seal. The main issues identified at this site were:

- some (isolated) patchwork repairs
- flushing
- scabbing.

Figure 4.29 View of site C4, showing areas of flushing

4.4.6 Site C5

This site had an 18-month-old seal. The main issues encountered at this site were:

- rutting
- shape loss
- scabbing/chip loss.

The engineer noted that prior to the last seal, severe flushing had occurred in the wheeltracks at this site.

Figure 4.30 View of site C5, showing the reasonable condition of the pavement

Figure 4.31 View of site C5, showing patchwork repairs and flushing

4.4.7 Site C6

This site had a three-year-old seal. The main issues at this site were:

- significant flushing
- some cracking
- some scabbing/chip loss.

Figure 4.32 View of site C6, showing an area of considerable flushing

Figure 4.33 View of site C6, showing more flushing

4.4.8 Site C7

Part of the seal at this site was two years old, while the remainder was between two and seven years old. The main issues identified at this site were:

- significant flushing, mainly through the centreline
- rutting (minor)
- shape loss (minor)
- existing repairs because of trenching.

Figure 4.34 View of site C7, showing an area of good pavement condition

Figure 4.35 View of site C7, showing shape loss and flushing

4.4.9 Site C8

This site had a two-year-old seal. The main issues found at this site were:

- significant flushing
- scabbing/chip loss
- significant wheeltrack rutting
- some shape loss
- potholing
- cracking
- SCRIM issues (polishing)
- patchwork repairs
- shear failures.

According to the engineer, this site was missed and should have been on the programme for this year.

Figure 4.36 View of site C8, showing flushing

Figure 4.37 View of site C8, showing chip loss and flushing

4.4.10 Site C10

The main issues at this site were:

- flushing (not extreme but consistent throughout the site)
- shape loss (isolated; on curve)
- wheeltrack rutting in isolated locations
- potholing
- cracking.

The majority of failures for this site appear on a curve.

Figure 4.38 View of site C10, showing several areas of flushing

Figure 4.39 View of site C10, showing another area of flushing

4.4.11 Site C11

At this site, the road is largely curvilinear and on a grade, and the traffic mix includes a high percentage of heavy vehicles. This site was lined with trees and historically required only moderate maintenance. The trees were then removed. Almost immediately, the surfacing started to bleed significantly, leading to hot chipping at least once per year then ultimately the decision to treat by AWPT. The main issues identified at this site were:

- significant flushing on the full width of the road
- some patchwork repairs
- Isolated wheeltrack rutting
- scabbing caused by trucks lifting chip.

Figure 4.40 View of site C11, showing flushing on the full width of the road

Figure 4.41 View of site C11, showing patchwork repairs and wide flushing on a curve

4.4.12 Site C12

This site has been treated by hot chipping for the last two summers as the seal is lifting off with heavy vehicles trafficking a steep gradient on an unstable seal. Other maintenance treatments for the site include scabbing (to achieve SCRIM) and water blasting. The main issues identified at this site are:

- significant flushing
- scabbing/chip loss
- some loss of shape and rutting

No photos are available for this site.

4.4.13 Site C13

This site had a two-year-old seal. For the last 15 years, this site has had the lowest routine repair costs compared to other sites in this region. The main issues identified at this site were:

- rutting in the inside and outside wheeltracks
- significant flushing
- cracking
- shape loss
- isolated potholing/failed repairs.

Figure 4.42 View of site C13, showing shape loss at the edge of the seal

Figure 4.43 View of site C13, showing extensive flushing and potholing

4.4.14 Site C15

This site had a five-year-old seal. It did not seem particularly bad, with the exception of some flushing issues. Otherwise, the main issues identified at this site were:

- rutting (minimal)
- flushing
- some SCRIM issues from flushing and polishing
- shape loss (minimal).

Figure 4.44 View of site C15, showing some of the flushing


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Figure 4.45 View of site C15, showing the general condition of the pavement


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4.4.15 Site C16

This site had a two-year-old seal. This site has problems with drainage and is also two years into what will probably be the last reseal before an AWPT is undertaken (ie it will hold up for another two years before failing completely (see section 4.4.1). The main issues at this site were:

- rutting (minimal but evident)
- moderate flushing
- some patchwork repairs.

Figure 4.46 View of site C16, showing flushing

Figure 4.47 View of site C16, showing patchwork repairs and flushing

4.4.16 Site C17

This site had a three-year-old seal. The main issues identified at this site were:

- moderate rutting and shoving
- moderate flushing
- patchwork repairs (isolated)
- shape loss (minor).

Figure 4.48 View of site C17, showing general condition


23/06/2009

Figure 4.49 View of site C17, showing patchwork repairs


23/06/2009

4.4.17 Site C18

The main issue on this site seems to involve drainage. Water is possibly migrating into sublayers on the high side of curve as a result of:

- slips
- papa[1] blocking drains
- water being held in table drain and unable to escape.

Apparently, water pumps up through the seal on this site even during summer. A sandwich seal was put down two years ago; the site had significant issues with flushing prior to this. The main issues identified at this site were:

- moderate flushing
- isolated patchwork repairs
- shape loss (significant in places).

Figure 4.50 View of site C18, showing the extensive flushing evident at this site

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[1] Papa is a common name for a type of soil/rock of the mudstone or sandstone type that is common in the central North Island (Nathan 2009).

Figure 4.51 View of site C18, showing shape loss and patchwork repairs

4.5 Region D

4.5.1 Site D1

This site had a 45-year-old pavement. The last reseal was an 8.5m wide single-coat seal in 1999. This site is incurring increasing maintenance costs and further maintenance is not likely to be economic. The main issues identified at this site were:

- increasing maintenance
- flushing
- pavement failures in the form of shear failures and rutting.

Figure 4.52 View of site D1, showing patchwork repairsand flushing

Figure 4.53 View of site D1, showing another area of patchwork repairs

4.5.2 Site D2

This site had a 47-year-old pavement. The last reseal was a 8.5m wide two-coat seal in 2001. This site has also been incurring increasing maintenance costs, and further maintenance is not likely to be economic. The main issues noticed at this site were:

- increasing maintenance
- pavement failures in the form of shear failures and rutting, flushing and potholes.

Figure 4.54 Close-up view of site D2, showing the depth of the rutting

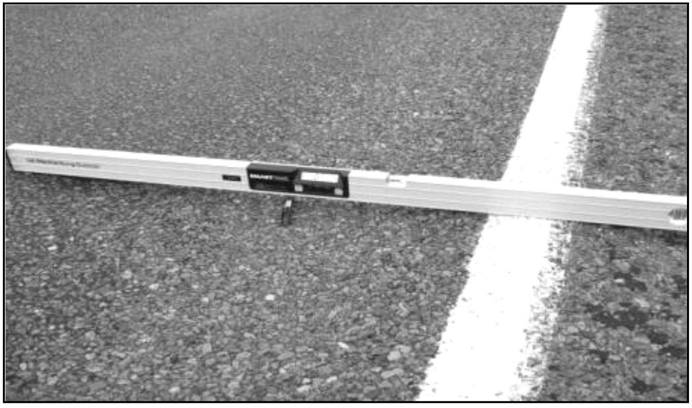


Figure 4.55 View of site D2, showing flushing and patchwork repairs

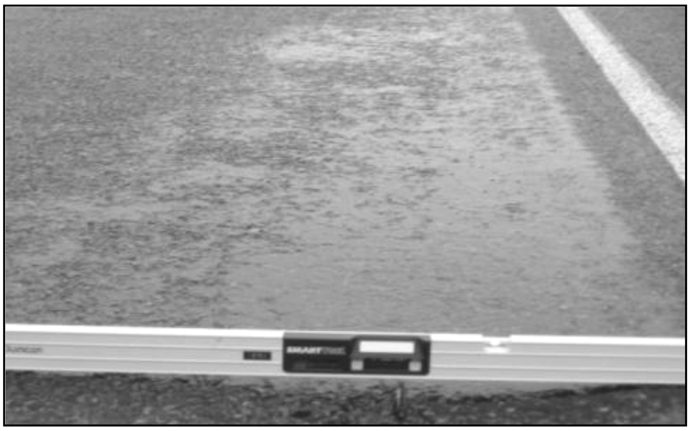
4.5.3 Site D3

This site had a 47-year-old pavement. The last reseal was a 10m wide single-coat seal in 2006. Like sites D1 and D2, this site was incurring increasing maintenance costs and further maintenance is not considered economic. The main issues at this site were:

- increasing maintenance
- increasing pavement failures from rutting, shoving and potholes.

Figure 4.56 View of site D3, showing potholes

Figure 4.57 Close-up view of site D3, showing the depth of the rutting



4.5.4 Site D4

This site had an 18-year-old pavement and the last reseal was a 7.5m wide single-coat seal in 2001. The main issues identified at this site were:

- increasing maintenance (further maintenance is not considered economic because of increasing maintenance costs)
- surface flushing causing in lower values for texture and skid resistance
- increasing pavement failures caused by rutting.

Figure 4.58 View of site D4, showing the depth of the rutting

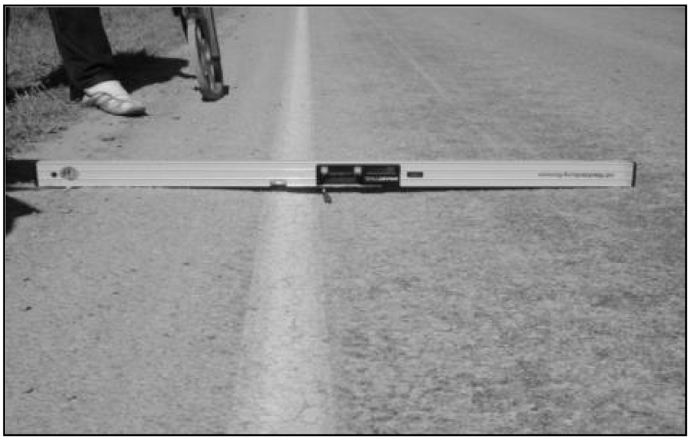


Figure 4.59 View of site D4, showing the overall poor condition of the pavement surface

4.5.5 Site D5

This site had a nine-year-old pavement. The last reseal was an 8.0m wide two-coat seal in 2002. Increasing maintenance costs mean that further maintenance is not economically justifiable. The main issues encountered at this site were:

- a history of pavement failures, including horizontal shear failures
- extensive flushing and rutting.

Figure 4.60 Close-up view of site D5, showing the depth of the rutting

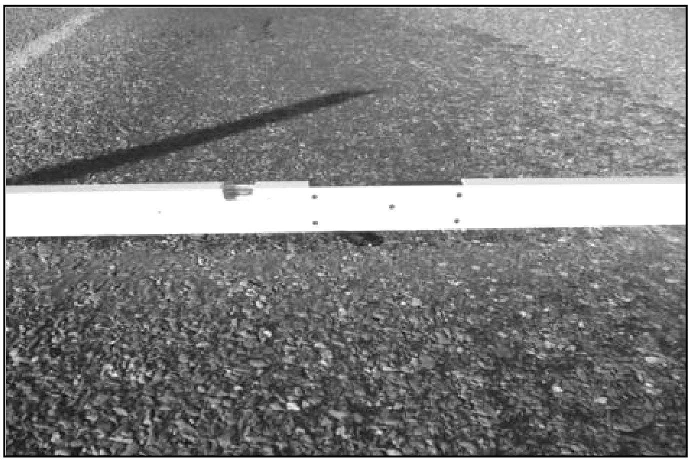


Figure 4.61 View of site D5, showing extensive flushing and rutting

4.5.6 Site D6

The last reseal at this site was a 7.5cm wide single-coat seal in 1997. This site also faces issues with the increasing cost of further maintenance, similar to the other sites in this region. The main issues found at this site were:

- increasing levels of pavement maintenance in the form of flushing, rutting and shear failures
- repairs failing and being expected to increase.

Figure 4.62 Close-up view of site D6, showing flushing and the depth of the rutting

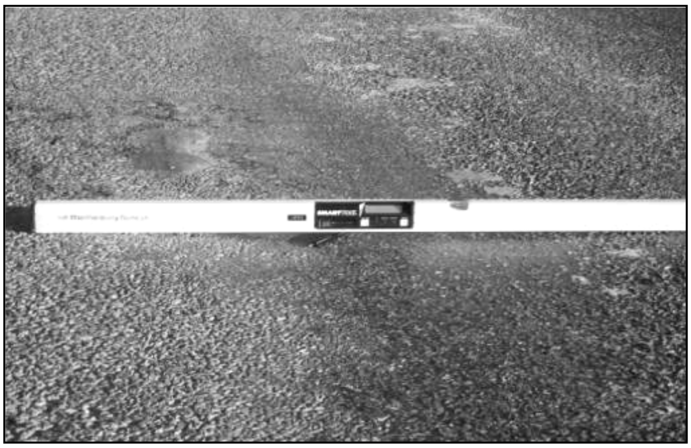


Figure 4.63 Second close-up view of site D6, showing flushing

4.5.7 Site D7

This site had a 41-year-old pavement. The last reseal was a 8.5cm wide single-coat seal in 2003. This site also faced issues of increasing maintenance costs and further maintenance not being economic. The main issues at this site were:

- increasing levels of pavement maintenance in the form of rutting and shear failures
- flushing evident in the wheelpaths.

Figure 4.64 View of site D7, showing flushing in the wheelpaths

Figure 4.65 View of site D7, showing more detail of the flushing

4.5.8 Site D8

This site had a 52-year-old pavement. The last reseal was a 6.5cm wide single-coat seal in 2003. Increasing maintenance meant that for this site, like the others in this region, further maintenance was not economic. The main issues identified at this site were:

- increasing maintenance
- pavement failures in the form of rutting and flushing.

Figure 4.66 View of site D8, showing flushing and pavement repair

Figure 4.67 View of site D8, showing the depth of the rutting

4.5.9 Site D9

This site had a 43–year-old pavement. The last reseal was an 8.2cm wide single-coat seal in 2003. The main issues encountered at this site were:

- increasing maintenance and associated costs – further maintenance is not economic
- repair failures
- increased wheeltrack rutting and flushing.

Figure 4.68 Close-up view of site D9, showing the depth of the rutting in the wheeltracks

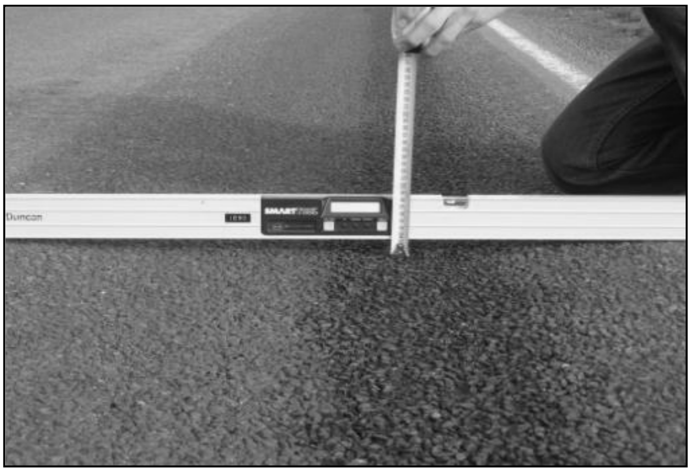


Figure 4.69 View of site D9, showing the overall poor condition of the pavement

4.5.10 Site D10

The last reseal at this site was an 8.5cm wide single-coat seal in 2005. The main issues identified at this site were:

- increasing maintenance and associated costs (further maintenance is not economic)
- repair failures
- increased wheeltrack rutting and flushing.

Figure 4.70 View of site D10, showing extensive flushing in the wheeltracks

Figure 4.71 View of site D10, showing the depth of the rutting

4.5.11 Site D11

This site had a 43-year-old pavement. The last reseal was an 8.5cm wide two-coat seal in 2004.

The main issues at this site are:

- increasing maintenance and associated costs
- repair failures
- wheeltrack rutting and flushing.

Figure 4.72 View of site D11, showing repair failures and flushing

Figure 4.73 Alternative view of site D11, showing the depth of rutting

5 Inspection length

5.1 Qualities of maintenance

The area of the sections that required maintenance for the do-minimum option for the three examples given in chapter 3 is given in table 5.1.

Table 5.1 Immediate maintenance requirements for the three examples

	Total area (m^2)	Repair area (m^2)	%
Example 1	10,700	2782	26
Example 2	2116	1200	57
Example 3	5525	1600	29

The areas needing repair appear to be very high and are significantly greater than would be expected. For example, in the RAMM treatment selection algorithm, the trigger for immediate resealing is for cracking to exceed 3% of the area. This implies that when the area of distress is of the order of 5% then treatment is required. In order to give a visual appreciation of the area of distress, figures 5.1 and 5.2 show the area of distress (in black) for two cases where the area of distress is 10% and 20%. Each black square represents 1m^2 on a road that is 8m wide and 50m long. For the examples 1, 2 and 3 in chapter 3, it would be expected that that the distress would be more evident than what is depicted in figure 5.2.

Figure 5.1 Illustration of distress of 10% of pavement area

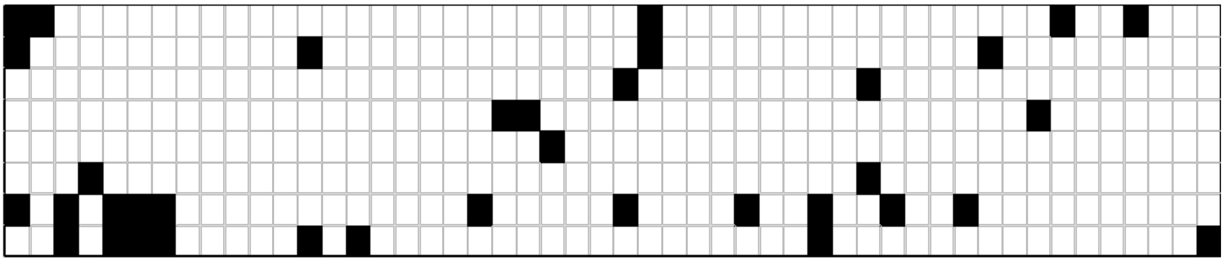
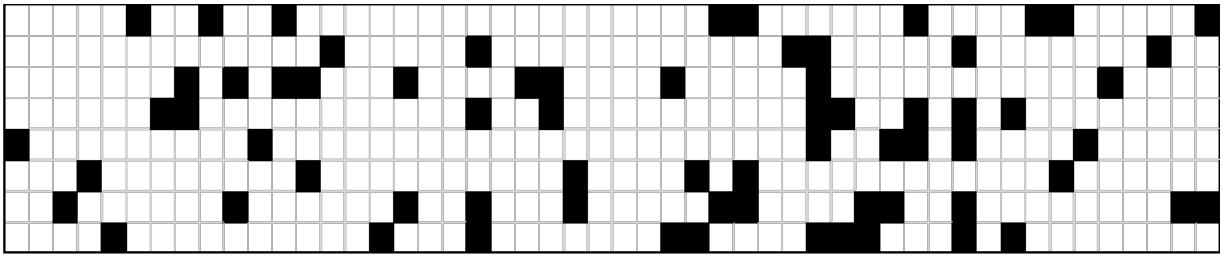


Figure 5.2 Illustration of distress of 20% of pavement area



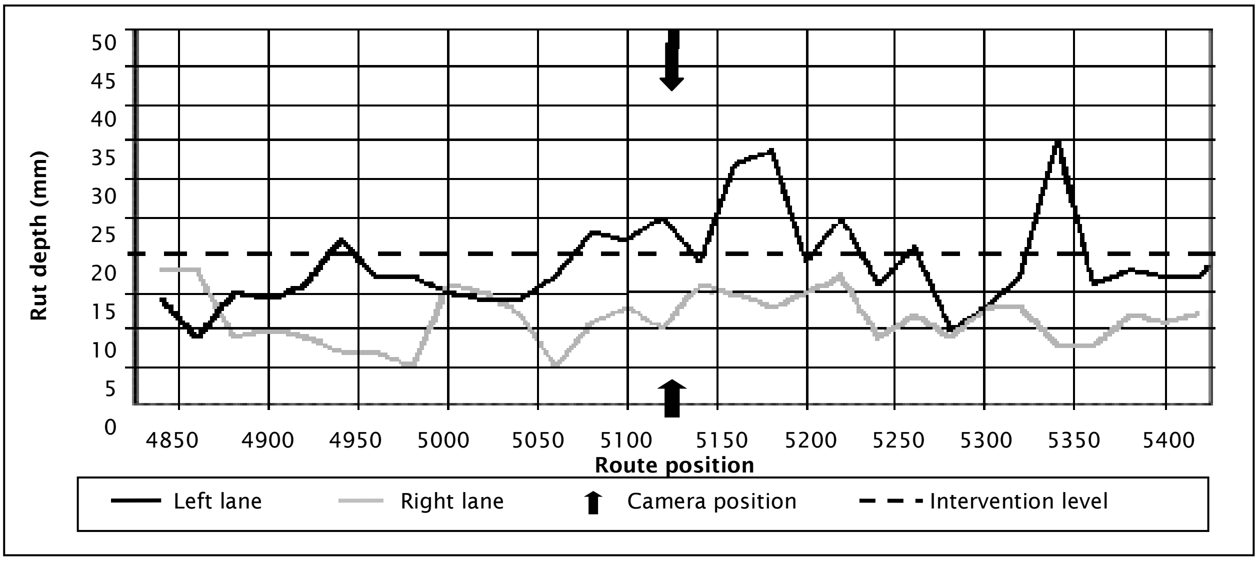
As this extent of distress was not evident in the research performed by Gribble et al (2008), it was considered that the inspection length used to rank the section may not be representative. A number of sites throughout the regions were inspected using the high-speed data video, and the inspection length condition was then compared with the rest of the section.

In the following examples, the arrow in the rutting plot is the position of the inspection length. The rutting data in the graphs is the maximum rut depth in each 20m section. The rut depth in the modelling was the average of the 20m sections. For each site, the average and 95th percentile value (95%) of the 20m sections has been included. From the video, a decision has been made on the representative nature of the inspection length.

5.2 Region A

5.2.1 Site A1

Figure 5.3 Site A1 maximum rutting: 20m data average = 7.0mm, 95% 12.8mm



Survey data collection date: 9 January 2009

Figure 5.4 Typical view of site A1: RP 279/5525

Figure 5.5 Another typical view of site A1: RP 279/5225 decreasing

Inspection length 1 for this site was RP 279/4900- 4950 (figure 5.6 and 5.7).

Figure 5.6 Inspection length 1 for site A1: RP 279/4936 decreasing

Figure 5.7 Inspection length 1 for site A1: RP 279/4908 increasing

The second inspection length (inspection length 2) for site A1 was 279/5380-5421 (figures 5.8 and 5.9).

Figure 5.8 Inspection length 2 for site A1: RP 279/5391 increasing

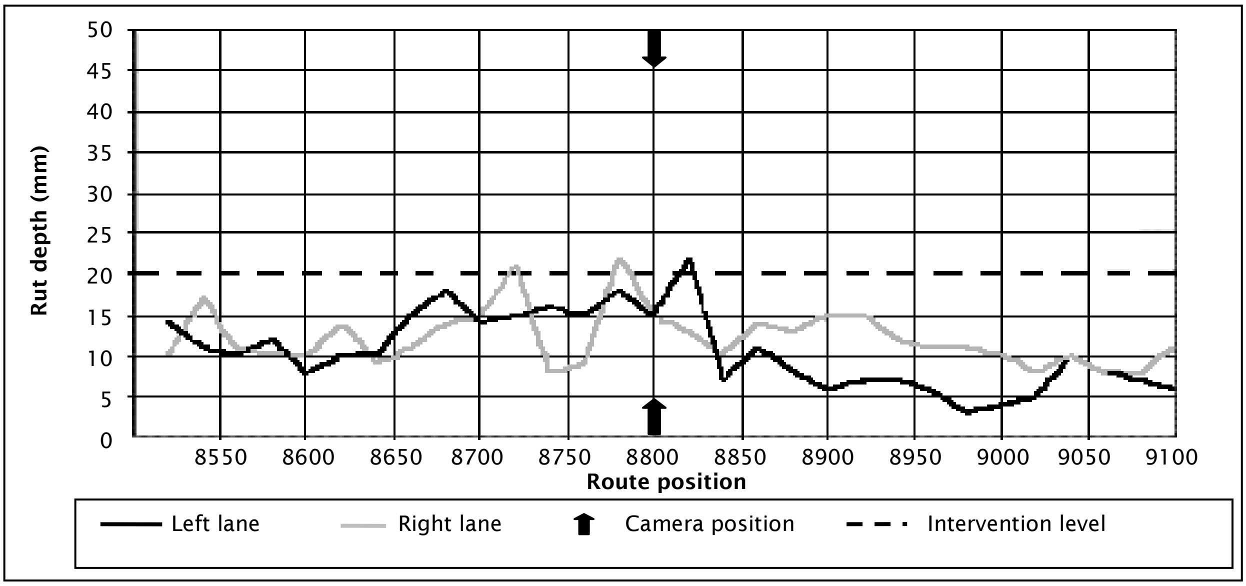
Figure 5.9 Inspection length 2 for site A1: RP 279/5411 decreasing

The inspection section **does not** represent the full rehabilitation section very well.

5.3 Region B

5.3.1 Site B2

Figure 5.10 Site B2 maximum rutting: 20m data average = 7.0mm, 95% = 10.9mm



Survey data collection date: 16 November 2009

Note that the photos shown in figures 5.11 to 5.14 were taken in a different part of figure B2 from those shown in section 4.3.3.

Figure 5.11 Typical distress in site B2 (RP 8801), showing evidence of corrugation

Figure 5.12 Another view of site B2 (RP 8503 decreasing)

The inspection length chosen for site B2 was 274/8700–8750 (figures 5.13 and 5.14).

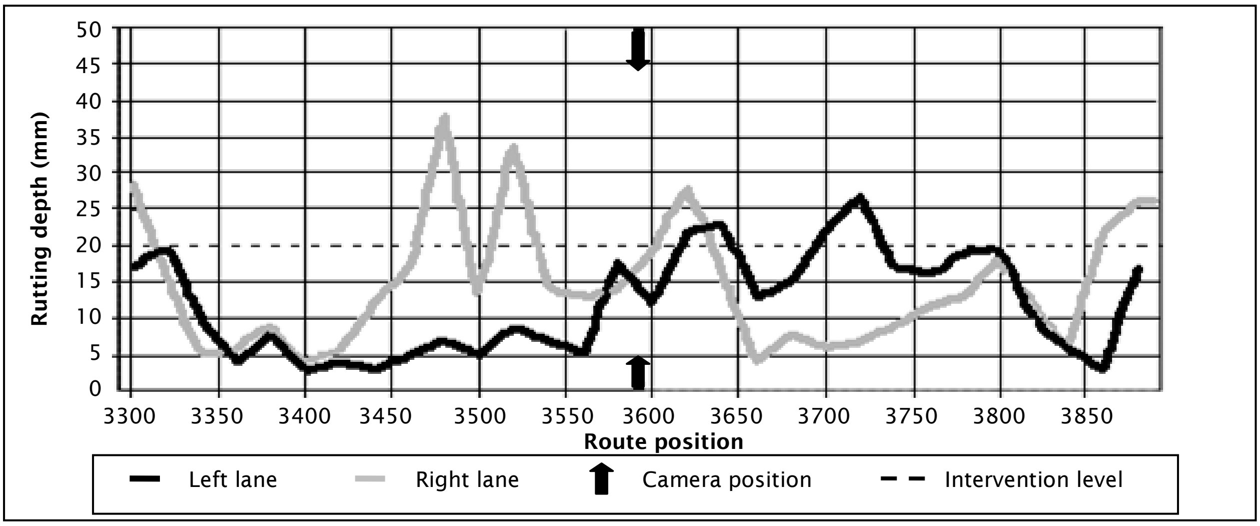
Figure 5.13 Typical view of the inspection length in site B2 (RP 8721), showing evidence of pavement distress

Figure 5.14 Typical inspection length distress in site B2 (RP 8736), showing evidence of corrugation

The inspection section **closely** reflects the full rehabilitation section.

5.3.2 Site B6

Figure 5.15 Site B6 maximum rutting: 20m data average = 4.4mm, 95% 9.6mm



Survey data collection date: 12 November 2009

Figure 5.16 Typical view of site B6 (RP 3478 increasing)

Figure 5.17 Another typical view of site B6 (RP 3763 increasing), showing evidence of pavement repairs

Figure 5.18 Another section of site B6: RP 3943 increasing

Figure 5.19 RP 4323 increasing in site B6, showing evidence of pavement distress

Figure 5.20 Site B6 inspection length 1: RP 3350–3400

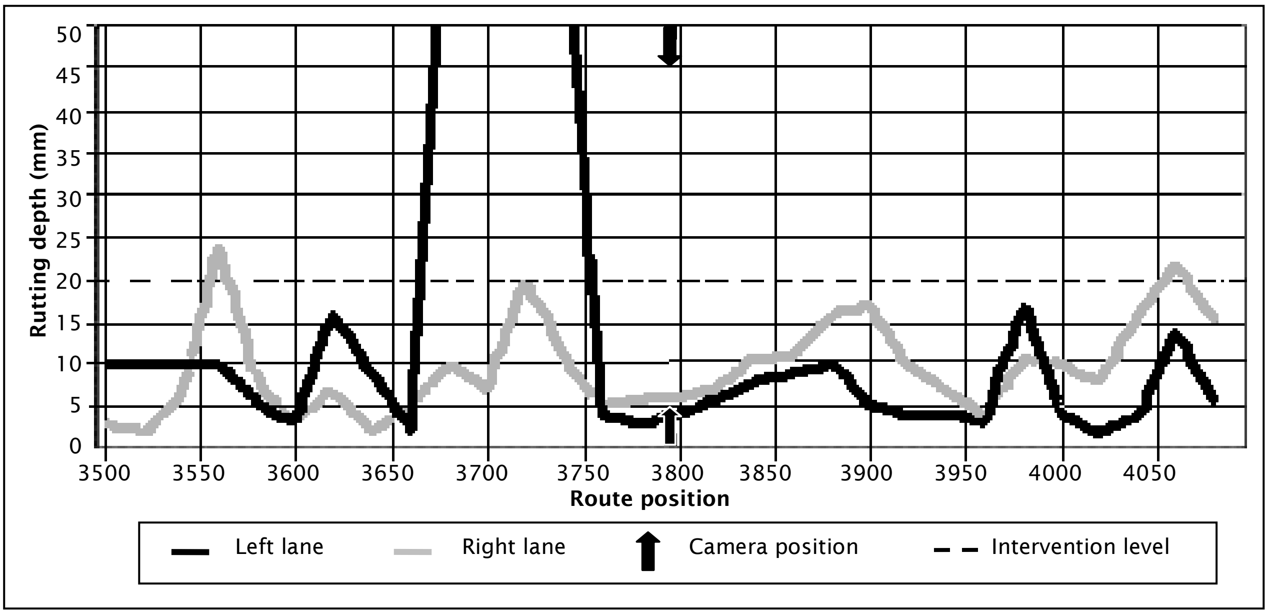
Figure 5.21 **Inspection length 2: RP 3840–3884**

The inspection section **closely** reflects the full rehabilitation section.

5.4 Region C

5.4.1 Site C1

Figure 5.10 **Site C1 maximum rutting: 20m data average = 3.6mm, 95% 14.9mm**



Survey data collection date: 12 November 2009

Figure 5.23 Typical view of site C1 (RP 3717 increasing) showing repairs

Figure 5.24 Typical view of site C1 (RP 3991 increasing), showing repairs and flushing

Figure 5.25 Typical view of site C1 (RP 33/3816 decreasing), showing repairs

Figure 5.26 Typical view of site C1 (RP 33/3661 decreasing), showing extensive flushing

The inspection length in site C1 covered RP 3540 –3598 (figures 5.27 and 5.28).

Figure .5.27 Inspection length of site C1: RP 33/3570 decreasing

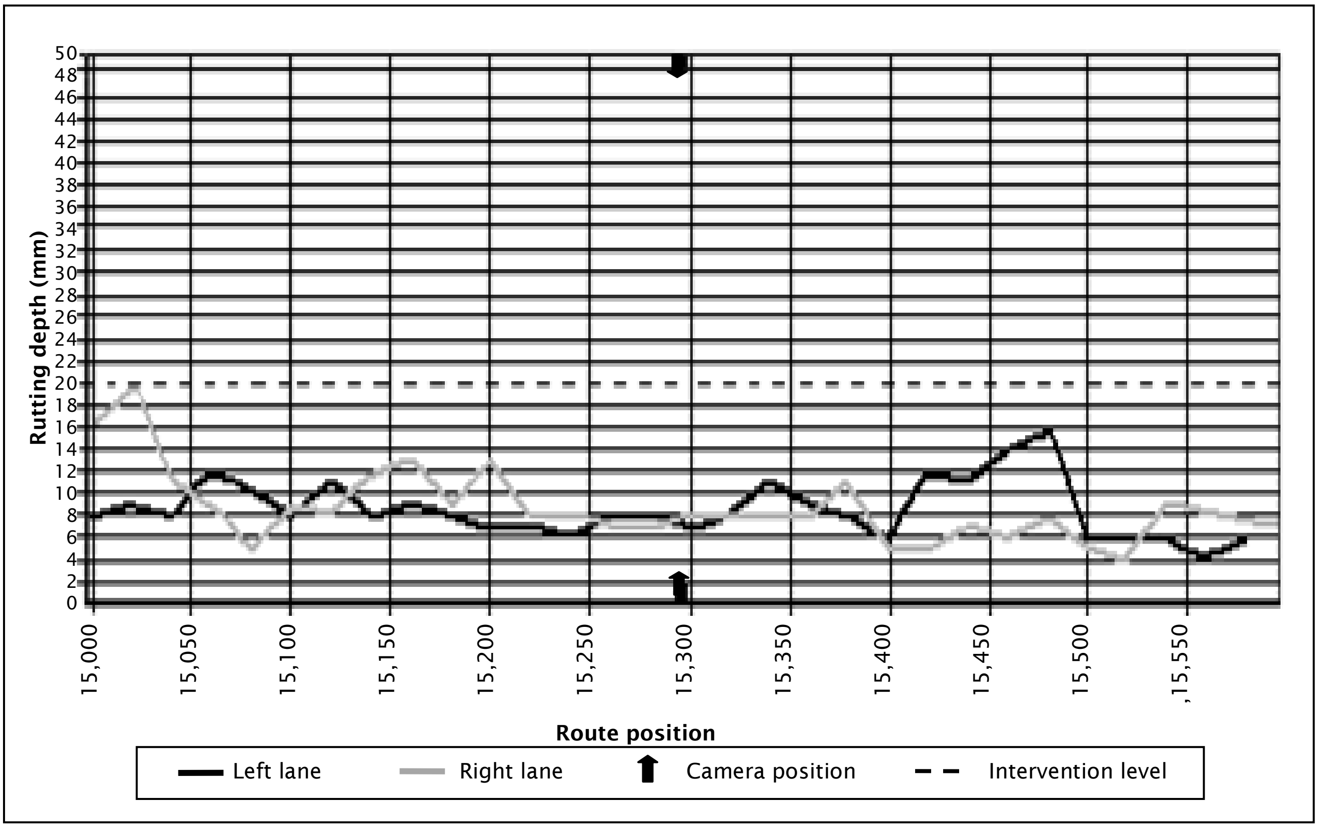
Figure 5.28 Inspection length of site C1: RP 33/3548 increasing

The inspection section **does not** represent the full rehabilitation section very well.

5.4.2 Site C4

The section of road investigated covered RP 15,000–15,730.

Figure 5.29 Site C4 maximum rutting: 20metre data average = 3.9mm; 95% 6.9mm



Survey data collection date: 13 November 2009.

Figure 5.30 A typical section of road in site C4: RP 15,108 increasing

Figure 5.31 A typical section of road in site C4: RP 15,205 decreasing

The inspection length, RP 17/15,520–15,570, is shown in figures 5.32 and 5.33.

Figure 5.32 Inspection length in site C4: RP 15,533 increasing

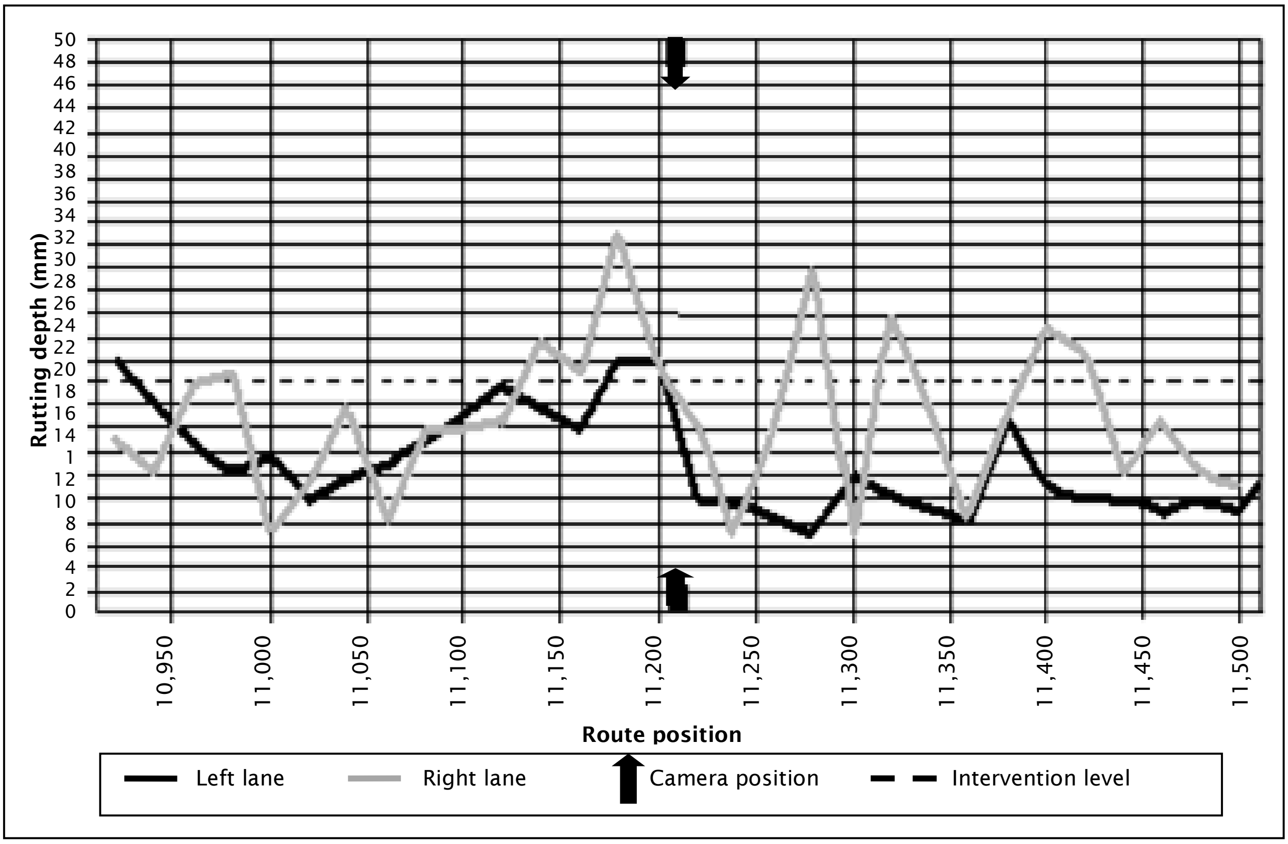
Figure 5.33 Inspection length in site C4: RP 15,546 decreasing

The inspection section **closely** reflects the full rehabilitation section.

5.4.3 Site C10

This section of road covered RP 11,210-11,440.

Figure 5.34 Site C10 maximum rutting: 20m average = 6.0mm; 95% 10.9mm



Survey data collection date: 14 November 2009

Figure 5.35 Typical section of site C10 (RP 544/11,378 increasing), showing flushing

Figure 5.36 Typical section of site C10 (RP 544/11,315 decreasing), again showing some areas of flushing

The inspection length in site C10 covered RP 544/11,230–11,280 (figures 5.37 and 5.38).

Figure 5.37 Inspection length in site C10: RP 444/11,270 decreasing

Figure 5.38 Inspection length in site C10: RP 544/11,273 increasing

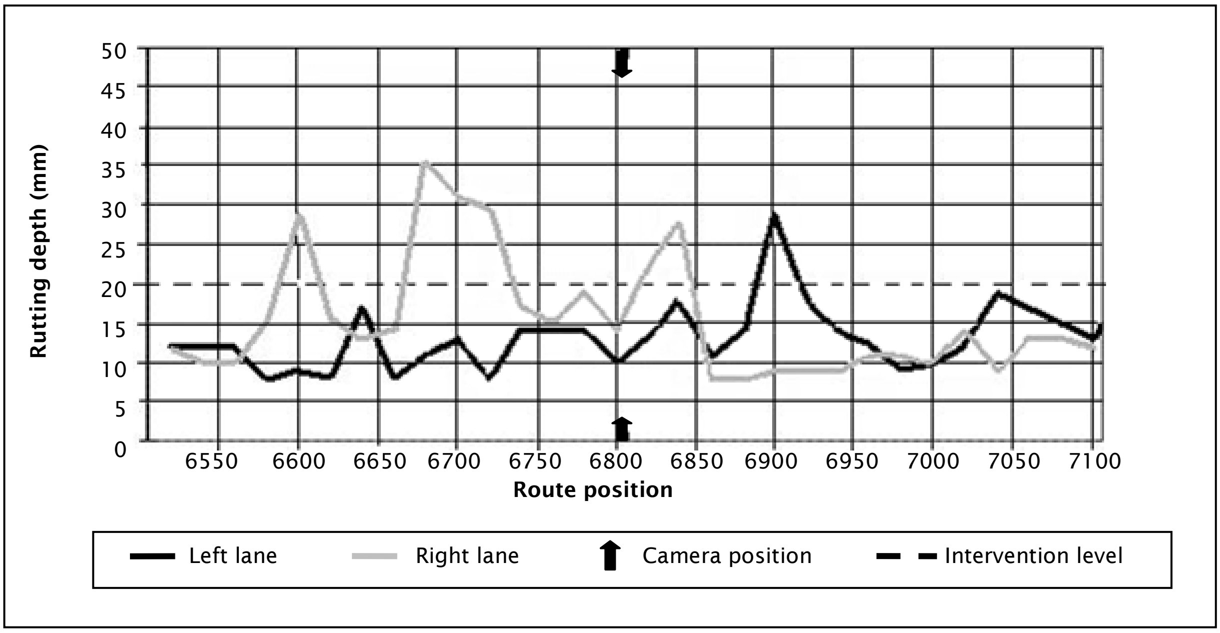
The inspection section **closely** reflects the full rehabilitation section.

5.5 Region D

5.5.1 Site D2

This section of road covered RP 6560–6910.

Figure 5.29 Site D2 maximum rutting: 20m average = 7.2mm; 95% 12.5mm



Survey data collection date: 4 February 2009.

The inspection length in site D2 covered RP 1145/6580–6630 (figures 5.40 and 5.41).

Figure 5.40 Inspection length in site D2 (RP 1145/6583), showing the poor condition of the pavement

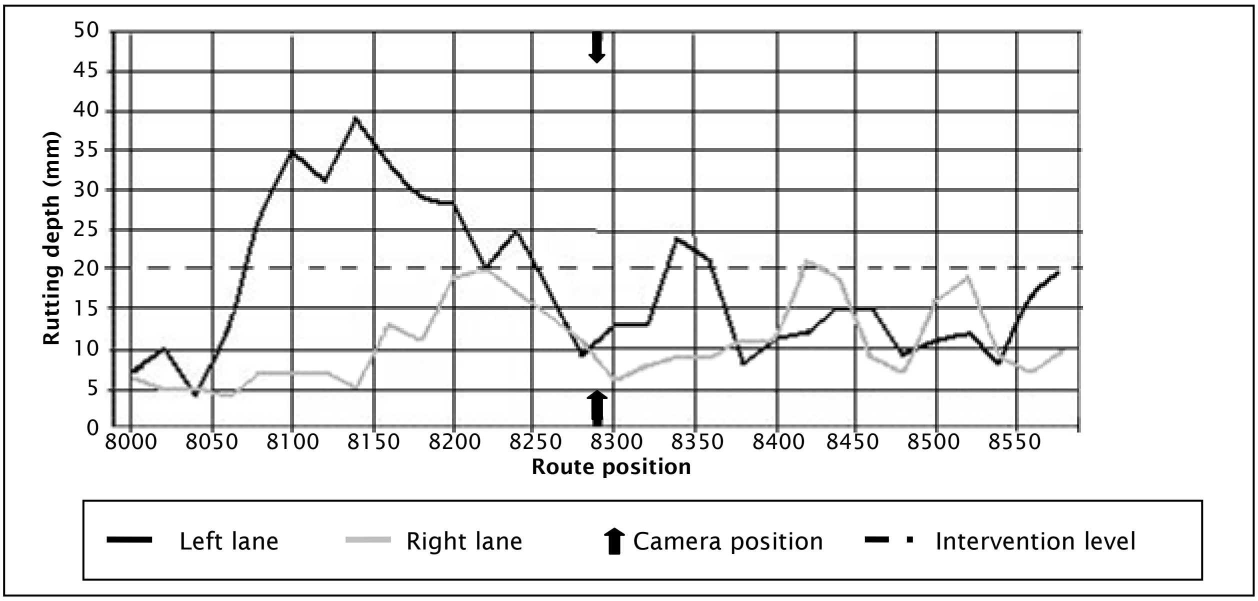
Figure 5.41 Another section of the inspection length in site D2 (RP 1145/6615), showing patchwork repairs, flushing and other evidence of poor pavement condition

The inspection section represents the full rehabilitation section well.

5.5.2 Site D6

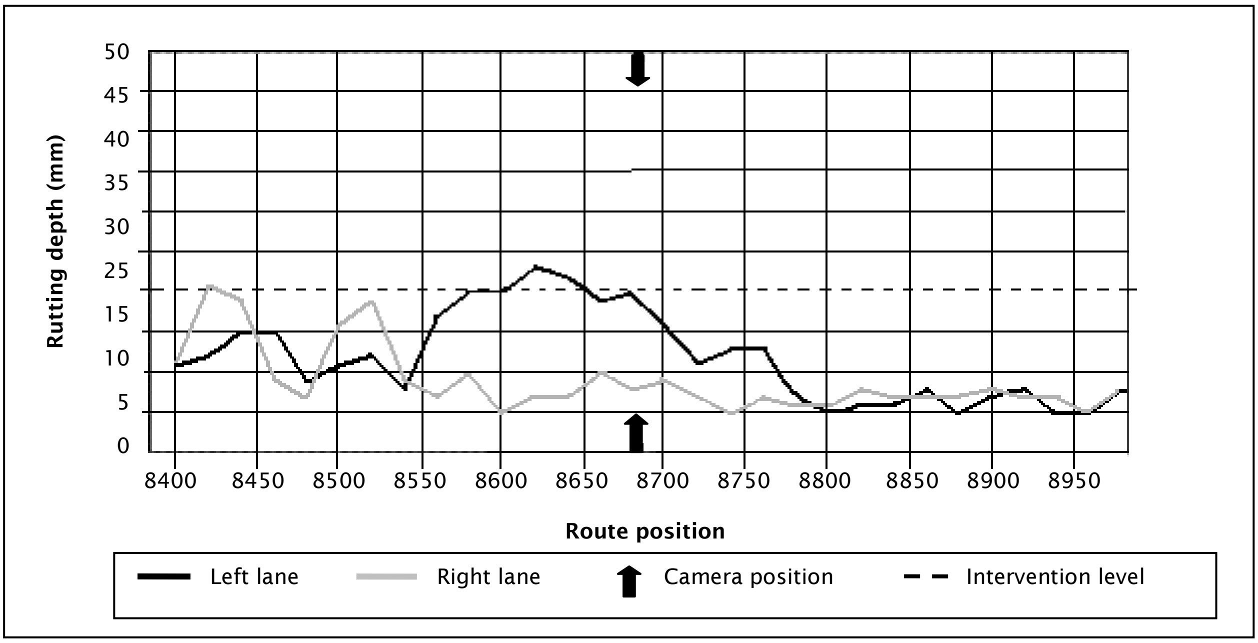
This section of road covered RP 8000-8900 and two inspection lengths were chosen (figures 5.42 and 5.43). The first inspection length covered RP 31/8020-8099 (figures 5.48 and 5.49) and the second inspection length covered RP 31/8810-8860 (figures 5.50 and 5.51).

Figure 5.42 Site D6 (RP 8000-8550) maximum rutting: 20m data average = 5.6mm; 95% 12.7mm



Survey data collection date: 4 February 2009.

Figure 5.43 Site D6 (RP 8400–8950) maximum rutting: 20m data average = 5.6mm; 95% 12.7mm



Survey data collection date: 4 February 2009.

Figure 5.44 Typical section of site D6 (second half, shown in figure 5.43): RP 8675 decreasing

Figure 5.45 Another typical section of the second half of site D6: RP 8595 decreasing

Figure 5.46 Typical section of site D6 (first half, shown in figure 5.43): RP 8470 decreasing

Figure 5.47 Another typical section of the first half of site D6: RP 8210 increasing, showing generally poor pavement surface condition

Figure 5.48 Inspection length 1 from site D6: RP 8052

Figure 5.49 Another view of inspection length 1 from site D6: RP 8082

Figure 5.50 Inpsection length 2 from site D6: RP 8814

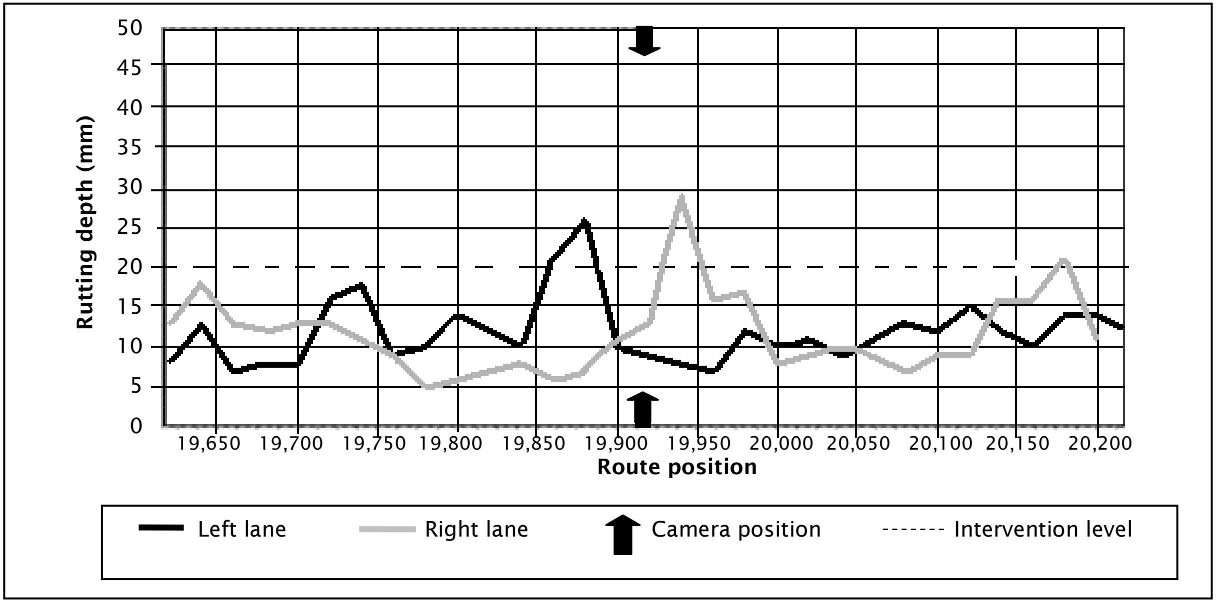
Figure 5.51 Another view of inspection length 2 from site D6: RP 8849

The inspection section **does not** represent the full rehabilitation section very well.

5.5.3 Site D10

This section of the road network covered RP 19,650–20,500 (figure 5.52).

Figure 5.52 Site D10 maximum rutting: 20m data average = 6.4mm; 95% 12.3mm



Survey data collection date: 4 February 2009.

Figures 5.53–5.56 show the typical condition of the pavement within site D10.

Figure 5.53 Typical view of site D10 (RP 0/19,939 increasing, showing evidence of potholing and flushing

Figure 5.54 Another view of site D10 (RP 0/19,969 increasing), showing generally poor pavement condition

Figure 5.55 Another view of site D10 (RP 0/20,154)

Figure 5.56 Typical section of pavement in site D10 (RP 0/20,234 increasing), showing extensive flushing

The inspection length in site D10 covered RP 0/19,740–19,814 (figures 5.57–5.58).

Figure 5.57 View of the inspection in site D10 (RP 0/19,747)

Figure 5.58 Alternate view of the inspection length in site D10 (RP 0/19,807)

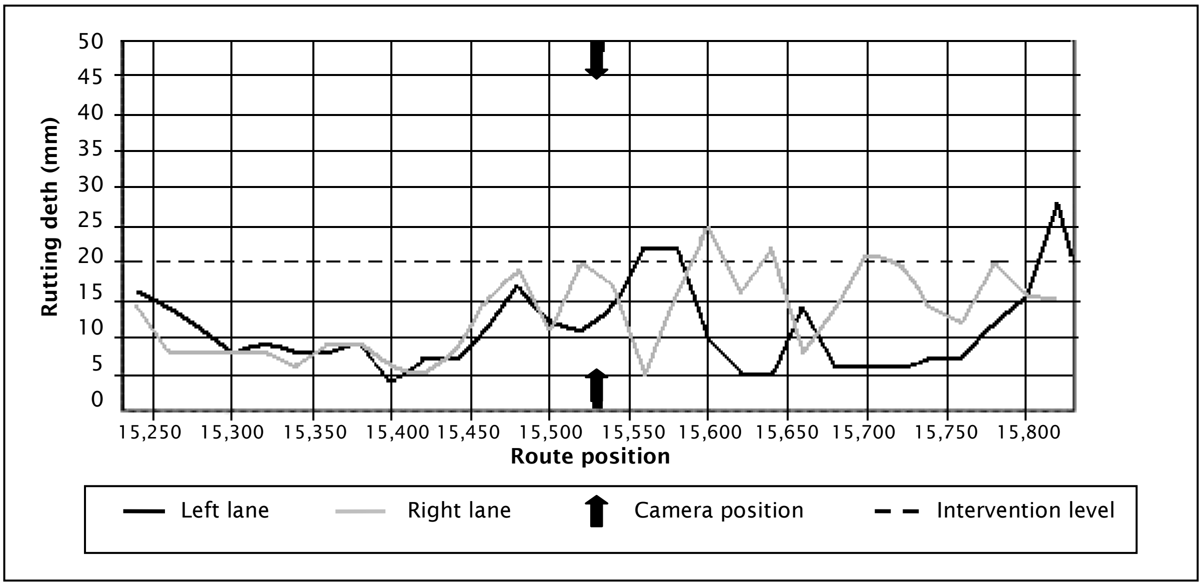
The inspection section **does not** correctly reflect the full rehabilitation section.

5.6 Region E

5.6.1 Site E1

Site E1 covered RP 15,500–15,780 (figures 5.59 and 5.60).

Figure 5.59 Site E1 maximum rutting: 20m data average = 4.5mm; 95% 7.2mm



Survey data collection date: 22 February 2009.

Figure 5.60 Typical section of of site E1: RP 118/15,681

The inspection length in site E1 covered RP 15,520–15,548 (figures 5.61 and 5.62).

Figure 5.61 The inspection length in site E1: RP 118/15,531 increasing

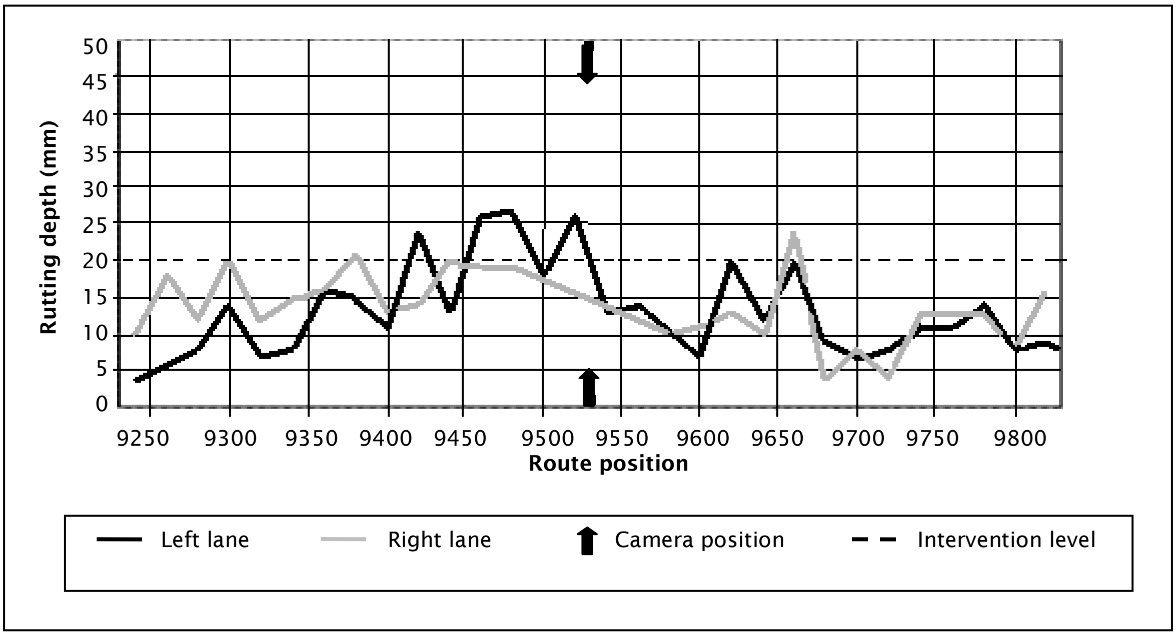
Figure 6.52 Another view of the inspection length in site E1 (RP 15,531 decreasing), showing flushing

The inspection section **closely** reflects the full rehabilitation section.

5.6.2 Site E2

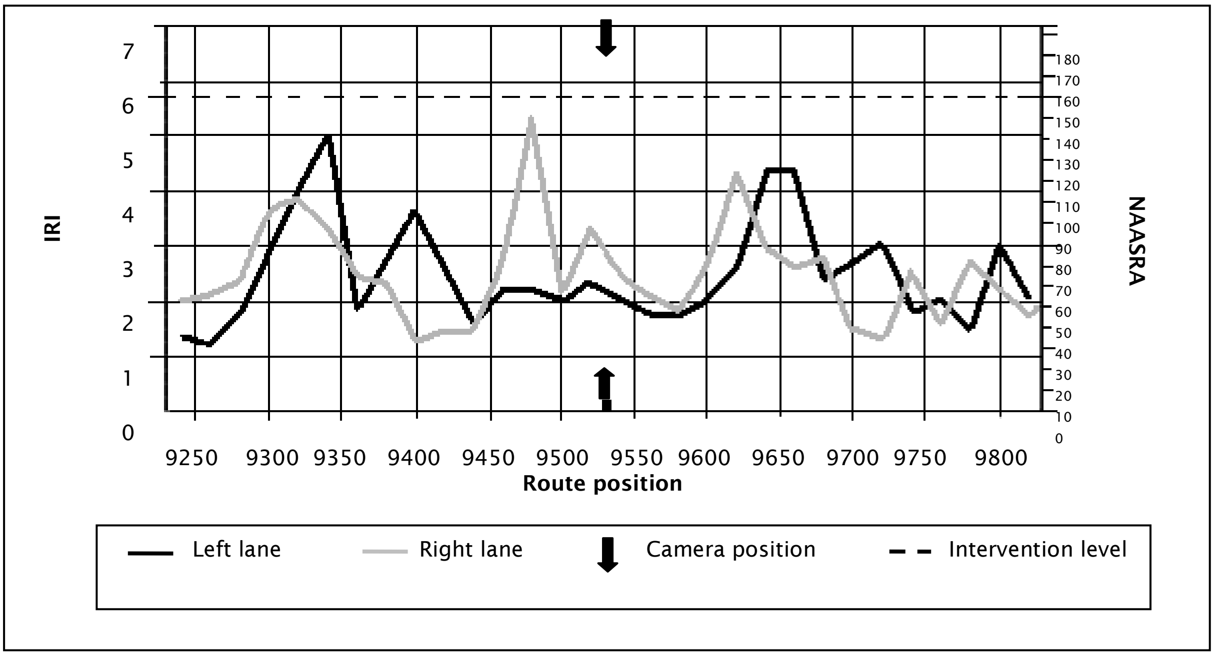
This site covered RP 9350–9650 (figures 5.63 and 5.64).

Figure 5.63 Site E2 maximum rutting: 20m data average = 5.6mm; 95% 10.0mm



Survey data collection date: 15 February 2009.

Figure 5.64 Site E2 roughness



Survey data collection date: 15 February 2009.

Figure 5.65 Typical section of pavement in site E2: RP 9527 decreasing

Figure 5.66 Another typical view of site E2 (RP 9452 increasing), showing flushed surface. condition

Figures 5.63 and 5.64 show that rut and roughness levels are mostly low within the inspection section but the areas above the limit are outside the inspection sections.

Inspection length 1 in site E2 covered RP 9370–9381 (figure 5.67 and 5.68).

Figure 5.67 Inspection length 1 in site E2: RP 9375 increasing

Figure 5.68 Another view of inspection length 1 in site E2: RP 9377 decreasing

Inspection length 2 at this site covered RP 9401–9428 (figures 5.69 and 5.70).

Figure 5.69 Inspection length 2 in site E2: RP 284/9410 increasing

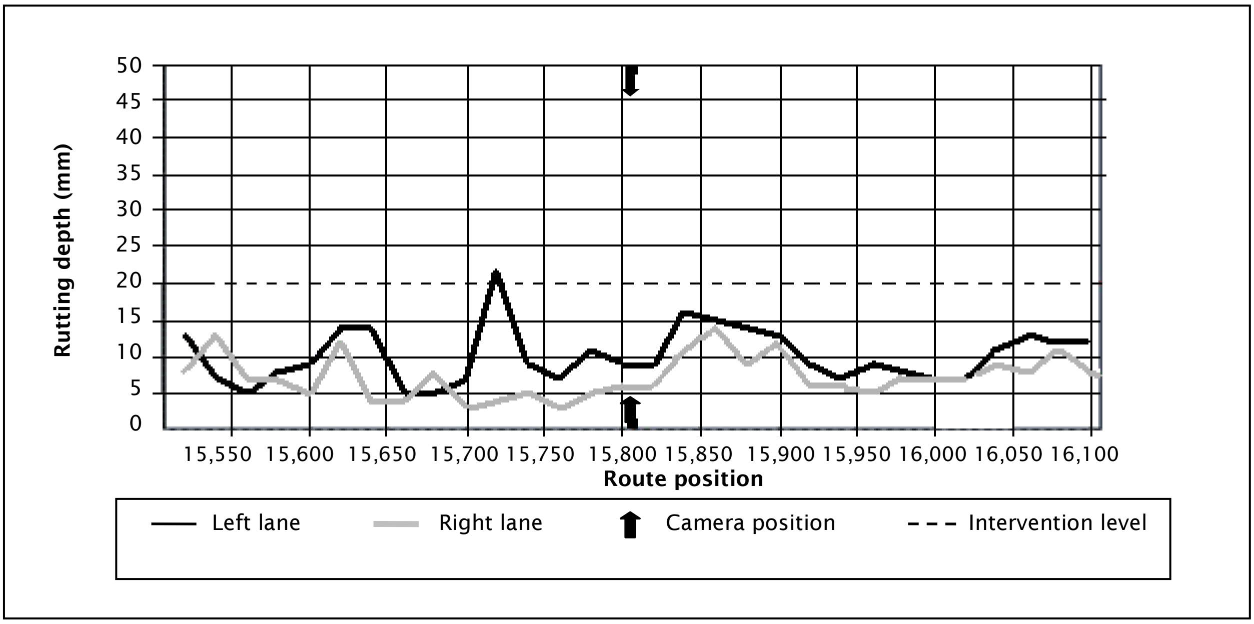
Figure 5.70 Alternative view of inspection length 2 in site E2: RP 284/9422 decreasing

The inspection sections **do not** reflect the full rehabilitation section correctly.

5.6.3 Site E4

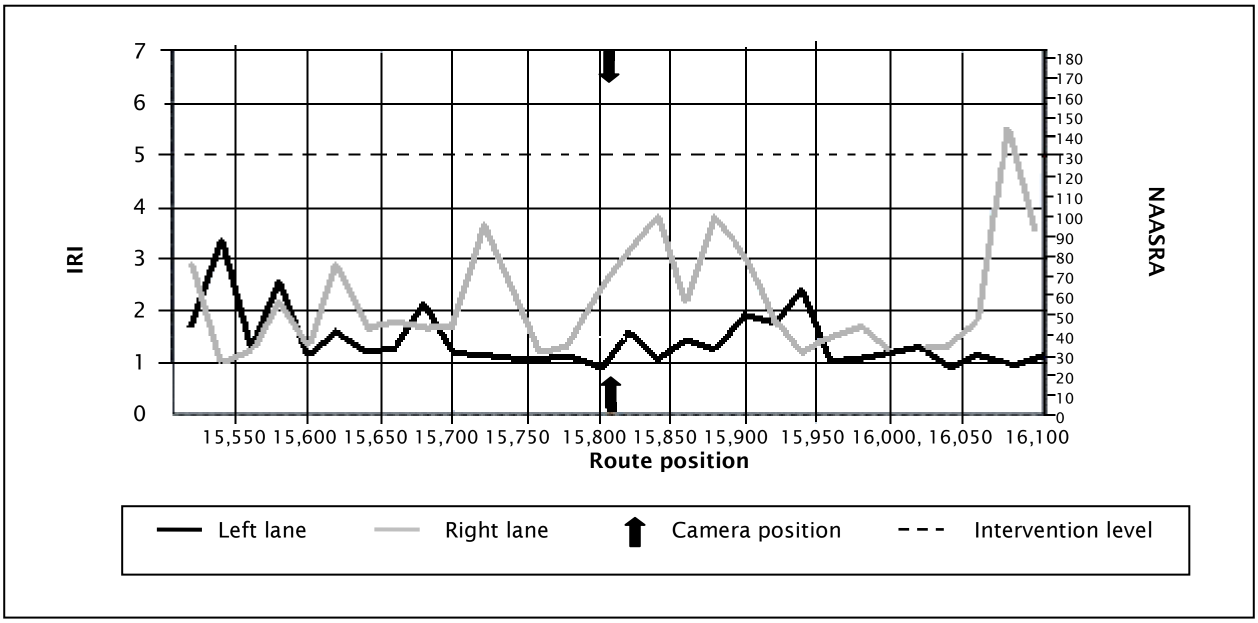
This site covered RP 15,800-16580 (figures 5.71 and 5.72).

Figure 5.71 Site E4 maximum rutting: 20m data average = 4.6mm; 95% 8.0mm



Survey data collection date: 14 February 2009.

Figure 5.72 Site E4 roughness



Survey data collection date: 14 February 2009.

Figures 5.71 and 5.72 show that the rutting and roughness are below the intervention threshold throughout the site.

Figure 5.73 Typical view of site E4: RP 16,528 decreasing

Figure 5.74 Another view of site E4: RP 16,722 decreasing

The inspection length in site E4 covered RP 15,820–15,898 (figures 5.75 and 5.76).

Figure 5.75 Inspection length in site E4: RP 15,817 increasing

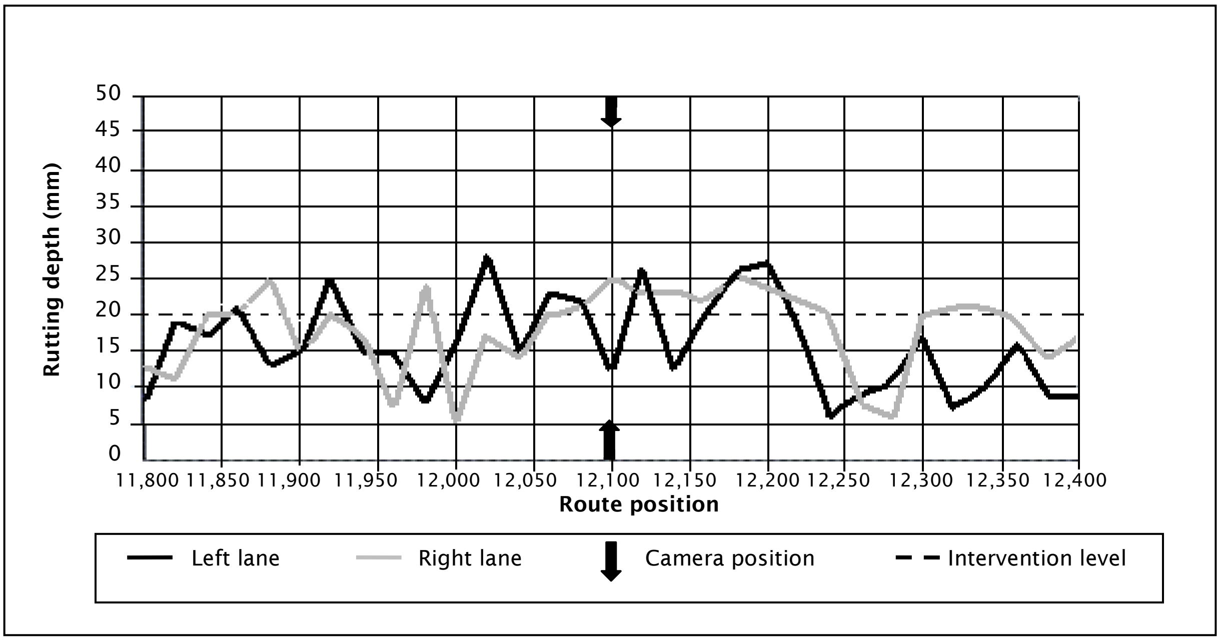
Figure 5.76 Another view of the inspection length in site E4: RP 15,867 increasing

The inspection section closely reflects the full rehabilitation section.

5.6.4 Site E5

This site covered RP 11,800–13,100 (figure 5.77). The inspection length in site E5 covered RP 76/12,220–12310.

Figure 5.77 Site E5 maximum rutting: 20m data average = 6.0mm; 95% 11.2mm



Survey data collection date: 17 February 2009.

Figure 5.78 Typical veiw of site E5: RP 75/12,185

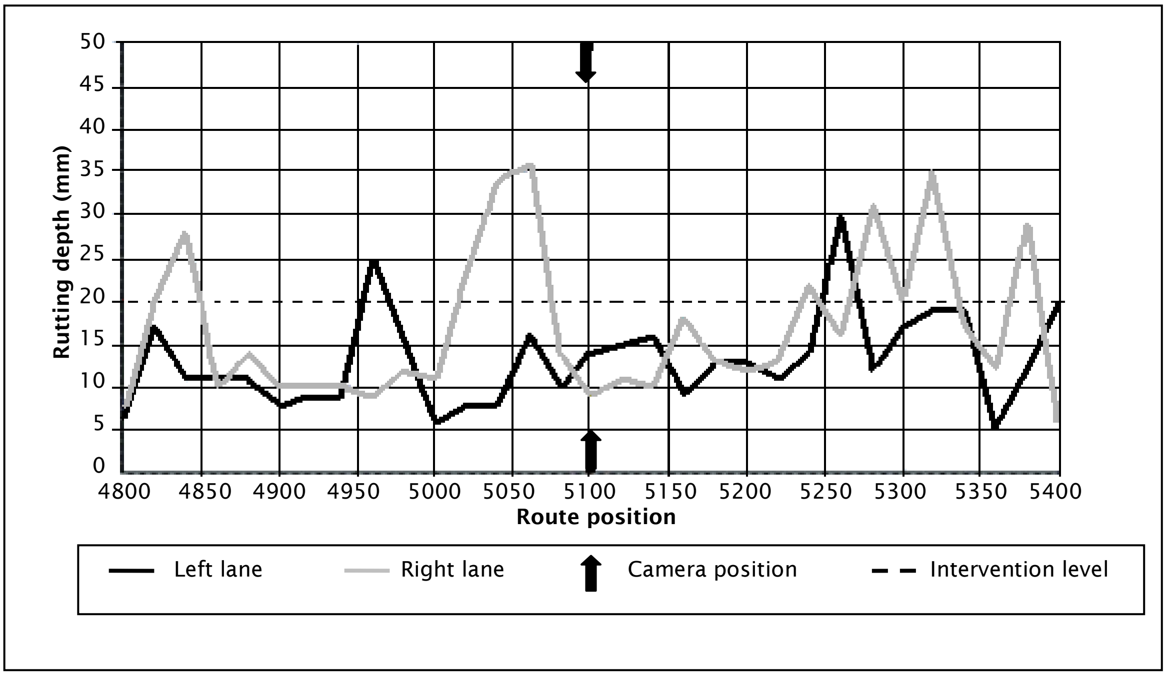
Figure 5.79 Another typical view of site E5: RP 76/12,180 decreasing

The inspection section does **not** correctly reflect the full rehabilitation section. However, this is more visible in figure 5.77 than in the photos (figures 5.78 and 5.79).

5.7 Region F

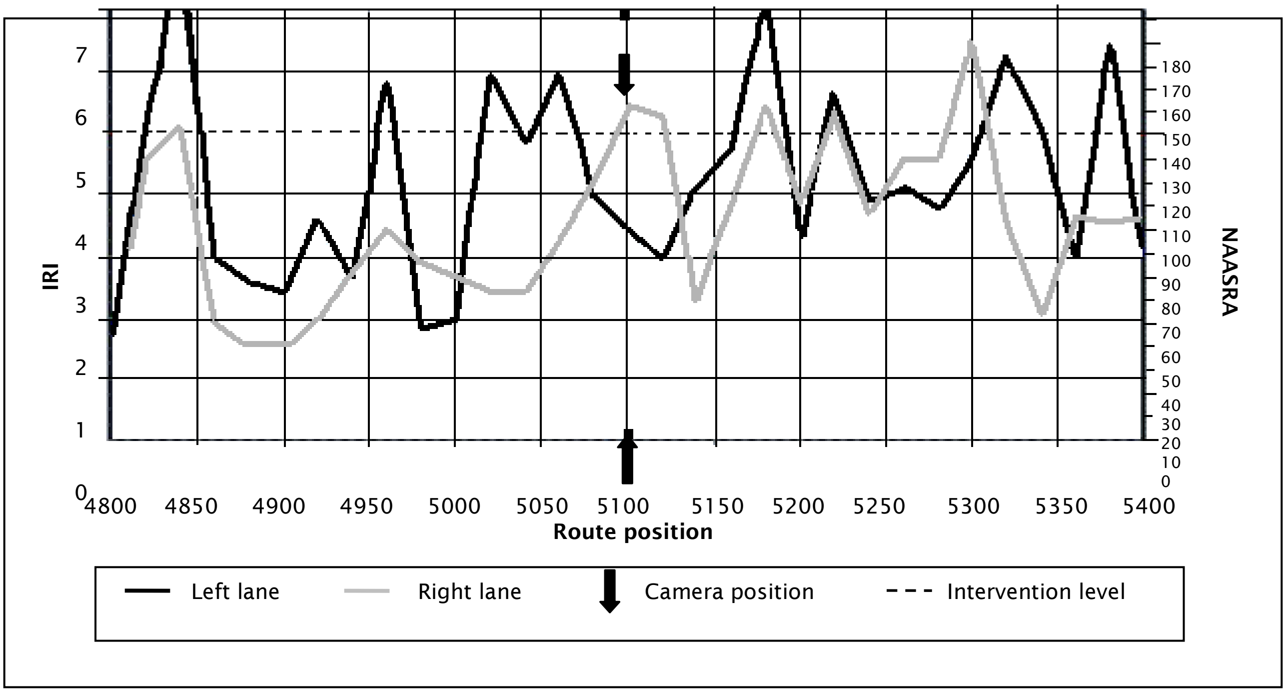
Site F1 covered RP 4800–5390 (figures 7.80 and 7.81).

Figure 5.80 Site F1 maximum rutting: 20m data average = 6.4mm; 95% 12.0mm



Survey data collection date: 21 February 2009.

Figure 5.81 Site F1 roughness



Survey data collection date: 21 February 2009.

The inspection length in site F1 covered RP 225/4835–4899 (figures 5.82 and 5.83).

Figure 5.82 The inspection length in site F1: RP 225/4863 increasing

Figure 5.83 Another view of the inspection length in site F1: RP 225/4868 decreasing

The inspection section **closely** reflects the full rehabilitation section.

6 Discussion

The types of distress that prompt the call for the pavements to be rehabilitated are summarised in table 6.1

It can be seen that in all regions, rutting and flushing was given as a reason for rehabilitation in most assessments. Although rutting could be seen as a pavement failure, flushing is more of a surfacing problem. The build-up of multiple chipseal layers can lead to an unstable layer, and thus to short seal lives, so premature flushing could be seen as a form of pavement failure. It was noted that some regions quantified the loss of life in that they demonstrated the seals on site had reduced lives while other regions presumed that pavement failure was going to occur under the do-minimum scenario.

It is of interest that rutting was mentioned in 88% of the justifications reviewed but it did not appear as a predictor in the research performed by Gribble et al (2008). This suggests that the extent of rutting on the pavements is either low or that it is similar to the network in general, ie the rutting is not significantly different from the rest of the network.

Flushing was not a variable that was investigated by Gribble et al but it is obviously regarded as a problem that can justify a rehabilitation treatment.

Table 6.1 Summary of distress reasons given as a jusification for rehabilitation

Region	Total number	Rutting	Roughness	Flushing	Cracking	Chip loss	SCRIM	Edge break	Digout repairs	Shearing	Pot-holes
A	2	2			1						
B	10	10	8	7	8	8	1	1	9	2	1
C	17	12	10	15	7	7	2	1	10	2	3
D	11	11		10					3	6	2
Overall %		88	45	80	40	38	8	5	55	25	15

The area of total deferred maintenance for the three examples in section 3 ranged between 26% and 57%. Six further examples from region E are given in table 6.2. Even without water cutting treatment for flushing, the area of repair is close to 20%.

Flushing associated with short seal lives can have a significant effect on future maintenance costs but table 6.2 shows that water cutting treatment can have a significant impact on the deferred maintenance costs.

Table 6.2 Area of deferred maintenance in region E

Site #	Total area (m^2)	Deferred repairs (m^2)	%	% minus water cutting
1	5525	1600	29	29
2	2380	1645	70	19
3	23,205	13,450	58	12
4	2550	500	20	20
5	1620	100	6.2	5.5
6	2890	401	14	12

Additionally, annual pavement and surfacing costs play a pivotal role in the analysis, but consistency seems to be lacking with respect to its calculation, where maintenance values have been averaged over a differing number of preceding years.

Maintenance costs for a range of repairs averaged over four regions are given in table 6.3. It can be seen that digouts are a significant cost compared to some of the other repairs. These have been used to estimate the cost of repairs for a range of percentage area of distress.

Table 6.3 Average cost of maintenance treatments from four networks

Treatment	Unit	Cost ($)
First coat seal	($/$m^2$)	5.20
Digout	($/$m^2$)	52.20
Rut filling	($/m)	23.04
Crack sealing	($/$m^2$)	10.08
Filling potholes	(each)	19.47
Repair flushing	($/lane metre)	12.57
Edge repair	($/m)	9.16
Scabbing repair	($/$m^2$)	6.54

The effect of maintenance costs on the model of the probability of rehabilitation was discussed in chapter 1. To obtain an annual average cost of repairs of $15,000/km would trigger a high probability of rehabilitation that (according to figure 1.1) would require 287m^2 of digouts per year. Over six years, which is the timeframe of the predictive model, the area would be 1724m^2. For a typical two-lane pavement 8.5m wide, this would represent 20% of the area. In none of the examples examined in this research was the area of current repairs close to 20% of the area but deferred maintenance did encompass this area.

Table 6.4 gives the average network maintenance costs for six regions for 2007–08. This cost was the total for the pavement, surface and shoulder. In table 6.4, the average five-year maintenance costs for the sections that were to be rehabilitated are also shown. The table does not support the view that the average maintenance cost for a section requiring rehabilitation is higher than the average for the network.

Table 6.4 Comparison of network and rehabilitation site maintenance costs

Region	Network maintenance ($/km/year)	Average maintenance for rehabilitation sites ($/km/year)
A	1820	250
B	5275	3710
C	2900	3160
D	2120	–
E	790	1070
F	2850	500

The treatment maintenance costs are comparable to the costs for a rehabilitation treatment and are typically in the \$30–\$40/m^2 range. Therefore, if the area of digouts gets to over 60% of the area then the maintenance cost is higher than the rehabilitation cost. Reviewing the justifications, it appears that if the digouts associated with rutting, shearing and general failure get to over 20% of the area then the combination of this immediate cost, with higher annual maintenance costs and shorter reseal lives, will be sufficient to obtain a positive NPV. The RAMM data currently records maintenance cost but the visual surveys do not record the area of digouts. If digouts are regarded as a pavement failure rather than a surfacing failure then recording them in RAMM could be advantageous. In some regions, it was noted that failure of repairs was common. Recording the area of repair would not capture this. Failure of repairs points to either poor workmanship, incorrect treatment or a rapidly failing pavement. Continued repairs upon repairs may not generate extra maintenance costs, depending on how rapidly the failure occurred and the contract details.

The overall prediction model in equation 1.3 was applied to the regions to determine the 'hit rate' that the current model attains. The results are given in table 6.5 alongside the average maintenance cost per kilometre for the network. It can be seen that where the average maintenance costs on a network are high, the relationship has a better hit rate. This demonstrates that the current model, which has maintenance costs as the main predictor of rehabilitation, may need to be normalised for the maintenance costs of the network. Region E, which was not one of the regions used in Gribble et al's study, has a low maintenance cost per kilometre and the algorithm did not correctly predict any of the engineers' rehabilitation sections.

Table 6.5 Sites correctly identified for rehabilitation by equation 1.3, with associated maintenance costs

Region	Sites (n)	Correctly identified (n)	Maintenance cost ($/km)
A	3	0	1820
B	9	6	5275
C	16	9	2900
D	11	3	2120
E	16	0	790

In general, the visual overview of the sites proposed for rehabilitation did not appear to require the level of maintenance associated with digouts that was suggested by the deferred maintenance assessments. The level of expenditure proposed by the do-minimum appears to be somewhat excessive.

The assumption that the inspection length may not give a true reflection of the section appears to have some merit. Of the 14 sites examined in chapter 5, the inspection length was judged to reflect the section condition in eight instances. This is approximately 60%. This would suggest that in RAMM, the visual condition data does reflect the true condition in 40% of the cases and thus it is understandable why the analysis of Gribble et al (2008) did not find a robust relationship.

However, even if the RAMM data reflected the whole section length, the extent of backlogged repairs that are over 20% of the area appears excessive. It is postulated that the engineers took the approach that the do-minimum repairs are those required to restore the pavement fully to an ‘as new’ condition.

This research has not found a consistent view on the triggers that prompt a decision to rehabilitate a pavement. It is suggested that the triggers may not necessarily be based solely on the current condition but may also be be based on the engineers’ assessment of the risk associated with a rapid and costly failure of the pavement. The risk profile will vary with factors such as the moisture susceptibility of the subgrade in the area, the rainfall pattern and the topography. It is considered that these influences are not currently in RAMM and thus are not able to be modelled. It is considered that a more robust model of rehabilitation prediction needs to take the risk assessment into account. To develop this form of the model would require the use of focus or Delphi groups to better capture the factors and the level that prompts to rehabilitate the decision. This is outside the scope of this project.

A school of thought states that renewal of the asset must be carried out in a systematic way. It is thought that if renewals are not performed then the asset is being consumed, and that this will lead to catastrophic failures and associated high repair/replacement costs. Recent research by Arampamoorthy and Patrick (2010) suggested that thin-surfaced unbound pavements in New Zealand did not follow the classic deterioration curve illustrated in figure 6.1 but instead followed the curve illustrated in figure 6.2, which reflects the fact that preseal repairs and resealing that occur at a regular basis result in areas of rutting and roughness being repaired.

Figure 6.1 Typical pavement deterioration from Arampamoorthy and Patrick (2010)

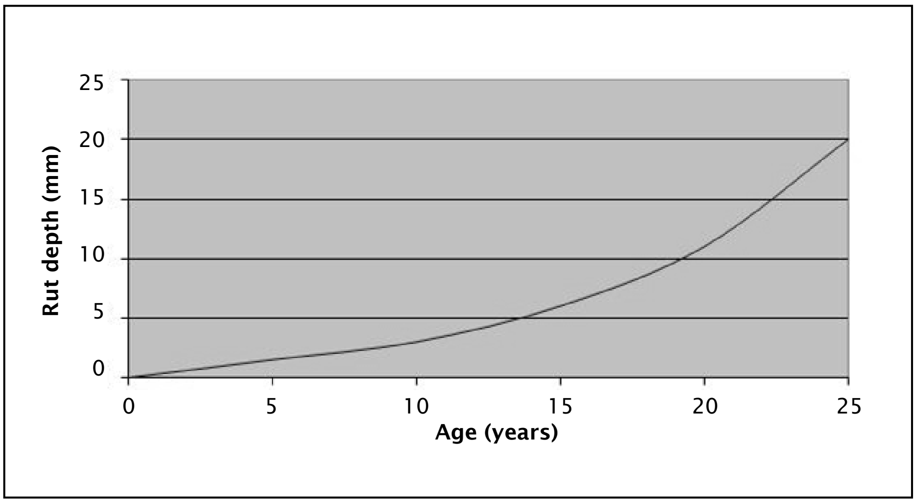
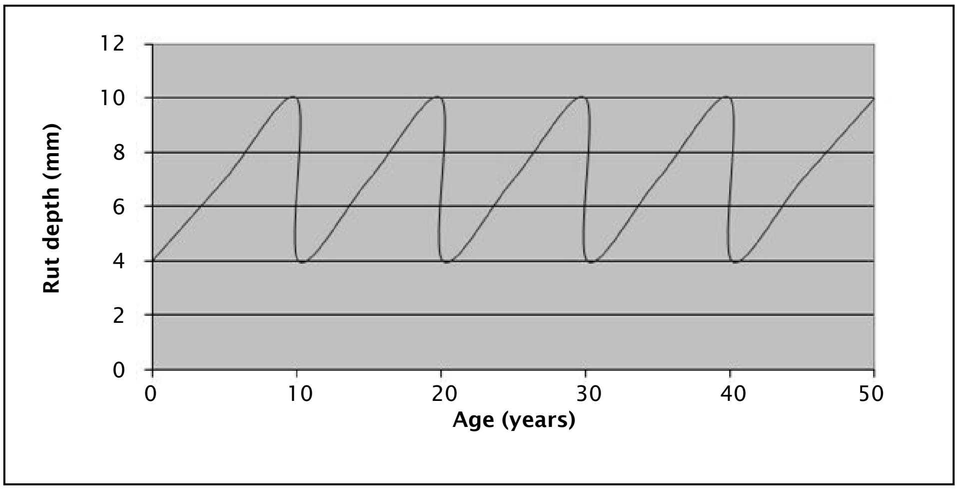


Figure 6.2 Proposed deterioration model from Arampamoorthy and Patrick (2010)



If this model (figure 6.2) is accepted then the New Zealand state highway network would typically not have significant areas of rutting and roughness. In general, this agrees with the finding of this research project in that although the engineers noted that rutting occurred, the high-speed data did not, in general, indicate rut depths over 20mm.

The driver for the engineer to propose a road section for rehabilitation may therefore be associated with:

- a desire not to consume the asset
- minimising the risk of a sudden large failure.

These concerns would then drive the engineer to find the high-risk areas and propose these for rehabilitation. The sections at the highest risk of failure would then be chosen and the economic justification would be performed. The number of sites that would be rehabilitated would then be driven by the available funding.

The situation appears to be similar to the decisions made on resealing. Ball and Owen (1998), in comparing sites that had been resealed against the RAMM surfacing criteria for resealing, found that in 75% of sites, the decision was based on other factors. These factors were not quantified, but Ball and Owen's research indicates that the lack of a relationship between resealing decisions and pavement condition is similar to that found in this research for rehabilitation decisions. For resealing, the NZTA have recently formulated a policy that restricts the number of reasons that an engineer can give for the decision to reseal. Examples of reasons no longer allowed are 'hard binder' and 'old age'. It may be appropriate to tighten the definitions and reasons that can be given for rehabilitation.

7 Conclusions

This research had the objective of developing an improved method of modelling the decision to rehabilitate a typical New Zealand thin-surfaced unbound granular pavement. This was driven by previous research that had found a poor correlation between the data recorded in RAMM and the decision to rehabilitate. It had been hoped that by talking to local engineers and examining pavements proposed for rehabilitation, distress not currently recorded may be identified. This would have then driven the development of better models and may also have expanded the detail collected in the visual surveys. The research found, however, that the drivers are not obvious and that the decision maybe being based on factors such as the engineers' assessment of the risk of rapid failure.

The conclusions from this research are:

- Visual engineering inspections indicate that many pavement sections require rehabilitation.
- In many cases, a significant quantum of deferred maintenance needs to be performed for the do-minimum option. This maintenance is not necessarily obvious from the data in RAMM or visual observations of the high-speed data videos.
- Wide variation can be found in the methods used to determine future maintenance costs. This ranges from including the deferred maintenance cost into one year and extrapolating from this cost, to ignoring the deferred maintenance cost in the analysis.
- The timeframe for assessing maintenance cost history is variable.
- The NPV calculation can be very sensitive to assumptions made on future maintenance and seal lives. This includes assuming that higher priced polymer modified seals need to be used.
- Rutting and flushing at 88% and 80% of the surveyed pavements are the two most commonly quoted distress mechanisms. These do not appear in the rehabilitation algorithm proposed by Gribble et al (2008).
- Digouts are a factor mentioned in 55% of justifications.
- The influence of the perceived risks of 'consuming the asset' and fears of rapid pavement failure need to be investigated.
- The difference in condition between the typical pavements in a network and those chosen for rehabilitation can often be minor and thus very difficult to quantify.
- Better guidelines should be developed to assist and standardise the decision process. These guidelines need to be based on a risk and consequence approach, which, it is believed, will better reflect the engineers' approach.

8 Recommendations

This research project has found that engineers have a wide range of opinions on the need to rehabilitate a pavement. Therefore, New Zealand has no ‘standard’ definitions or consistency in decisions about the extent of pavement failure that is at a level at which rehabilitation is required.

The present system of justifying rehabilitation is primarily based on the NPV of future maintenance costs. It is not based on the present condition of the pavement in terms of, for example, roughness and rutting, but is justified on the assumed increased costs of maintaining the pavement. The emphasis on the assumed costs must, by its nature, be very subjective, as no reliable maintenance cost models are available.

The perceived increasing maintenance costs are thus the justification for rehabilitation, rather than the current pavement condition.

It is recommended that if more emphasis in the justification was placed on the present pavement condition, this would lead to more consistent decisions.

Through the use of an expert group, analysis of the Long Term Pavement Performance trials, Canterbury Accelerated Pavement Testing Indoor Facility trials, dTIMS modelling etc, an acceptable definition of the degree of pavement distress and the rate of increase of this distress that triggered pavement rehabilitation could be developed. The expert group would need to consist of owner, consultant and contractor representatives to ensure that a balance was struck between the funders and the doers.

The definition would need to consider the effects of resealing in improving the pavement performance and masking distress. This would ensure that, for example, a surface condition such as flushing was not by itself a justification for rehabilitation, but unstable seal layers could be used.

It is envisaged that maintenance cost differences throughout the country could be normalised through analysing a section in terms of percentage increase from the mean for the network, and the rehabilitation cost as a percentage of the mean maintenance cost.

This approach would take into account both the engineering judgement associated with the inherent strength of the pavement, and the economic tension between maintenance and rehabilitation. The assessment of an NPV would not be the final step in the decision making but be a part of a maintenance cost/rehabilitation cost ratio.

It is also recommended that the use of inspection lengths be reconsidered. As the inspection length associated with the visual pavement inspection did not reflect the treatment section length in 40% of sites surveyed in this study, it is recommended that an investigation into a method of obtaining a more representative sample be explored. This could be by determining the position of the inspection length or by taking subsamples or via other means.

Data collected must be in a degree of precision and form that reflect the requirements of any proposed rehabilitation decision matrix.

It is considered that the methodology of determining the need for rehabilitation must be standardised. It is recommended that the structure of such a methodology could consist of the following modules:

- Data analysis: In this first step, the RAMM data would be screened to highlight sections. It is envisaged that the expert group would develop a selection algorithm that would include factors such as:

  - the shape of the section (roughness or rutting) above certain thresholds or changing rapidly
  - the maintenance activities significantly above a predetermined percentage of the average for the network
  - the condition in terms of shoving, edge breaks, potholes and digouts above predetermined limits
  - the risk profile of the network associated with traffic volumes, subgrade moisture susceptibility, safety etc.
- The highlighted sections would be inspected, the data summarised and the cost of rehabilitation estimated.
- The results would be peer reviewed and possibly presented to a group that considered and debated the forwards work programme. This could mean that the members of the review group may not be directly associated with the network.

9 References

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