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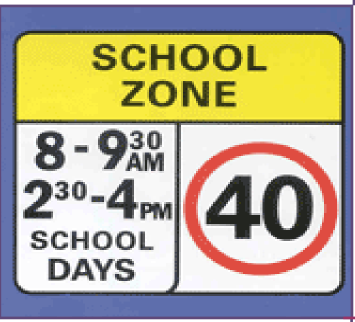
AUSTROADS TECHNICAL REPORT

Field Validation of Warm Mix Pavements



Austroads

Field Validation of Warm Mix Pavements

Field Validation of Warm Mix Asphalt Pavements

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Field Validation of Warm Mix Pavements

Austroads
Sydney 2012

About Austroads

Austroads' purpose is to:

- promote improved Australian and New Zealand transport outcomes
- provide expert technical input to national policy development on road and road transport issues
- promote improved practice and capability by road agencies.
- promote consistency in road and road agency operations.

Austroads membership comprises the six state and two territory road transport and traffic authorities, the Commonwealth Department of Infrastructure and Transport, the Australian Local Government Association, and NZ Transport Agency. Austroads is governed by a Board consisting of the chief executive officer (or an alternative senior executive officer) of each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Department of Transport and Main Roads Queensland
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of Infrastructure, Energy and Resources Tasmania
- Department of Transport Northern Territory
- Department of Territory and Municipal Services Australian Capital Territory
- Commonwealth Department of Infrastructure and Transport
- Australian Local Government Association
- New Zealand Transport Agency.

The success of Austroads is derived from the collaboration of member organisations and others in the road industry. It aims to be the Australasian leader in providing high quality information, advice and fostering research in the road transport sector.

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SUMMARY

The asphalt industry, like any other, wants to manage and use resources efficiently and continually improve their environmental performance. Reducing greenhouse gas emissions that contribute to global warming is of increasing interest and concern to the industry. Industry across all sectors can achieve a significant reduction in carbon dioxide equivalent ($CO_{2\text{-eq}}$) emissions by improving energy efficiency in their manufacturing processes. Unlike other pavement construction processes, asphalt requires that the aggregates and bituminous binders be heated and dried in their production process. This is an energy intensive production process.

Although construction sector emissions represented only about 1.5% of overall greenhouse emissions in Australia in 1997–98, this sector is showing a willingness to adopt strategies that will lead to the use of energy more efficiently and respond to the challenge of meeting emissions targets to avoid dangerous climate change. In a practical sense this means more sustainable and less carbon intensive products and processes, which are recognised within procurement policies and valued by infrastructure construction and maintenance practitioners.

There are several products comprising warm mix asphalts (WMA) being used in Australia and overseas. From an Austroads perspective these need to be better understood in terms of their relative environmental and structural performance.

On behalf of its members Austroads sponsored a project (*TT1454: Performance of Warm Mix Asphalt Pavements*) to evaluate WMA technologies for Australian road conditions. A major element of the project was the planning and conduct of a comprehensive field validation assessment of a range of WMA and hotmix asphalt (HMA) surfacings in order that their performance could be compared and a draft WMA Evaluation Protocol for the conduct of validation trials assessed and appropriate changes made. An extensive laboratory testing program was also conducted to support the validation trial.

This report describes the planning and conduct of a validation trial of three thin (40 mm thick) warm mix asphalt surfacings (chemical additive, polymer additive, foaming) and a hotmix asphalt ‘control’ surfacing at a site in Melbourne, Australia. Issues addressed include the establishment of the validation site, the experimental design, a description of the site, details of the mixes tested, the condition parameters monitored, and the performance of the surfacings after two years of trafficking. Performance after two years of trafficking was excellent and also independent of asphalt mix type, type of warm mix asphalt, and the percentage of RAP (0–50%) incorporated into the mix.

In terms of the draft WMA Evaluation Protocol, the trial was far more detailed, in terms of demands, than a production/demonstration trial and much more in line with the requirements for a validation/implementation trial. The results of the validation trial only apply to the WMA surfacings manufactured with the particular technologies and binders trialled and for the traffic and environmental conditions experienced. In addition, only thin (nominally 40 mm thick) surfacings were tested. Further work is required to assess the structural performance of WMA pavements and any likely impacts on the structural design procedures currently documented in the Austroads guidelines.

ACKNOWLEDGEMENTS

The project was strongly supported by the Australian Asphalt Pavement Association (AAPA), members of which made extensive in-kind contributions to the laboratory and field validation elements of the project. The project was also strongly supported by VicRoads who also made a substantial in-kind contribution to the validation trial.

1 INTRODUCTION

The Australia Government has set a target of reducing greenhouse gas (GHG) emissions by 25% by 2020 compared with 2000 levels assuming there is global agreement to an ambitious program to stabilise the levels of GHGs in the atmosphere. Australia has undertaken to unconditionally reduce its emissions by 5% compared with 2000 levels by 2020 and by up to 15% by 2020 if the global agreement falls short of securing atmospheric stabilisation at 450 ppm carbon dioxide equivalent[1] ($CO_{2\text{-eq}}$). The aim in the longer-term is, by 2050, to reduce GHG emissions in Australia by 80% compared with the 2000 levels.

Emissions in Australia are projected to average about 580 Mt $CO_{2\text{-eq}}$ per year from 2008 to 2012, or 106% of the 1990 levels. Without further policy action, Australia's emissions are projected to continue to increase. By 2020, emissions are projected to reach 686 Mt $CO_{2\text{-eq}}$, or 24% above the 2000 levels. Australia's unconditional target of 5% represents a 23% decline below ‘business as usual’ (Department of Climate Change and Energy Efficiency 2010).

The Australian Government has introduced a carbon pricing scheme that takes effect from 1 July 2012. The *Clean Energy Bill 2011* was passed in the Lower House in October 2011. The carbon price will commence at $23 per tonne and be fixed for the first three years. On 1 July 2015 the carbon price will transition to a fully-flexible price under an emissions trading scheme where the carbon price will be determined by the market. Under the scheme, about 500 of Australia’s largest emitters will be required to buy permits for each tonne emitted.

The asphalt industry worldwide is committed to reducing the impacts of its operations on global warming and there are many global agreements and national and state legislative requirements which industry is obliged to meet. For example, the European Union (EU) is committed to reducing greenhouse gases under the terms of the Kyoto Agreement. There are also potentially attractive competitive advantages if lower-cost, reliable technologies can be developed and implemented.

The Australian asphalt industry wants to manage and use resources efficiently and to continually improve its environmental performance. Reducing greenhouse gas emissions that contribute to global warming is of increasing interest and concern to the industry. Industry across all sectors can achieve a significant reduction in $CO_{2\text{-eq}}$ emissions by improving energy efficiency in their manufacturing processes. The main source of emissions in the asphalt sector arises from the heating and drying of aggregates.

Although construction sector emissions represented only about 1.5% of overall greenhouse emissions in Australia in 1997–98[2], this sector is showing a willingness to adopt strategies that will lead to using energy more efficiently and to respond to the challenge of meeting emissions targets to avoid climate change. In a practical sense, this refers to the use of more sustainable and less carbon-intensive products and processes, which are recognised within procurement policies and valued by infrastructure construction and maintenance practitioners.

There are several products comprising warm mix asphalt (WMA) being used in Australia and overseas. From an Austroads Member Authority perspective these need to be better understood in terms of their relative environmental benefits and performance, including structural performance. All the issues associated with the adoption of WMA also need to be fully explored and understood.

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[1] Carbon dioxide equivalent ($CO_{2\text{-eq}}$) is a way of converting all greenhouse gases to a single value for ease of comparison. It is calculated by multiplying the mass of a gas by its global warming potential.

[2] Based on 1997–98 figures, the direct greenhouse gas emissions generated by the construction industry comprised 1.46% of the national emissions (Trewin 2003, p. 644).

1.1 Austroads Project TT1454

Austroads sponsored a project (*TT1454: Performance of Warm Mix Asphalt Pavements*) to evaluate WMA technologies for Australian road conditions. The project involved the following components:

1. The development of a WMA Evaluation Protocol, the purpose of which is to provide a guide to the evaluation of specific WMA technologies and processes such as additives, surfactants and foamed bitumen. The Protocol sets out the conduct of appropriate laboratory tests and field validation projects in order that the performance of WMA and conventional HMA can be compared. The Protocol is an evaluation tool only; it is not a specification. One of the main outputs of this project is the final version of the Protocol.
2. A literature review of existing CO_2 emission calculators with a view to recommending a system for inclusion into the WMA Evaluation Protocol. These include tools to determine the carbon footprint of road infrastructure and life cycle analysis methodologies to assist with materials and technologies selection. This will facilitate a more consistent approach to the calculation of carbon footprints.

   It was concluded that, in the absence of sufficient Australian-based emissions factors, it was premature to recommend a carbon calculation system for inclusion in the Austroads WMA Evaluation Protocol. However, the recent work of the Transport Authorities Greenhouse Group (TAGG) in coordinating the development of a greenhouse workbook and calculator, and the recommendation that it be adopted as a national standard, means that any further work would need to be in line with this recommendation.
3. A review of field trials of WMA technologies conducted in various countries in the world, with the emphasis on field performance data that could be used to complement the Austroads WMA evaluation field trial.
4. The planning and conduct of a comprehensive field validation assessment of a range of WMA and HMA surfacings in order that their performance can be compared and the draft Evaluation Protocol for the conduct of validation trials assessed and appropriate changes made. An extensive laboratory testing program was also conducted.

This report addresses a major component of Task 4 of this project. It presents details of the establishment of the validation sites including the experimental design, a description of the site, details of the surfacings tested, and the performance of the validation sites after two years of trafficking.

The project was strongly supported by the Australian Asphalt Pavement Association (AAPA), members of which made extensive in-kind contributions to the laboratory and field testing elements of the project. The project was also strongly supported by VicRoads who also made a substantial in-kind contribution to the trial.

2 WARM MIX ASPHALT

Warm mix asphalt (WMA) technologies involve additives and/or production processes which allow the temperature at which asphalt mixes can be produced and placed to be reduced – typically by 20–50 °C below that of hotmix asphalt (HMA). The reduction in energy associated with asphalt production at a lower temperature results in a reduction in greenhouse gas emissions. For example, D'Angelo et al. (2008) reported that the reductions in plant stack emissions from WMA production were very significant: 20–40% reduction in carbon dioxide (CO_2), 20–35% reduction in sulphur dioxide (SO_2), 10–30% reduction in carbon monoxide (CO), up to 50% reduction of volatile organic compounds (VOC) and 60–70% reduction in nitrous oxides (NOx). In terms of laboratory studies, Mallick, Bergendahl and Pakula (2009) reported a 32% reduction in CO_2 when the WMA mixing temperature was lowered by 20 °C.

In Australia, about 390 000 tonnes of CO_2 are generated annually from the 8 million tonnes of asphalt produced (Jenny 2009). A reduction in production temperature through the use of WMA technologies would roughly translate to a reduction of more than 120 000 tonnes of CO_2 per annum. This is a potentially significant impact on the Australian CO_2 balance.

As WMA technologies (new additives and/or production processes) can have similar transport and workability characteristics as HMA, they can be used as a compaction aid for stiff mixes. Other advantages associated with a reduction in asphalt production and compaction temperatures include: improved conditions for operators (less fumes), reduced binder aging during production, improved operational efficiency (earlier trafficking), extended paving seasons (paving in cool weather and/or at night) and the potential to increase haulage distances if the temperature of production is not lowered.

The concept of WMA originated in Europe in the early 1990s and, since then, a variety of technologies have emerged. Over the last five years, several new WMA technologies have been developed in the USA. Currently, WMA is being evaluated, and increasingly used, as a replacement for traditional HMA in many countries. Several WMA technologies have already been introduced into Australia.

It is important that the widespread and successful adoption of this technology in Australia is supported by a thorough understanding of overseas experience and the review of the performance of WMA under Australian conditions. Differences between current HMA practices (associated with material selection, material characterisation (specification requirements and performance-related laboratory testing), mix design, construction processes and standards and pavement design methodologies used in Australia, Europe and the USA might affect the approach to the implementation of WMA technologies in Australia.

2.1 WMA Evaluation Protocol

A draft *WMA Evaluation Protocol* was circulated for comment by the Asphalt Research Reference Group (ARRG) and Austroads in May 2010. It was written in such a way that, as a type of WMA was evaluated, the results could be distributed and discussed across Australian States and Territories and New Zealand through the Austroads framework. It is expected that the use of the Protocol will assist jurisdictions in the acceptance of the use of WMA without the need for additional testing and trials. The Protocol is an evaluation tool only; it is not a specification.

2.1.1 Evaluation Protocol: Field Validation

Sections 5 and 6 of the draft Protocol address the field validation of WMA mixes. Issues addressed include site selection, field validation details, initial field performance and short-term and long-term monitoring. Relevant material in the draft Protocol is referred to in the relevant sections of this report.

The Protocol includes the need to monitor the field performance of WMA and conventional HMA ‘controls’, i.e. manufactured using the same mix design method without the WMA additives or foaming. It is suggested in the Protocol that the field validation should be conducted after the successful completion of the testing of the laboratory and/or production mixes. Local asphalt specifications would form the basis for the acceptance of the asphalt works. At the completion of placement the asphalt should be homogeneous and not rut or ravel.

It was also suggested that care should be taken to ensure that only a single variable (i.e. the WMA process) is evaluated during the field validation. Factors that might affect the evaluation must be addressed adequately.

3 VALIDATION SITE: EXPERIMENT DESIGN

3.1 Site Selection Criteria

The validation site was selected to meet a number of criteria to ensure that the evaluation was conducted as objectively as possible. The criteria documented in the draft Protocol are:

- minimum length of 100 metres
- straight section, consistent crossfall and longitudinal grade
- reasonable shape – assessed visually and by roughness and shape testing using a multi-laser profilometer (MLP)
- strong structural condition (assessed visually and by pavement strength testing)
- uniform distress condition
- known traffic counts and commercial vehicle percentage
- medium to heavy traffic conditions
- all sites to be compacted to the same level of density
- minimum level of rutting and uniform rutting.

It is recommended in the draft Protocol that the validation sites, including the 'control' sections, be offset such that the following pattern is achieved on multi-lane roads:

direction of travel WMA section HMA 'control' section
direction of travel HMA 'control' section WMA section
(the HMA/WMA can be reversed to retain the pattern).

For single-lane roads the pattern should be:

direction of travel WMA section HMA 'control' section
(the HMA/WMA can be reversed to retain the pattern).

It is also recommended in the draft Protocol that the following information be recorded for each validation site(s):

- production details:
    - mix and bitumen type
    - bitumen content
    - other additives used (if any)
    - WMA type and concentration
    - date and time of production
    - production temperature
    - mix design details
    - tonnage of asphalt produced
    - haulage time (from plant to site)

- placement details:
  - site details, e.g. Site ID, road name, etc.
  - overlay, or mill and replace
  - thickness of asphalt laid
  - asphalt temperature upon arrival at the site
  - date and time of production
  - paver type
  - shuttle buggy (if used)
  - roller type and pattern.

Most of this information was collected during the validation trial. However, as some of the industry mixes were experimental (e.g. contained various percentages of RAP), mix design details were confidential.

3.2 Initial Field Performance

It was also important that the asphalt works met local applicable contractual or specification requirements. According to the draft Protocol, the following parameters should be measured and recorded:

- rutting at 10 metre intervals (using a 3 metre straight edge or MLP – minimum of nine lasers)
- texture at 10 metre intervals (using the sand patch method or the MLP)
- stripping potential (using Roads and Traffic Authority NSW (RTA) Test Method T649 (RTA NSW 2010) (optional).

In the case of this validation trial, rutting and texture was measured using an MLP. Some testing was also conducted on cores according to RTA T649 (RTA NSW 2010).

3.3 Performance Monitoring

The field performance of WMA under traffic and variable climatic conditions was the key factor in this project. It was therefore important that the validation sites were monitored for a number of critical performance parameters, both in the short term and long term.

3.3.1 Pre-construction

Crack sealing and patching of the existing site was conducted by VicRoads Metro North West Region. A summary of the patching conducted prior to construction is discussed in Section 4.3.1 of this report. This data was derived from a visual survey of patching and cracking prior to construction as typified by the data presented and discussed in Section 5.2.2. A condition survey was also conducted by ARRB and VicRoads prior to the placement of the overlays, as was a structural evaluation using the Falling Weight Deflectometer (FWD). The results of this testing are discussed in Section 5.3 to Section 5.6.

3.3.2 Construction

The following parameters were monitored before and during the construction of the validation sites:

- temperature of the asphalt when the mixes were in the auger and also in the mat after placement
- location/placement of the various asphalt mixes (chainage, etc.).

3.3.3 Short-term and Long-term Monitoring

Given the importance of field validations in demonstrating the viability of WMA for its adoption into practice by road authorities in Australia and New Zealand as soon as possible, it was agreed that any validation sites should be initially monitored for two summers, on the basis that any early problems with WMA will be identified during this period. The following performance parameters were to be measured and recorded at the end of two summers after the placement validation:

- cracking (visual assessment/Hawkeye)
- rutting at 10 metre intervals (using straightedge or MLP – minimum of nine lasers)
- texture at 10 metre intervals (using the sand patch method or MLP)
- stripping potential (according to RTA T649) (optional).

In the case of this validation trial, rutting and texture were measured using an MLP. Cameras attached to the MLP took a pictorial record of the condition of the surface. In addition, manual cracking surveys were conducted by VicRoads and ARRB staff.

It was recognised when the project was being developed that it would probably be important to continue to monitor the performance of the validation sites beyond the first two summers. However, as discussed later, this will not be necessary in this case.

4 DETAILS OF VALIDATION SITE

4.1 Location

The location selected for the validation trials was a south-bound (Melbourne-bound) section of Sydney Road (also called the Old Hume Highway). The site is predominantly flanked by industrial properties, with kerb and channel drainage and a table drain. The posted speed limit is 80 km/h. The site was selected by VicRoads Metro North West Region in consultation with the industry participants.

Photos of the validation site before treatment are shown in Figure 4.1.

Figure 4.1: Photos of validation site before treatment

The site had the following attributes:

- job commenced approximately 30 m south of Ainslie Road running south to Glenbarry Road (Melways reference Map 7, E1)
- three lanes, each approximately 3.5 metres wide
- length approximately 1335 m, including a signalised intersection located at an approximate chainage of 405 m
- AADT of 24 000, including 14% CVs (VicRoads records)
- existing surface: ultra-thin asphalt which was cracked and ravelled – normal end-of-service distress
- pavement assumed to be structurally sound with observed distress only related to surfacing.

4.2 Layout of Validation Sites

As the Old Hume Highway was a three-lane road at the location of the validation trial, the WMA and the HMA 'control' sections needed to be laid out in such a way that each mix type was subject to the same level of traffic as shown in Figure 4.2. The layout of the HMA and WMA sites could be reversed to retain the pattern.

↓ Direction of travel	**WMA section**	**HMA 'control' section**
	HMA 'control' section	**WMA section**

Figure 4.2: General layout of WMA and HMA validation sites

The WMA and HMA sites were laid out according to Figure 4.3 whilst general details of the mixes trialled are shown in Table 4.1. The three asphalt manufacturers taking part in the validation trials were assigned generic titles: A, B and C.

North					
Chainage (m)	Distance (m)	Lane 3 (fast)	Lane 2	Lane 1 (slow)	
0–160	160	WMA (A1) 0% RAP	HMA (B)	HMA (C)	Direction of Traffic ↓
160–335	175	WMA (A2) 10% RAP	WMA (B2) 10% RAP	WMA (C1) 0% RAP	
335–485	150	Intersection Type V WMA	Intersection Type V WMA	Intersection Type V HMA	
485–700	215	HMA (C)	HMA (A)	HMA (B)	
700–910	210	WMA (C3) 0% RAP	WMA (A2) 10% RAP	WMA (B1) 0% RAP	
910–1120	210	HMA (B)	HMA (C)	HMA (A)	
1120–1335	215	WMA (B1) 0% RAP	WMA (C2) 50% RAP	WMA (A1) 0% RAP	
South / Melbourne					

Figure 4.3: Layout of validation sites, (intersection not part of validation trial)

Table 4.1: General details of mixes tested in validation trial

A, B, C: HMA	14 mm HMA, 0% RAP, C320 Binder (VicRoads DGA Type H mix)
A1: WMA	14 mm WMA 0% RAP (organic additive)
A2: WMA	14 mm WMA 10% RAP (organic additive)
B1: WMA	14 mm WMA 0% RAP (water-based binder foaming)
B2: WMA	14 mm WMA 10% RAP (water-based binder foaming)
C1: WMA(1)	14 mm WMA 0% RAP (chemical additive)
C2: WMA(2)	14 mm WMA 0% RAP (water-based binder foaming)
C3: WMA(1)	14 mm WMA 50% RAP (water-based binder foaming)

Note that an organic additive (Sasobit®) and a chemical additive (CECABASE RT®) were tested, whilst the Astec water-based binder foaming method was used in all of the foaming applications. Various percentages of RAP (0%, 10%, 50%) were also tested. Details of the Astec foaming method are contained in: http://www.astecinc.com/index.php?option=com_content&view=article&id=117&Itemid=188.

4.3 Construction of Validation Sites

4.3.1 Patching Prior to Overlay

The pre-construction crack sealing and patching was conducted by VicRoads Metro North West Region at their cost; one or two turning lanes also needed treatment. A summary of the patching conducted prior to construction is presented in Table 4.2. This data was derived from a visual survey of patching and cracking prior to construction as typified by the data presented in Figure 5.2 and discussed in Section 5.2.2.

Table 4.2: Details of patching conducted prior to construction

Lane	Start chainage (m)	End chainage (m)	Approx. length (m)	Approx. width (m)	Approx. total area (m^2)	Design asphalt (tonnes)
Slow	300	335	35	3.5	123	29.4
Centre	485	487	2	3.0	6	1.4
Slow & centre	455	499	44	4.0	176	42.2
Slow	610	682	72	2.0	144	34.6
Slow	700	730	30	5.0	150	36.0
Slow	730	815	85	3.5	298	71.4
Slow	815	880	65	2.0	130	31.2
Slow	915	943	28	2.0	56	13.4
Slow	959	977	18	3.5	63	15.1
Slow	986	1002	16	2.0	32	7.7
Slow	1014	1028	14	2.0	28	6.7

Notes:

Nominal thickness of patching: 100 mm.

Asphalt: VicRoads Type SP Size 20.

4.3.2 Construction of Overlays

Construction was conducted on the nights of Tuesday 20, Wednesday 21 and Saturday 24 April 2010. As the trial site was initially identified as part of the VicRoads maintenance program, the construction costs were met by VicRoads Metro North region. The industry participants met the costs associated with the preparation and testing of the laboratory samples.

The Project Working Group agreed that the HMA and WMA surfacings would be placed by one of the contractors using the same equipment and that temperature and density measurements would be conducted during and after placement. The placement of the asphalt was carried out in accordance with VicRoads Specification 407 (VicRoads 2007).

It was also agreed that an extensive program of testing would be undertaken at the asphalt laboratories at the time of asphalt placement. Laboratory technicians from VicRoads Technical Consulting, other jurisdictions and ARRB agreed to observe the manufacture of the laboratory samples. The testing included modulus, wheel tracking, fatigue, moisture sensitivity and bitumen viscosity, as well as the normal testing for bitumen content, volumetrics, etc.

Operations at the site were managed by the contractor installing the surfacings. All field visitors were required to undergo an on-site safety induction. Traffic management for the works included a full detour of the southbound carriageway.

4.4 Data Collected During Construction

4.4.1 Location and Temperature of Mixes at Construction

The mixes were manufactured by the three industry participants in their plants and trucked to the site where they were placed by the contractor appointed to install all the sites, including the HMA ‘control’ sites and the intersection. As the mixes arrived at the site the location of the pavers was noted. The temperature of the mixes was also recorded, both when the mixes were in the auger and also in the mat after placement. This data is presented in Appendix A, whilst a summary is presented in Table 4.3.

Circumstances demanded that two operators were required to collect the location and temperature data and, as a result, there was some variation related to reproducibility. Generally, however, the mat temperature was lower than the auger temperature. The overall average temperature of the HMA in the mat, not including the intersection mixes, was 154 °C whilst the overall average temperature of the WMA in the mat was 125 °C. The data also suggested that the mixes were placed very close to the designated chainages.

4.4.2 Thickness of Asphalt Cores

Coring was conducted so that the final compacted thickness of the surfacing could be checked against the nominal design thickness of 40 mm. Data was, however, only provided by one company. A summary of this data is presented in Table 4.4.

The data pertain to six cores in each site. It can be seen that there was some variation in the thickness and that the mean thicknesses were lower than the nominal thickness of 40 mm.

Table 4.3: Summary of temperature data (asphalt placement)

Company/Mix type	Average temperature (°C)	
	Auger	Mat
Slow lane		
A: HMA	153	146
B: HMA	164	159
C: HMA	142	141
A: WMA – 0% RAP	128	121
B: WMA – 0% RAP	141	131
C: WMA(1) – 0% RAP	126	118
Middle lane		
A: HMA	164	158
B: HMA	161	152
C: HMA	168	161
A: WMA – 10% RAP	124	115
B: WMA – 10% RAP	139	125
C: WMA(1) – 50% RAP	133	125
Fast lane		
B: HMA	158	153
C: HMA	168	163
A: WMA – 0% RAP	133	130
A: WMA – 10% RAP	125	119
B: WMA – 0% RAP	132	127
C: WMA(2) – 0% RAP	140	136

Table 4.4: Summary of core thickness data

Site/Mix	Core thickness (mm)		
	Mean	Std dev.	Range
HMA	35.6	4.3	30.8–42.2
WMA(1) 0% RAP	36.1	2.6	32.8–39.6
WMA(2) 0% RAP	34.1	4.2	29.8–40.4
WMA(1) 50% RAP	35.3	1.4	34.7–39.0

5 DATA COLLECTION AND ANALYSIS

5.1 Data Collection

5.1.1 Cracking

One of the parameters monitored during the trial was the generation of surface cracking in the WMA and the HMA and its location compared to the cracking in the existing surface. Cracking was measured using two methods: manual collection and video imaging using digital cameras mounted on ARRB's network survey vehicle (NSV).

Manual method

The manual collection method of crack mapping requires a person to observe and record cracking and patching, etc. on-site. The cracking information is later transferred to a spreadsheet for analysis. The information recorded (location, length, width and type of cracking) is necessarily somewhat subjective and requires some interpretation or estimation during the analysis.

Network survey vehicle

As already discussed, the validation site was also surveyed using the NSV, which consists of the survey equipment detailed in Table 5.1 and Figure 5.1. Digital cameras were used to record digital images in May 2010 (shortly after construction) and in December 2010. These images were later processed at ARRB.

The NSV collected images every 5 m along the validation site. The images were reviewed, cracking and patching of the pavement estimated and the data then placed into approximate performance bands, i.e. 0–5%, or 5–10% of the surface area cracked, etc.

Table 5.1: Network survey vehicle equipment

Equipment	Description
Digital imaging system (DIS)	The DIS captures images every five metres of travel from cameras orientated in different directions. A geospatial reference is captured and associated with each image, making it possible to display information in a GIS. Each camera is calibrated, making it possible to measure and extract geometric data including height, length and width data about inventory and condition.
Digital laser profiler (DLP)	The DLP is used to capture a three-dimensional profile of the pavement surface. This profile is then used to calculate pavement roughness, rutting and texture.
GIPSI-Trac	The GIPSI-Trac device is used to capture road geometry and location data. It consists of a GPS logger, accelerometer and gyroscopes. Effectively the combination of accelerometers and gyroscopes measures the change in vehicle position in all directions. The inertial guidance system of the GIPSI-Trac is smart enough to ensure that valid data is captured, even in the event of satellites becoming temporarily unavailable.
Distance transducer	A distance transducer measuring 4000 pulses per tyre revolution is attached to a rear tyre. It has been calibrated to a measured distance that has been established using traditional geodetic techniques. It is used to link each system to a common linear reference.

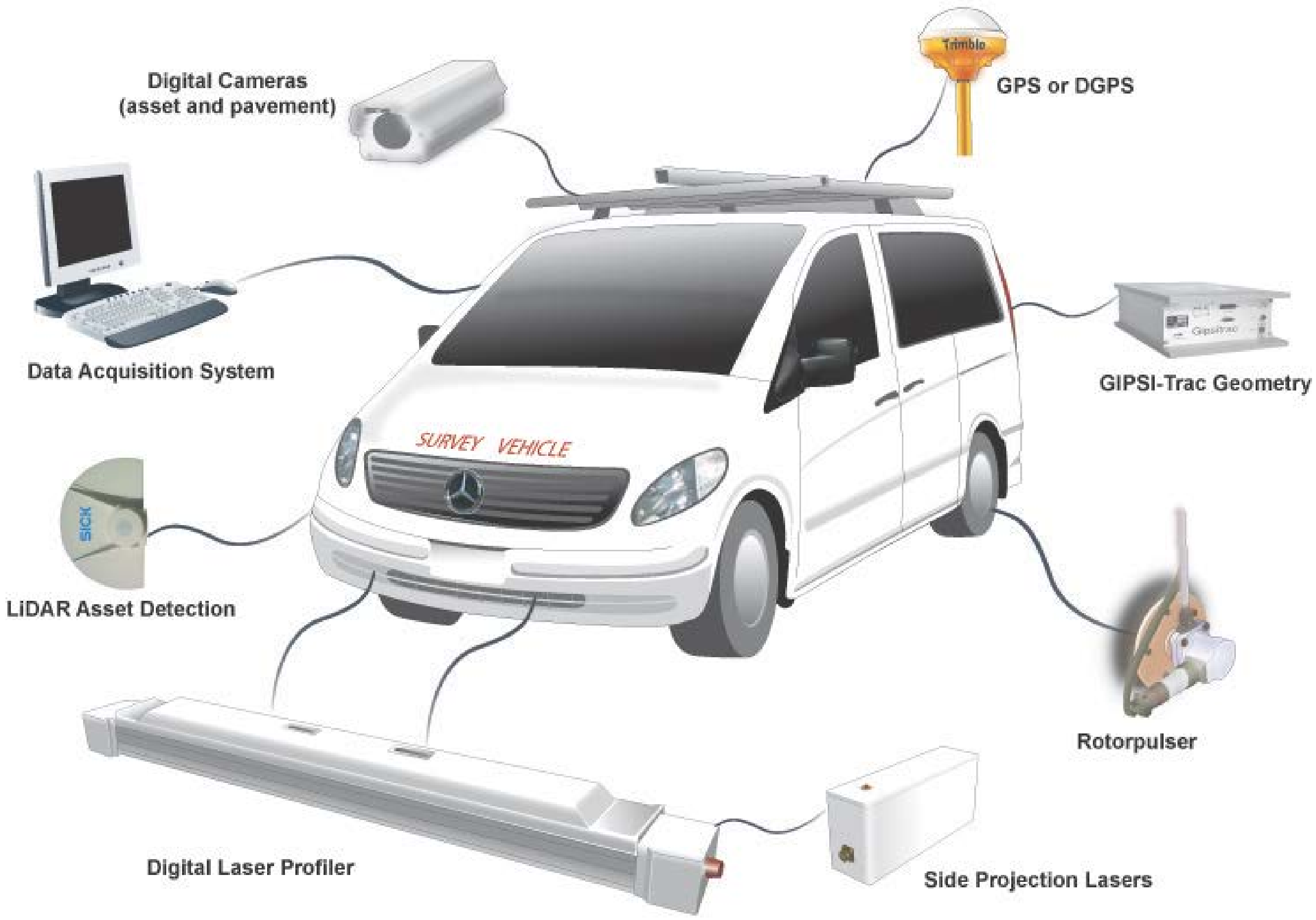


Figure 5.1: NSV and equipment

5.1.2 Condition Monitoring

Roughness, rutting and texture data was collected using the ARRB NSV in April 2010 (just prior to overlay), May 2010 (shortly after overlay), December 2010, July 2011 and March 2012. Roughness data was also collected by VicRoads (in the slow lane only) in January 2009 and January 2011. Deflection (strength) testing was conducted using the Falling Weight Deflectometer (FWD) in March 2010, August 2010 and August 2011.

5.2 Analysis of Data

5.2.1 Traffic

The limited data available suggests that the traffic was in line with expectations (i.e. AADT of about 24 000, including about 14% CVs).

5.2.2 Cracking: Manual Survey

The first manual cracking survey was conducted in March 2010 on the original surface about one month prior to patching and overlay. This survey was conducted by VicRoads, with the information then transferred into a spread sheet by ARRB.

An example of the data collected manually by VicRoads is shown in Figure 5.2. The data was collected with the chainage divided into 5 m long sections with cracking reported in terms of the ‘percentage’ of the area in the 5 m long section that was cracked. The start and end points of the location of the cracks were measured and recorded; however, as crack width was not recorded, estimations of crack width and size were used, when required, to generate the percentage measures. As such, this data is not an absolute measure but merely a comparison against the cracking over the remainder of the test section and also to the cracking determined by the digital cameras attached to the NSV.

The cracking was characterised in terms of the guidelines presented in Austroads (2011):

CR	crocodile cracking
CL	longitudinal cracking
CT	transverse cracking
CD	diagonal cracking
PA	patching

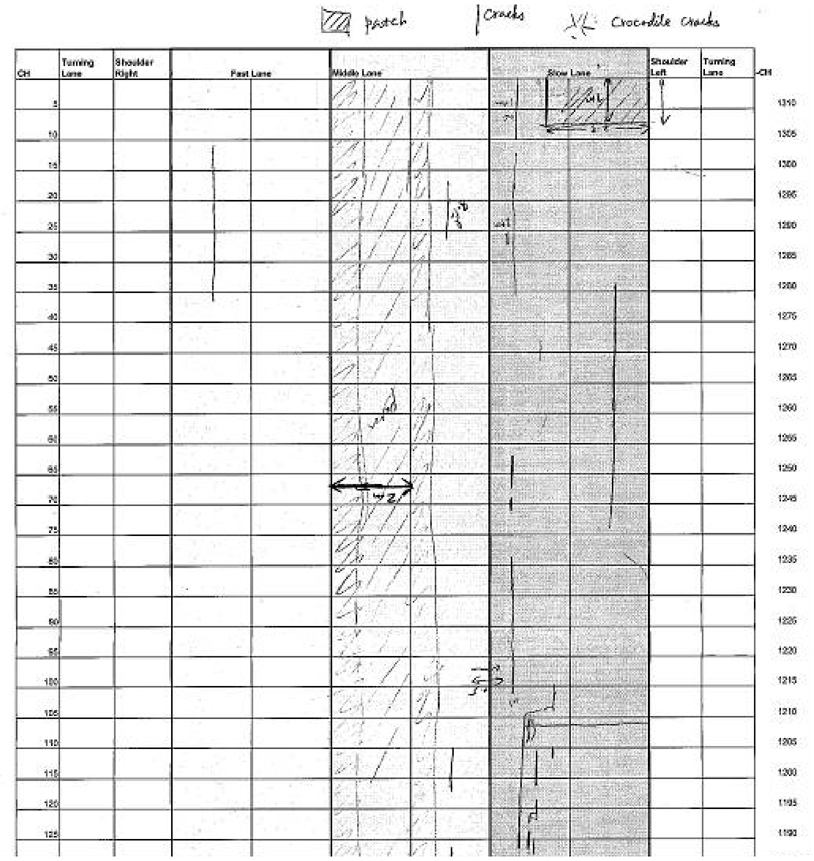
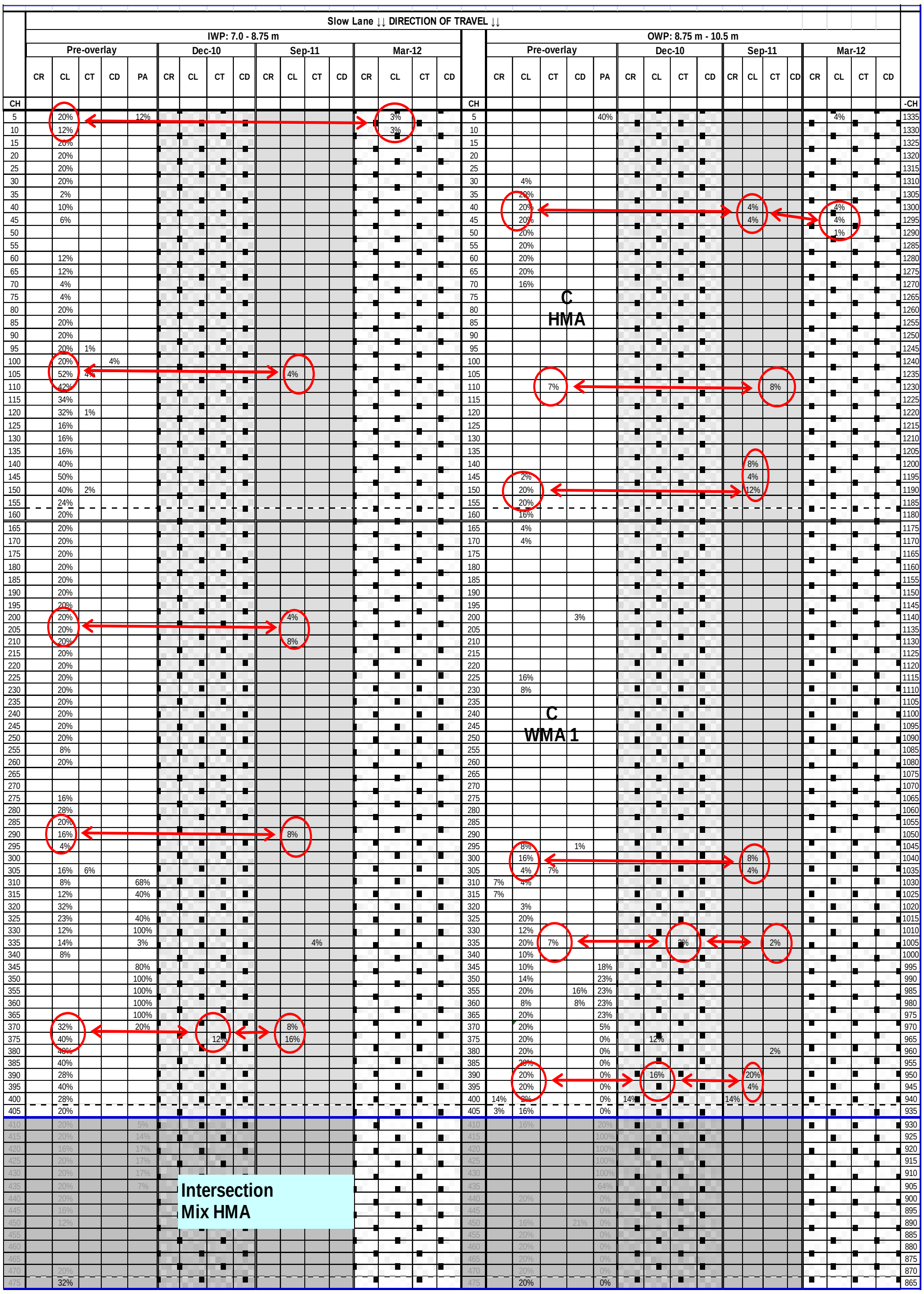


Figure 5.2: Portion of manual crack map as prepared by VicRoads

Development of cracking

A comparison of the cracking in the original surface of the most heavily-trafficked (slow) lane prior to overlay and in December 2010, September 2011 and March 2012 (almost two years after the sites were opened to traffic) is shown in Figure 5.3, Figure 5.4 and Figure 5.5. It can be seen that:

- the extent of cracking after almost two years of trafficking, compared to the extent of cracking prior to patching and overlay, was small
- almost all of the cracking that was observed appeared to have reflected through from the original surface
- no cracking was observed in the middle lane whilst some minor (shear) cracking observed in one section of the fast lane could be attributed to differential movement under the surfacing compared to the movement under the concrete kerb and channel.



Notes:

CR: crocodile cracking

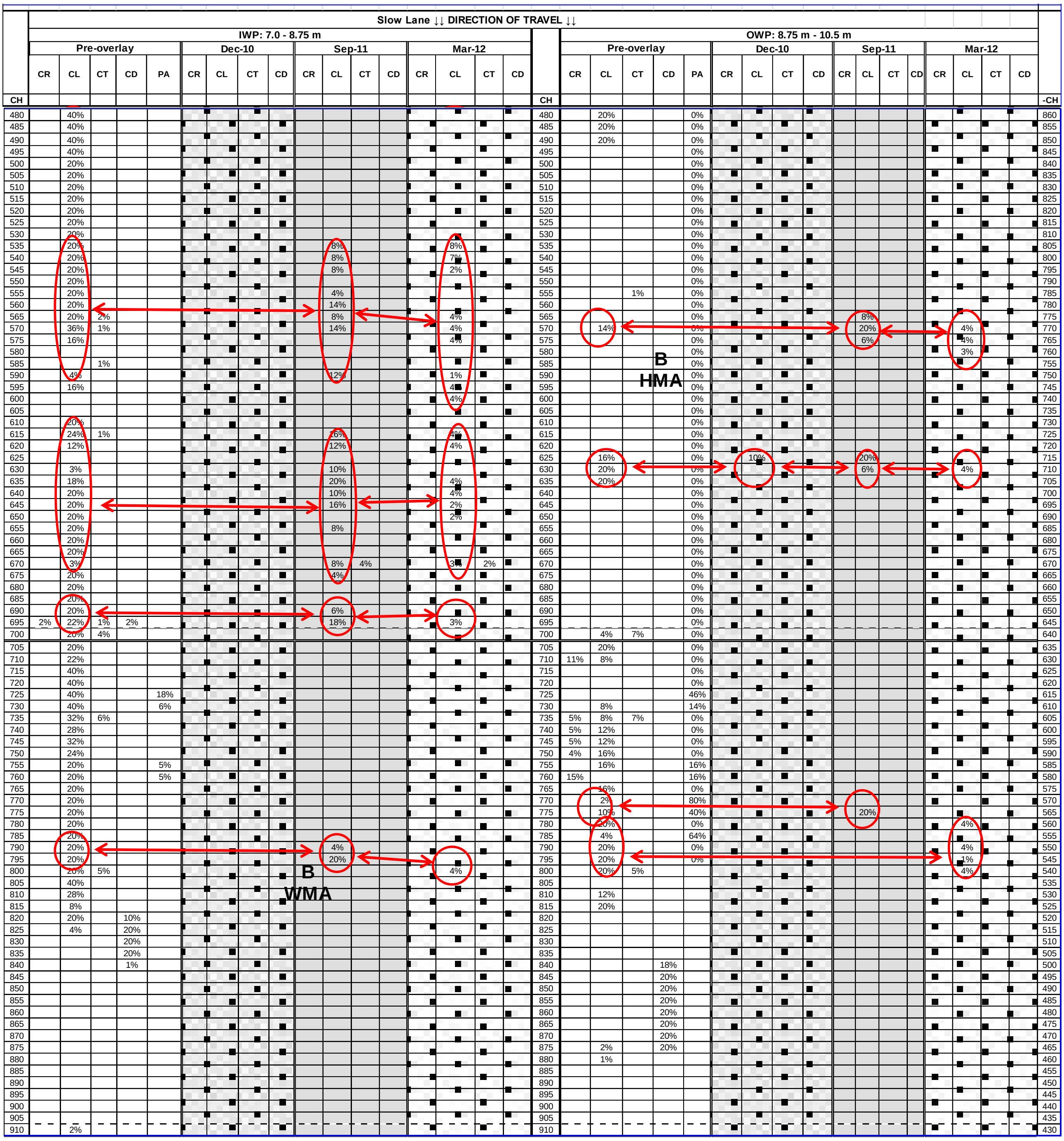
CL: longitudinal cracking

CT: transverse cracking

CD: diagonal cracking

PA: patching.

Figure 5.3: Comparison of cracking in original surface and in March 2012: slow lane; manual survey (chainage 0–475 m); (data for intersection mix not included in analysis)



	Slow Lane ↓↓ DIRECTION OF TRAVEL ↓↓																																			
	IWP: 7.0 - 8.75 m																		OWP: 8.75 m - 10.5 m																	
	Pre-overlay					Dec-10				Sep-11				Mar-12					Pre-overlay					Dec-10				Sep-11				Mar-12				
CH	CR	CL	CT	CD	PA	CR	CL	CT	CD	CR	CL	CT	CD	CR	CL	CT	CD	CH	CR	CL	CT	CD	PA	CR	CL	CT	CD	CR	CL	CT	CD	CR	CL	CT	CD	-CH
480		40%																480		20%			0%													860
485		40%																485		20%			0%													855
490		40%																490		20%			0%													850
495		40%																495					0%													845
500		20%																500					0%													840
505		20%																505					0%													835
510		20%																510					0%													830
515		20%																515					0%													825
520		20%																520					0%													820
525		20%																525					0%													815
530		20%																530					0%													810
535		20%									8%				8%			535					0%													805
540		20%									8%				7%			540					0%													800
545		20%									8%				2%			545					0%													795
550		20%																550					0%													790
555		20%									4%							555			1%		0%													785
560		20%									14%							560					0%													780
565		20%	2%								8%				4%			565					0%						8%							775
570		36%	1%								14%				4%			570		14%			0%						20%				4%			770
575		16%													4%			575					0%						6%				4%			765
580																		580					0%										3%			760
585			1%															585					0%													755
590		4%									12%				1%			590					0%													750
595		16%													4%			595					0%													745
600															4%			600					0%													740
605																		605					0%													735
610		20%																610					0%													730
615		24%	1%								16%				4%			615					0%													725
620		12%									12%				4%			620					0%													720
625																		625		16%			0%		10%				20%							715
630		3%									10%							630		20%			0%						6%				4%			710
635		18%									20%				4%			635		20%			0%													705
640		20%									10%				4%			640					0%													700
645		20%									16%				2%			645					0%													695
650		20%													2%			650					0%													690
655		20%									8%							655					0%													685
660		20%																660					0%													680
665		20%																665					0%													675
670		3%									8%	4%			3%	2%		670					0%													670
675		20%									4%							675					0%													665
680		20%																680					0%													660
685		20%																685					0%													655
690		20%									6%							690					0%													650
695	2%	22%	1%	2%							18%				3%			695					0%													645
700		20%	4%															700		4%	7%		0%													640
705		20%																705		20%			0%													635
710		22%																710	11%	8%			0%													630
715		40%																715					0%													625
720		40%																720					0%													620
725		40%			18%													725					46%													615
730		40%			6%													730		8%			14%													610
735		32%	6%															735	5%	8%	7%		0%													605
740		28%																740	5%	12%			0%													600
745		32%																745	5%	12%			0%													595
750		24%																750	4%	16%			0%													590
755		20%			5%													755		16%			16%													585
760		20%			5%													760	15%				16%													580
765		20%																765		16%			0%													575
770		20%																770		2%			80%													570
775		20%																775		10%			40%						20%							565
780		20%																780		20%			0%										4%			560
785		20%																785		4%			64%													555
790		20%									4%							790		20%			0%										4%			550
795		20%									20%							795		20%			0%										1%			545
800		20%	5%												4%			800		20%	5%												4%			540
805		40%																805																		535
810		28%																810		12%																530
815		8%																815		20%																525
820		20%		10%														820																		520
825		4%		20%														825																		515
830				20%														830																		510
835				20%														835																		505
840				1%														840				18%														500
845																		845				20%														495
850																		850				20%														490
855																		855				20%														485
860																		860				20%														480
865																		865				20%														475
870																		870				20%														470
875																		875		2%		20%														465
880																		880		1%																460
885																		885																		455
890																		890																		450
895																		895																		445
900																		900																		440
905																		905																		435
910		2%																910																		430

Notes:

CR: crocodile cracking

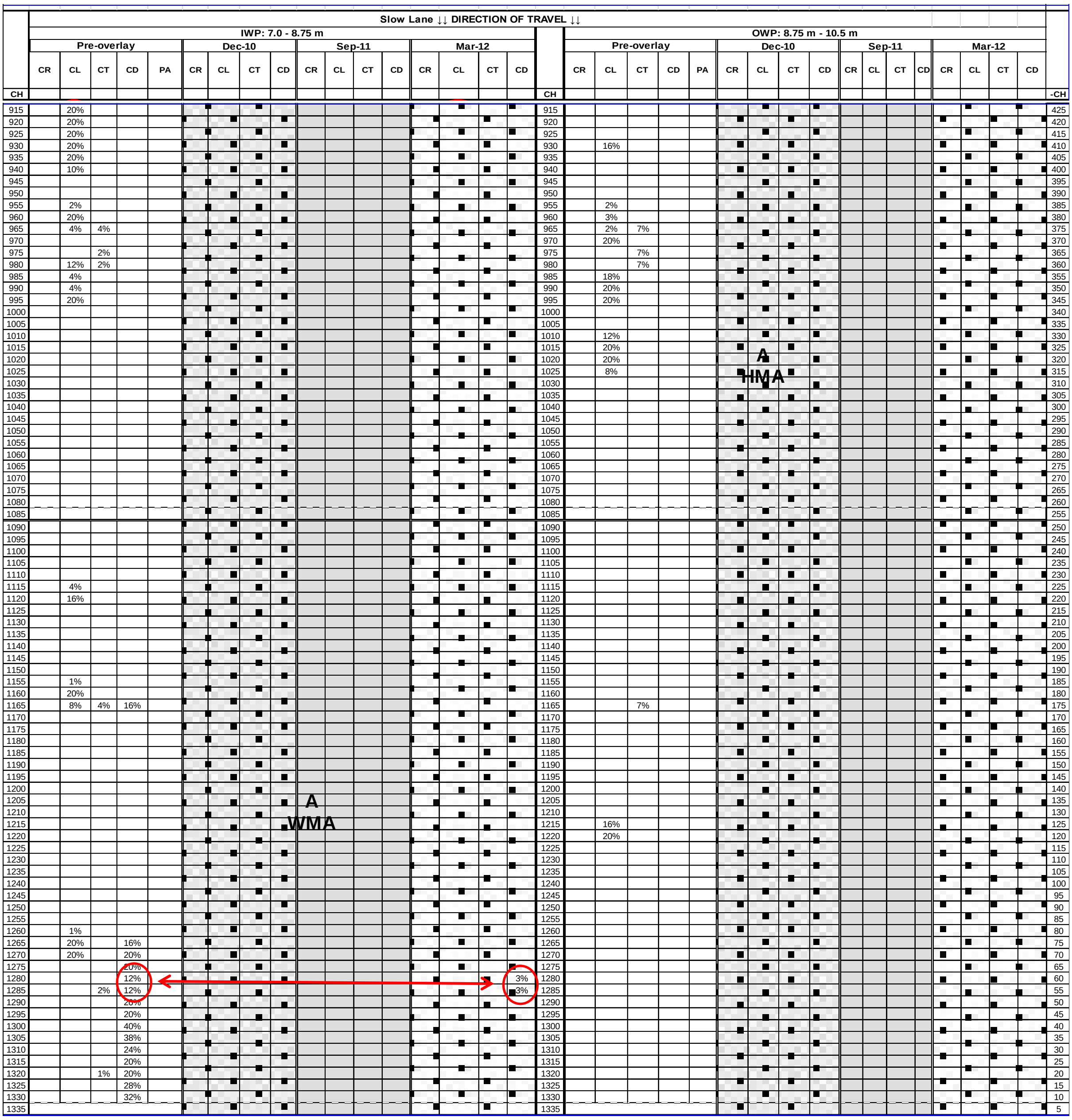
CL: longitudinal cracking

CT: transverse cracking

CD: diagonal cracking

PA: patching.

Figure 5.4: Comparison of cracking in original surface and in March 2012: slow lane; manual survey (chainage 480–910 m)



	Slow Lane ↓↓ DIRECTION OF TRAVEL ↓↓																																			
	IWP: 7.0 - 8.75 m																		OWP: 8.75 m - 10.5 m																	
	Pre-overlay					Dec-10				Sep-11				Mar-12					Pre-overlay					Dec-10				Sep-11				Mar-12				
CH	CR	CL	CT	CD	PA	CR	CL	CT	CD	CR	CL	CT	CD	CR	CL	CT	CD	CH	CR	CL	CT	CD	PA	CR	CL	CT	CD	CR	CL	CT	CD	CR	CL	CT	CD	-CH
915		20%																915																		425
920		20%																920																		420
925		20%																925																		415
930		20%																930		16%																410
935		20%																935																		405
940		10%																940																		400
945																		945																		395
950																		950																		390
955		2%																955		2%																385
960		20%																960		3%																380
965		4%	4%															965		2%	7%															375
970																		970		20%																370
975			2%															975			7%															365
980		12%	2%															980			7%															360
985		4%																985		18%																355
990		4%																990		20%																350
995		20%																995		20%																345
1000																		1000																		340
1005																		1005																		335
1010																		1010		12%																330
1015																		1015		20%																325
1020																		1020		20%																320
1025																		1025		8%																315
1030																		1030																		310
1035																		1035																		305
1040																		1040																		300
1045																		1045																		295
1050																		1050																		290
1055																		1055																		285
1060																		1060																		280
1065																		1065																		275
1070																		1070																		270
1075																		1075																		265
1080																		1080																		260
1085																		1085																		255
1090																		1090																		250
1095																		1095																		245
1100																		1100																		240
1105																		1105																		235
1110																		1110																		230
1115		4%																1115																		225
1120		16%																1120																		220
1125																		1125																		215
1130																		1130																		210
1135																		1135																		205
1140																		1140																		200
1145																		1145																		195
1150																		1150																		190
1155		1%																1155																		185
1160		20%																1160																		180
1165		8%	4%	16%														1165			7%															175
1170																		1170																		170
1175																		1175																		165
1180																		1180																		160
1185																		1185																		155
1190																		1190																		150
1195																		1195																		145
1200																		1200																		140
1205																		1205																		135
1210																		1210																		130
1215																		1215		16%																125
1220																		1220		20%																120
1225																		1225																		115
1230																		1230																		110
1235																		1235																		105
1240																		1240																		100
1245																		1245																		95
1250																		1250																		90
1255																		1255																		85
1260		1%																1260																		80
1265		20%		16%														1265																		75
1270		20%		20%														1270																		70
1275				20%														1275																		65
1280				12%													3%	1280																		60
1285			2%	12%													3%	1285																		55
1290				20%														1290																		50
1295				20%														1295																		45
1300				40%														1300																		40
1305				38%														1305																		35
1310				24%														1310																		30
1315				20%														1315																		25
1320			1%	20%														1320																		20
1325				28%														1325																		15
1330				32%														1330																		10
1335																		1335																		5

Notes:

CR: crocodile cracking

CL: longitudinal cracking

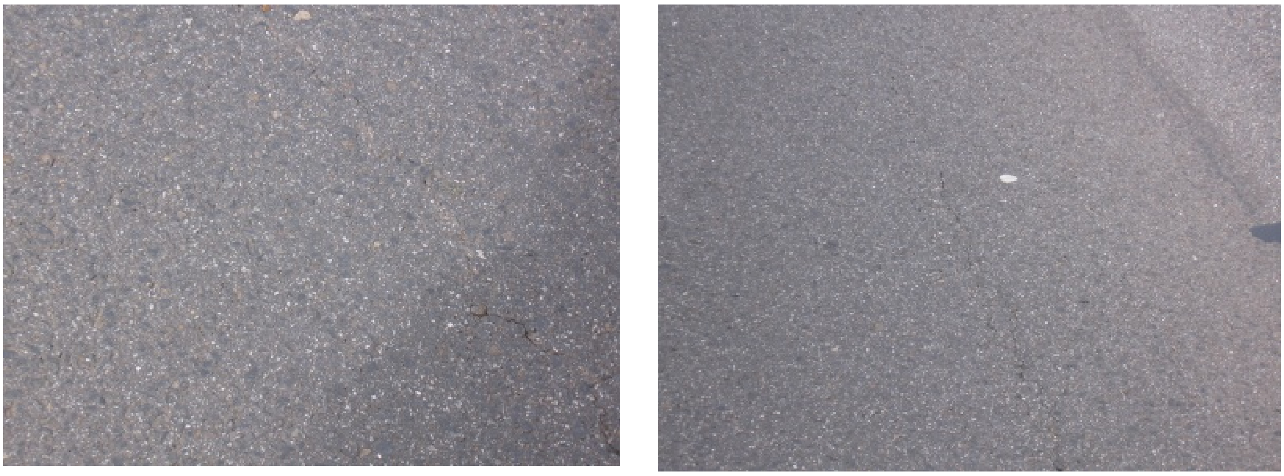
CT: transverse cracking

CD: diagonal cracking

PA: patching.

Figure 5.5: Comparison of cracking in original surface and in March 2012: slow lane; manual survey (chainage 910–1335 m)

Some photos of cracking observed in the survey conducted in September 2011, and typical of that observed in March 2012, are shown in Figure 5.6.



Cracking: slow lane, OWP
chainage 143 m

Cracking: slow lane, OWP
chainage 292 m

Cracking: slow lane, OWP
chainage 611 m

Cracking in fast lane between
OWP and kerb

Figure 5.6: Cracking in surface after almost 18 months of trafficking (September 2011)

5.2.3 Cracking: Network Survey Vehicle

A comparison of imaging data collected by the NSV on the original surface prior to the placement of the overlays (March 2010) and in December 2010 is shown in Table 5.2. The influence of the overlay on surface condition (in this case cracking) is clearly demonstrated.

5.2.4 Comparison of Methods

The two methods used to collect the cracking data were compared and a sample of the results for the first 160 metre length in the slow lane of the validation site is shown in Table 5.3. This data is typical of that recoded throughout the site.

Table 5.2: Comparison of NSV cracking data (March 2010 and December 2010) (chainage 0–160 m)

CH (m)	Slow **lane** ↓↓ direction of travel ↓↓																			
	IWP: 7.0–8.75 m										OWP: 8.75–10.5 m									
	Original (March 2010) (%)					December 2010 (%)					Original (March 2010) (%)					December 2010 (%)				
	CR	CL	CM	CT	CD	CC	CR	CL	CM	CT	CR	CL	CM	CT	CD	CC	CR	CL	CM	CT
5																				
10																				
15																				
20																		<2.5		
25			<5	<5				<2.5												
30			10–20											5–10						
35			<5																	
40			<5										<5							
45			<5											5–10						
50			<5									5–10								
55			<5									5–10								
60			<5											5–10						
65			<5																	
70			5–10																	
75				5–10																
80			5–10																	
85			<5																	
90			<5																	
95			<5																	
100			<5																	
105			<5																	
110				10–20																
115				10–20	<5										<5					
120				10–20																
125			10–20															<2.5		
130			5–10																	
135			5–10										<5							
140			<5																	
145				<5																
150			5–10										5–10							
155				5–10									<5							
160				10–20										<5						

Whilst the two methods generated quite comparable results, there were some differences in the data, including the following:

- Whilst the general location of the cracks can be recorded quite well using the manual method, the level of detail is limited to what can be reasonably recorded. It is difficult and time-consuming to accurately measure crack lengths and widths and this data must be interpreted and entered into a spread sheet.
- The data collected by the NSV can be recalled and reviewed at any time. The digital pavement camera was not used in the initial survey, so crack determinations were reliant on the forward-facing cameras only. These provide a lower fidelity view of the road surface. The second survey involved the use of the digital pavement camera.
- The on-site physical inspections required the observers to record the cracks for the whole length of the test site, and over all three lanes. The collection of data involving three lanes of road, each about 1.3 km long, was obviously very time-consuming and involved traffic control. The use of this method is clearly not suited to more extensive surveys. Alternatively, the NSV travels over the site at a speed of 80 km/h, and the data can be analysed later, requiring far less effort on site.
- The transfer of the manually-collected data into a spread sheet is a time-consuming task and can be open to error, particularly if the data notes are inadequate or unclear. On the other hand, the data collected by the NSV is reviewed by an operator and the results can be entered into a database or spread sheet. The NSV provides a visual record of the state of the road at the time of the survey, which can be stored permanently and reviewed at any time. No such review of the site ‘after the fact’ is possible with manual surveys.
- The manual survey can only reliably record longitudinal and crocodile cracking. The NSV survey generates a greater variety of crack type, as images of the crack can be reviewed and classified immediately, without the intermediary step of transferring through a hand-drawn ‘crack map’ which inherently simplifies the data that is recorded.

Table 5.3: Comparison of NSV cracking data (manual method and Hawkeye) (chainage 0–160 m)

CH (m)	Slow lane ↓↓ direction of travel ↓↓																	
	IWP: 7.0–8.75 m									OWP: 8.75–10.5 m								
	Manual (%)					Hawkeye (%)				Manual (%)					Hawkeye (%)			
	CR	CL	CT	CD	PA	CR	CL	CT	CD	CR	CL	CT	CD	PA	CR	CL	CT	CD
5		20			26									100				
10		20			12									40				
15		12																
20		20																
25		20					<5	<5										
30		20					10–20											5–10
35		20					<5				4							
40		2.4					<5				20						<5	
45		10.4					<5%				20							5–10
50		6.4					<5				20				5–10			
55							<5				20				5–10			
60							<5				20							5–10
65		12					<5				20							
70		12					5–10				20							
75		4						5–10			16							
80		4					5–10											
85		20					<5											
90		20					<5											
95		20					<5											
100		20	0.8				<5											
105		20.4		4			<5											
110		5	4.0					10–20				7						
115		41.6						10–20	<5									
120		33.6						10–20										
125		32	0.8				10–20											
130		16					5–10											
135		16					5–10										<5	
140		16					<5											
145		40						<5										
150		49.6					5–10				1.6						5–10	
155		40	1.6					5–10			20						<5	
160		24						10–20			20							<5

- The manual method can be more accurate because the surveyors can spend as much time as is practicably necessary to record any cracking.

In summary, the manual method is suited to ‘project-level’ surveys, whilst the use of digital cameras is more suited to ‘network-level’ surveys.

5.3 Roughness

As already discussed, roughness data was collected in January 2009 (VicRoads, slow lane only), April 2010 (ARRB – just before overlay), May 2010 (ARRB – just after overlay), December 2010 (ARRB), January 2011 (VicRoads, slow lane only), July 2011 (ARRB) and March 2012 (ARRB). In analysing the data, it should be noted that, in the roughness calculations, the VicRoads data was omitted, as the 100 m long data sets might have skewed the accuracy of the results.

A summary of the roughness data, averaged over each five metre length of section in each lane in the validation site, and also the overall average roughness, is presented in Table 5.4, whilst the average roughness in each site and lane is shown in Table 5.5.

Table 5.4: Change in average roughness over time

Lane	Average roughness (IRI)						
	January 2009 (VicRoads)	April 2010 (before overlay) (ARRB)	May 2010 (after overlay) (ARRB)	December 2010 (ARRB)	January 2011 (VicRoads)	July 2011 (ARRB)	March 2012 (ARRB)
Slow	3.17	2.38	1.83	1.93	2.02	1.88	1.96
Middle		2.76	1.32	1.44		1.45	1.47
Fast		2.28	1.55	1.74		1.84	1.80
Overall		*2.47*	*1.57*	*1.71*		*1.72*	*1.74*

It is also clear that there had been very little change in roughness levels since the overlay was placed and also that the performance of the validation sites is both satisfactory and uniform, i.e. the roughness levels were independent of both generic mix type (HMA and WMA) and type of WMA mix (foam process, additives, percentage of RAP, etc.). The data in the middle and fast lanes showed a similar trend.

The variation in average roughness in the slow lane over time is also shown in Figure 5.7. The peak IRI value of about 7.0 in the slow lane relates to the survey conducted by VicRoads in January 2009, about 15 months prior to the site being overlaid, whilst the peak value of about 4.0 relates to the survey conducted in April 2010 just prior to the overlay being installed.

The influence of the overlay, in terms of a reduction in roughness, is clearly evident, as is the fact that the average roughness levels after almost two years of trafficking were still low, with only a small increase in absolute values since the trial commenced.

Table 5.5: Average roughness (IRI) in each site and lane

Chainage (m)	Mix type/ Company	Average roughness (IRI)					
		April 2010 (before overlay)	May 2010 (after overlay)	December 2010	July 2011	March 2012	Change from May 2010 to March 2012
Slow lane							
0–160	HMA (C)	2.93	1.76	1.83	1.95	1.97	0.21
160–335	WMA (C1) (0% RAP)	2.20	1.76	1.76	1.71	1.79	0.03
485–700	HMA (B)	1.71	1.20	1.28	1.38	1.42	0.22
700–910	WMA (B1) (0% RAP)	2.98	2.25	2.27	2.17	2.32	0.06
910–1120	HMA (A)	2.81	2.00	2.14	2.11	2.08	0.09
1120–1335	WMA (A1) (0% RAP)	1.64	1.99	2.30	1.97	2.18	0.19
Average		2.38	1.83	1.93	1.88	1.96	0.13
Middle lane							
0–160	HMA (B)	3.43	1.56	1.73	1.89	1.84	0.28
160–335	WMA (B2) (10% RAP)	2.63	1.17	1.22	1.25	1.22	0.05
485–700	HMA (A)	2.53	1.17	1.21	1.19	1.23	0.06
700–910	WMA (A2) (10% RAP)	2.28	1.38	1.47	1.46	1.48	0.10
910–1120	HMA (C)	2.66	1.22	1.31	1.36	1.34	0.12
1120–1335	WMA (C2) (50% RAP)	3.04	1.43	1.71	1.56	1.68	0.25
Average		2.76	1.32	1.44	1.45	1.47	0.14
Fast lane							
0–160	WMA (A1) (0% RAP)	2.25	1.81	2.06	2.21	2.20	0.38
160–335	WMA (A2) (10% RAP)	2.05	1.78	1.91	2.01	2.00	0.22
485–700	HMA (C)	1.95	1.16	1.26	1.29	1.25	0.09
700–910	WMA (C3) (0% RAP)	1.86	1.33	1.32	1.40	1.31	-0.01
910–1120	HMA (B)	2.86	1.64	1.94	2.06	1.97	0.33
1120–1335	WMA (B1) (0% RAP)	2.68	1.61	1.97	2.04	2.05	0.44
Average		2.28	1.55	1.74	1.84	1.80	0.24

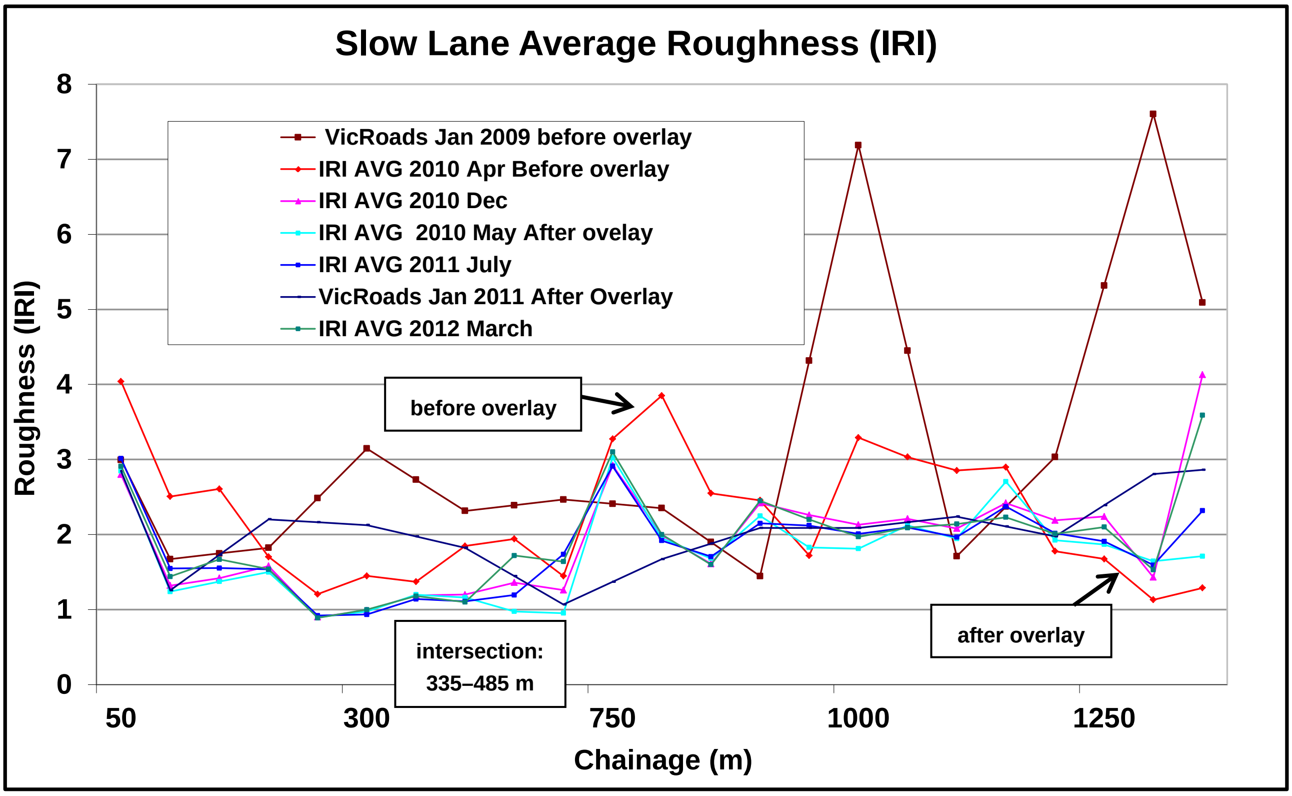


Figure 5.7: Variation in average roughness in the slow lane over time

5.4 Rutting

Rutting data was collected using the ARRB NSV in April 2010 (just before overlay), May 2010 (just after overlay), December 2010, July 2011 and March 2012. A summary of the rutting data, averaged over each lane in the validation site, and also the overall average, is presented in Table 5.6, whilst the average rutting in each site and lane is shown in Table 5.7. The average rutting in the OWP is reported rather than the average rutting in both the OWP and IWP as this is considered to be a truer reflection of maximum rutting.

Table 5.6: Change in average rutting in OWP over time (numbers rounded to one decimal place)

Lane	Average rutting in OWP (mm)				
	April 2010 (before overlay)	May 2010 (after overlay)	December 2010	July 2011	March 2012
Slow	3.3	0.6	1.5	1.3	2.0
Middle	4.7	0.6	2.0	1.9	3.2
Fast	2.6	0.5	1.7	1.4	2.3
Overall	*3.5*	*0.5*	*1.8*	*1.5*	*2.5*

Table 5.7: Average rutting in OWP (mm) in each site and lane

Chainage (m)	Mix type/ Company	Average rutting in OWP (mm)					
		April 2010 (before overlay)	May 2010 (after overlay)	December 2010	July 2011	March 2012	Change from May 2010 to March 2012
Slow lane							
0–160	HMA (C)	2.4	0.5	1.1	0.6	1.9	1.4
160–335	WMA (C1) (0% RAP)	1.9	0.4	1.3	1.2	2.1	1.7
485–700	HMA (B)	1.7	0.4	1.2	1.2	1.7	1.3
700–910	WMA (B1) (0% RAP)	4.8	0.7	1.8	1.8	2.4	1.7
910–1120	HMA (A)	3.7	0.4	1.4	1.0	1.5	1.1
1120–1335	WMA (A1) (0% RAP)	5.0	1.1	2.3	2.1	2.5	1.4
Average		3.3	0.6	1.5	1.3	2.0	1.4
Middle lane							
0–160	HMA (B)	6.2	0.8	2.6	2.3	3.7	2.9
160–335	WMA (B2) (10% RAP)	6.6	0.8	2.7	2.0	3.5	2.7
485–700	HMA (A)	4.1	0.5	1.5	1.5	3.1	2.6
700–910	WMA (A2) (10% RAP)	3.1	0.4	1.5	1.5	2.4	1.0
910–1120	HMA (C)	2.3	0.5	1.8	2.1	3.4	2.9
1120–1335	WMA (C2) (50% RAP)	5.6	0.4	2.1	2.0	3.4	3.0
Average		4.7	0.6	2.0	1.9	3.2	2.6
Fast lane							
0–160	WMA (A1) (0% RAP)	1.2	0.3	0.9	0.9	1.3	1.0
160–335	WMA (A2) (10% RAP)	2.4	0.6	2.1	1.9	2.7	2.1
485–700	HMA (C)	1.6	0.5	1.6	1.6	2.6	2. 1
700–910	WMA (C3) (0% RAP)	2.1	0.4	1.8	1.5	2.5	2.1
910–1120	HMA (B)	3.7	0.4	2.0	1.3	2.4	2.0
1120–1335	WMA (B1) (0% RAP)	4.2	0.4	1.8	1.2	2.1	1.7
Average		2.6	0.5	1.7	1.4	2.3	1.8

The variation in average rutting in the slow lane over time is also shown in Figure 5.8. As with the roughness data, the peak value of about 9 mm in the slow lane relates to the survey conducted in April 2010, just prior to the site being overlaid. It is noted, however, that the rutting in the original surface was also low (3–4 mm) with cracking being the main observed surface distress.

Once again, the influence of the overlay in terms of a reduction in rutting is clearly evident as is the fact that the average rutting after almost two years of trafficking is still low, with only a small increase in absolute values since the trial commenced. It can be seen that the level of rutting was independent of both generic mix type (HMA and WMA) and type of WMA mix (foam process, additives, percentage of RAP, etc.).

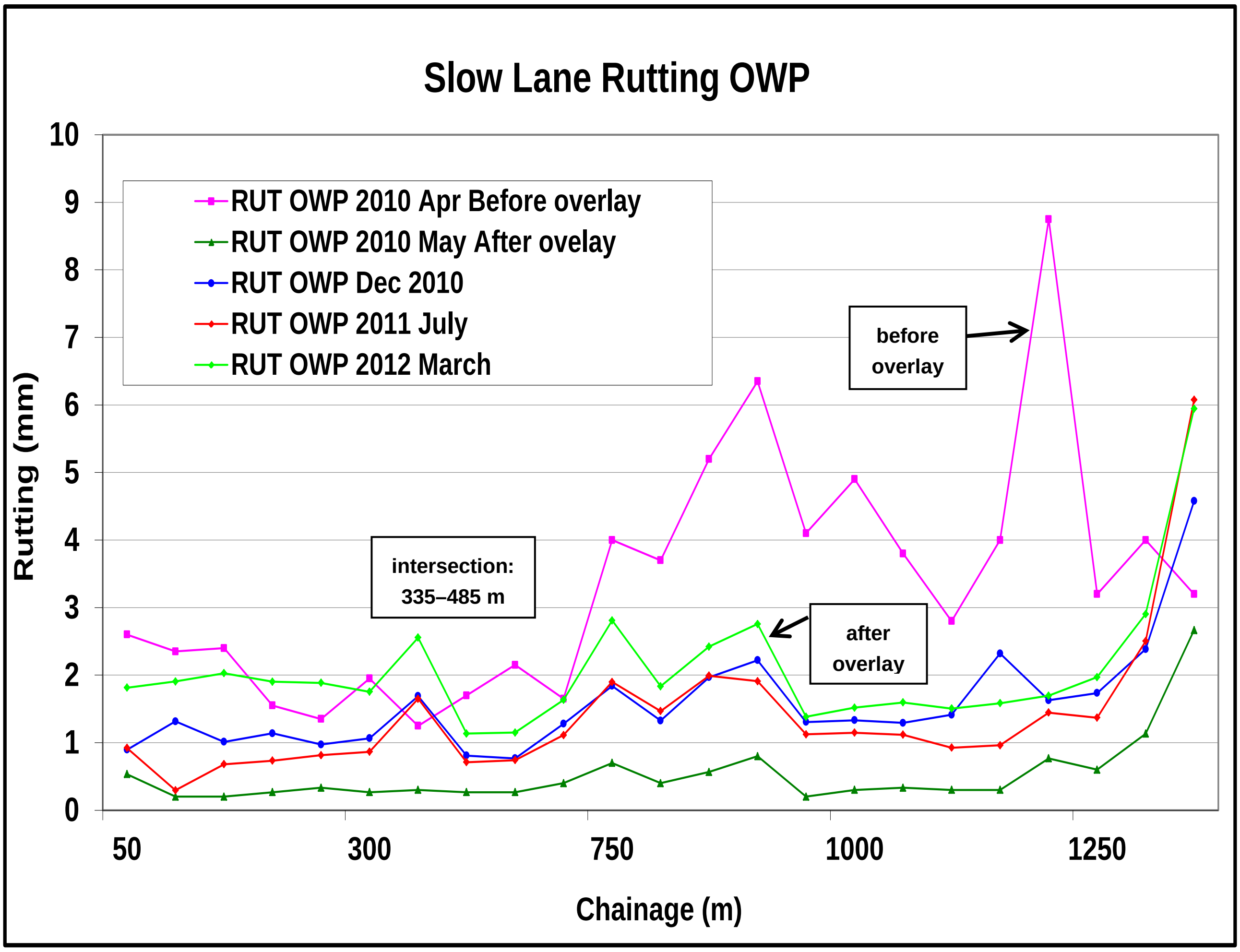


Figure 5.8: Variation in average rutting in the OWP in the slow lane over time

5.5 Texture

Surface texture (SPTD) data was collected by ARRB's NSV in April 2010 (just before overlay), May 2010 (just after overlay), December 2010, July 2011 and March 2012. Texture data was also collected by VicRoads in the slow lane in January 2009 (about 15 months before the installation of the overlays) and in January 2011.

A summary of the texture data, averaged over each lane in the validation site, and also the overall average, is presented in Table 5.8, whilst the average texture in each site and lane is shown in Table 5.9. The average texture in the OWP is reported rather than the average texture in both the OWP and IWP as this is considered to be a truer reflection of maximum texture.

Table 5.8: Change in average texture over time

Lane	Average texture (SPTD) (mm)				
	April 2010 (before overlay)	May 2010 (after overlay)	December 2010	July 2011	March 2012
Slow	2.20	0.98	0.81	0.72	0.77
Middle	2.58	1.06	0.92	0.82	0.89
Fast	2.33	0.96	0.82	0.73	0.78
Overall	*2.37*	*1.00*	*0.85*	*0.76*	*0.81*

Table 5.9: Average texture (SPTD) in OWP (mm) in each site and lane

Chainage (m)	Mix type/ Company	Average texture (SPTD) in OWP (mm)					
		April 2010 (before overlay)	May 2010 (after overlay)	December 2010	July 2011	March 2012	Change from May 2010 to March 2012
Slow lane							
0–160	HMA (C)	2.21	0.91	0.68	0.62	0.64	–0.26
160–335	WMA (C1) (0% RAP)	2.26	0.91	0.71	0.64	0.66	–0.25
485–700	HMA (B)	2.29	0.97	0.81	0.75	0.82	–0.14
700–910	WMA (B1) (0% RAP)	2.67	1.00	0.86	0.79	0.86	–0.14
910–1120	HMA (A)	1.88	1.08	0.92	0.76	0.82	–0.26
1120–1335	WMA (A1) (0% RAP)	1.90	1.03	0.87	0.76	0.80	–0.23
Average		2.20	0.98	0.81	0.72	0.77	–0.22
Middle lane							
0–160	HMA (B)	3.00	1.02	0.87	0.73	0.89	–0.13
160–335	WMA (B2) (10% RAP)	2.56	1.00	0.89	0.76	0.88	–0.12
485–700	HMA (A)	2.58	1.05	0.86	0.76	0.79	–0.27
700–910	WMA (A2) (10% RAP)	2.47	1.30	1.17	1.09	1.20	–0.11
910–1120	HMA (C)	2.00	0.89	0.77	0.70	0.70	–0.19
1120–1335	WMA (C2) (50% RAP)	2.90	1.11	0.99	0.86	0.89	–0.22
Average		2.58	1.06	0.92	0.82	0.89	–0.17
Fast lane							
0–160	WMA (A1) (0% RAP)	2.37	0.97	0.77	0.68	0.69	–0.28
160–335	WMA (A2) (10% RAP)	2.44	1.27	0.99	0.91	0.98	–0.28
485–700	HMA (C)	2.20	0.85	0.69	0.61	0.62	–0.23
700–910	WMA (C3) (0% RAP)	2.16	0.86	0.73	0.66	0.68	–0.18
910–1120	HMA (B)	2.45	0.89	0.89	0.74	0.85	–0.04
1120–1335	WMA (B1) (0% RAP)	2.38	0.95	0.86	0.79	0.86	–0.09
Average		2.33	0.96	0.82	0.73	0.78	–0.18

The variation in average surface texture in the slow lane over time is also shown in Figure 5.9. As with the roughness data, the peak macro-texture value of about 3 mm in the slow lane relates to the survey conducted in April 2010, just prior to the site being overlaid. However, this level of texture was not related to the roughness per se but rather to the fact that the existing surface was an ultra-thin asphalt which generally has a higher macro-texture level than generic dense-graded asphalt.

Once again, the influence of the overlay in terms of improved surface texture is clearly evident and, as was the case with the roughness and rutting data, the level of texture was uniformly very low and independent of both generic mix type (HMA and WMA) and type of WMA mix.

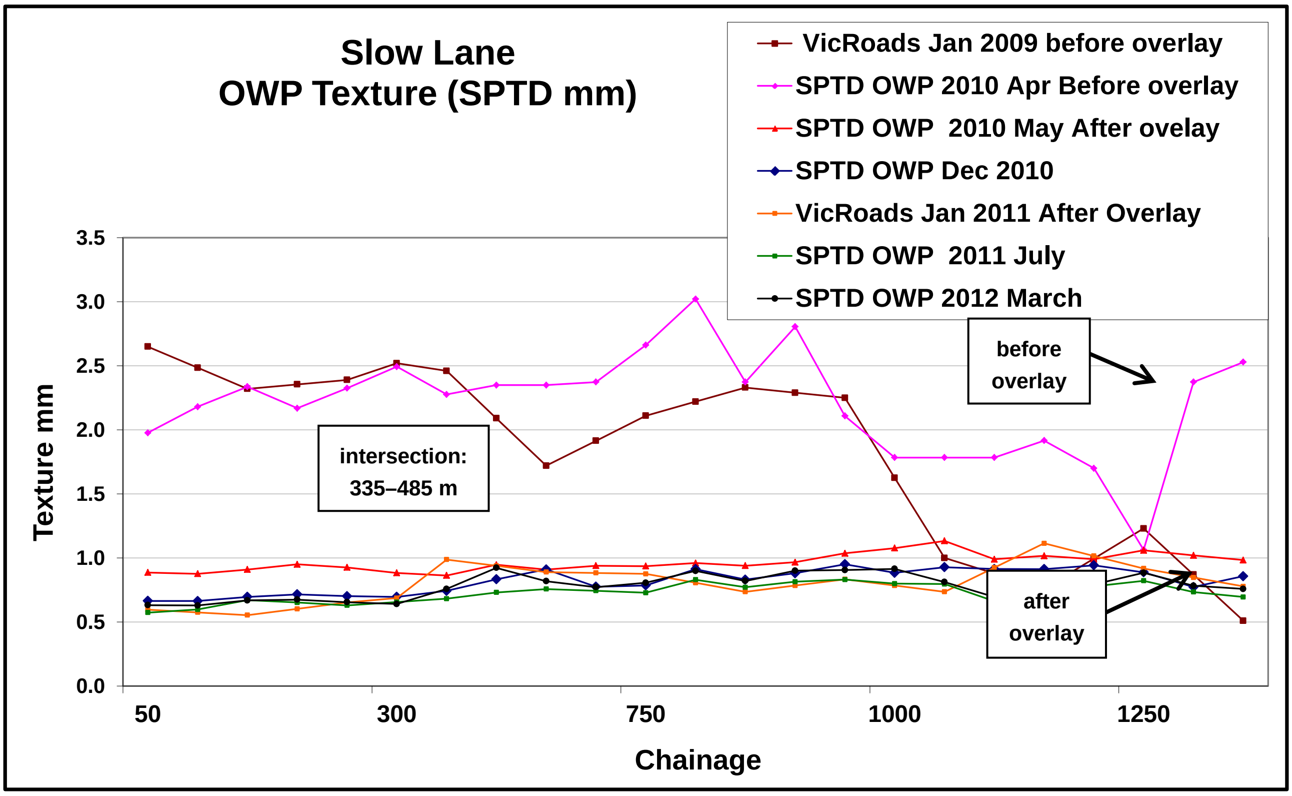


Figure 5.9: Variation in average surface texture in the OWP in the slow lane over time

5.6 Maximum Surface Deflection

Surface deflection testing was conducted by ARRB using their FWD in March 2010 (about one month before overlay), August 2010 (approximately three months after the overlays were applied) and in August 2011. The Steering Committee agreed that, in view of the very low deflection values recorded to that time, and the fact that surface cracking was the main performance indicator for such a thin surfacing, there was no need for another survey in March 2012.

The variation in the mean maximum rebound deflection and curvature over time over the length of the validation site in all three lanes is presented in Table 5.10 and Figure 5.10.

It can be seen from Table 5.10 and Figure 5.10 that the maximum deflections were generally very low, this being related to the very strong base on which the original pavement was constructed. The highest deflections were at the intersection. The introduction of the overlays had some minor influence on the deflection values. Once again, this is not a surprising result.

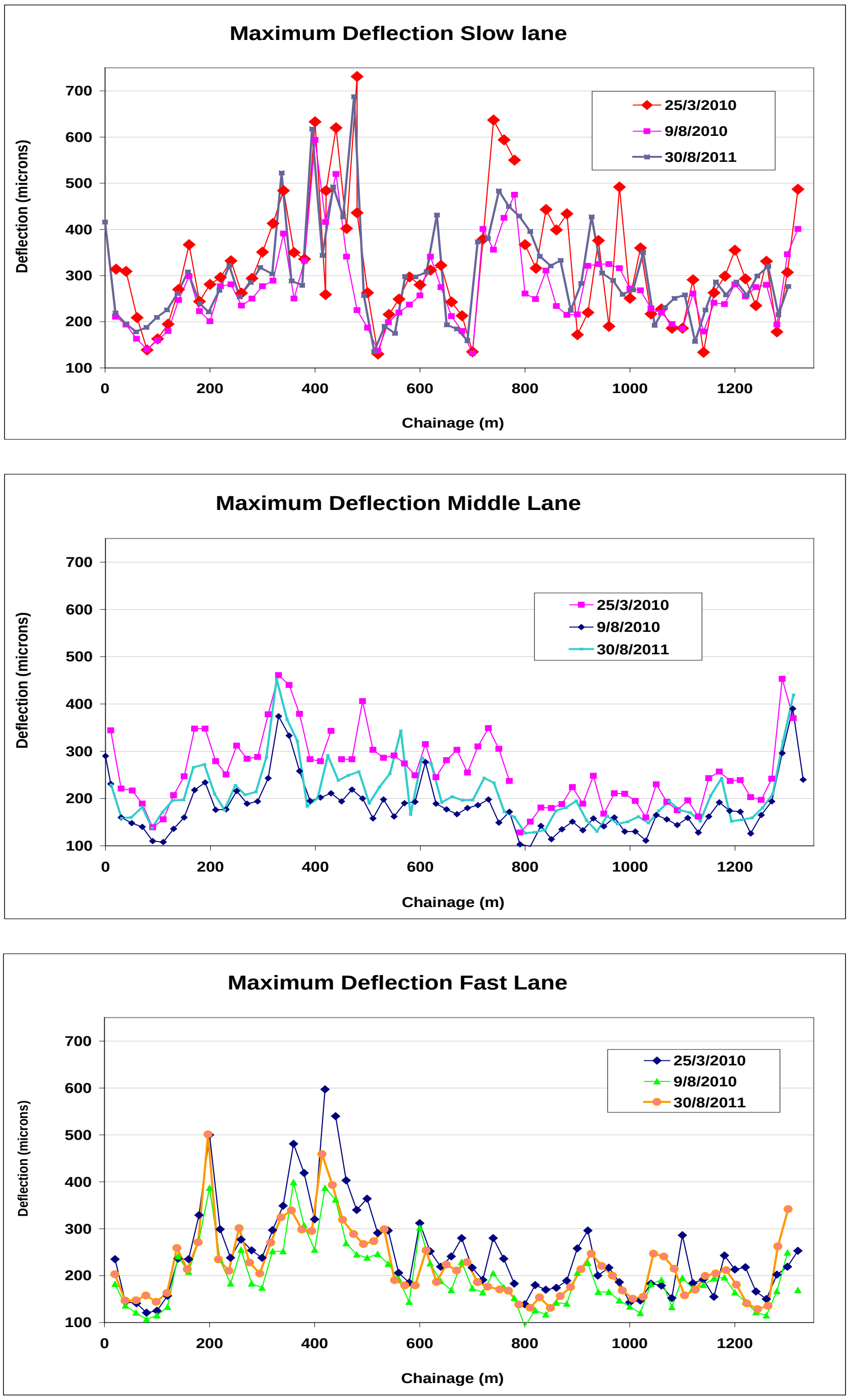
It can also be seen from Figure 5.10 that there was little, if any change, in maximum deflection over the 12 months between the two surveys in August 2010 and August 2011. Once again, the maximum surface deflection was independent of both generic mix type (HMA and WMA) and type of WMA mix.

Table 5.10: Variation in mean maximum deflection and curvature over time over length of site

Chainage (m)	Mix type/ Company	Max. deflection (microns)			Curvature (microns)		
		March 2010 (before overlay)	August 2010 (after overlay)	August 2011	March 2010 (before overlay)	August 2010 (after overlay)	August 2011
Slow lane							
0–160	HMA (C)	246	199	245	37	24	26
160–335	WMA (C1) (0% RAP)	309	254	304	56	39	41
485–700	HMA (B)	269	216	239	34	28	23
700–910	WMA (B1) (0% RAP)	402	314	365	78	47	52
910–1120	HMA (A)	272	269	272	39	30	31
1120–1335	WMA (A1) (0% RAP)	288	269	269	44	33	30
	Average	298	254	282	48	33	34
Middle lane							
0–160	HMA (B)	215	165	179	31	17	15
160–335	WMA (B2) (10% RAP)	328	225	257	50	31	35
485–700	HMA (A)	292	190	235	47	24	29
700–910	WMA (A2) (10% RAP)	222	144	175	33	20	22
910–1120	HMA (C)	199	145	161	36	14	13
1120–1335	WMA (C2) (50% RAP)	260	204	220	41	18	20
	Average	253	179	204	40	21	22
Fast lane							
0–160	WMA (A1) (0% RAP)	215	165	179	31	17	15
160–335	WMA (A2) (10% RAP)	328	225	257	50	31	35
485–700	HMA (C)	292	190	235	47	24	29
700–910	WMA (C3) (0% RAP)	222	144	175	33	20	22
910–1120	HMA (B)	199	145	161	36	14	13
1120–1335	WMA (B1) (0% RAP)	260	204	220	41	18	20
	Average	253	179	204	40	21	22

5.7 Long Term Evaluation

The original intention was to monitor performance for two years (i.e. until the end of April 2012) and then to monitor performance every two years. However, in view of the fact that the project is due for completion in June 2012, and the fact that the performance of all the validation sites is satisfactory, it is not proposed to conduct any further field testing at this stage.


Maximum Deflection Slow lane

Maximum Deflection Middle Lane

Maximum Deflection Fast Lane

Figure 5.10: Variation in maximum deflection over time – all lanes

6 EVALUATION OF DRAFT PROTOCOL: FIELD EVALUATION

In this section, the elements of the draft WMA Evaluation Protocol related to field evaluation are reviewed and discussed.

6.1 Types of Field Trials

Three types of field trials of a WMA technology were identified:

- development trial
- production/demonstration trial
- validation/implementation trial.

The review identified three types of field trials of a WMA technology: development, demonstration and validation/implementation. The scope, investigative method, verification criteria, etc. for each trial will depend on the technologies developed (i.e. additives/processes used to manufacture the mix and plant modifications required for these technologies), the asphalt producer's marketing strategy and the road agency's implementation strategy.

6.1.1 Development Trials

The main aim of a development trial is to meet a manufacturer's desire to obtain supporting evidence of material workability and performance for the purposes of developing the additives, processes and equipment prototypes used to produce WMA mixes.

The investigative works used during this stage include low-cost laboratory studies to assess WMA workability and performance. For WMA technologies that can easily produce replicated samples in the laboratory (e.g. technologies using chemical and organic additives), the laboratory-prepared samples are often used in the laboratory testing program. However, for WMA technologies that cannot produce replicated samples in the laboratory without expensive equipment (e.g. foaming technologies), full-scale mixing plants and road trials are also used to produce production and field samples for laboratory testing.

In other words, in many cases field/evaluation trials may not be required. Development trials are more likely to be conducted by industry with a field trial, if any, perhaps involving a trial set up in a quarry where the traffic (e.g. quarry trucks) is known and basic performance criteria (rutting, cracking, etc.) are monitored.

A formal evaluation protocol is therefore not required provided the processes used, and the data collected, is documented for future reference. The Protocol can, however, be used to provide guidance on the minimum requirements for a development trial.

6.1.2 Production/Demonstration Trials

The aim of a production/demonstration trial is to meet a road agency's desire to obtain supporting field evidence of the production and placement of a specific WMA product for the purposes of quality control and assurance (in terms of day-to-day production from mixing plants, contractor laying experience, product consistency, material quality, etc.).

The works during this stage include field studies using full-scale mixing plants of reasonable size to allow a full run of plant-production (to achieve a commercial production rate), and a road trial of reasonable length (to enable an assessment of workability and field performance immediately after compaction). A demonstration trial would normally be conducted by the asphalt producer, with both the asphalt producer and the road agency conducting performance measurements.

Production/demonstration trials are popular for road applications involved overlays using high-RAP content mixes and severe construction conditions (e.g. construction in cold/wet environments). It was noted that different road agencies may require different evidence of production and placement and performance criteria in the field.

A common strategy to promote a new product is to include in the WMA demonstration trial a control HMA section, which has the same specified asphalt mix and is placed under the same conditions (pavement type, climate), to allow a direct comparison between the WMA and HMA workability and field performance.

6.1.3 Validation/Implementation Trials

The purpose of a validation/implementation trial is to address a road agency's desire to obtain information regarding material workability and field performance (including both short-term performance after compaction and long-term performance over the design period) for the purposes of developing/validating mix designs (material specifications), construction standards and pavement design procedures. This stage may include a large number of field trials involving various asphalt mixes (binders, aggregate types, RAP, etc.) and applications (pavement structure, traffic and environmental conditions, etc.).

A common strategy for reducing the number of required implementation field trials is to examine studies of previous, or existing, field trials in terms of their relevance to the issues being addressed. This is one reason why a major component of the Austroads project was the review of overseas practice.

Several asphalt producers and road agencies have collaboratively conducted accelerated loading studies of the comparative performance of WMA and HMA technologies under heavy loading. Examples include the work at the National Center for Asphalt Technology (NCAT) in Auburn, Alabama (Prowell et al. 2007), and the work at the University of California Pavement Research Center (UCPRC) using the Heavy Vehicle Simulator (HVS) (Jones et al. 2008; Jones et al. 2010). These trials have involved the production of the mixes, the construction of test pavements, and the monitoring of field performance, including detailed (within-pavement) response-to-load data. In addition, extensive laboratory studies of both field and laboratory samples were carried out in order that the relative performance of WMA with HMA could be compared with recommendations made regarding the implementation of WMA in the current HMA mix design procedures.

Validation/implementation trials are the most expensive of the three options. As a result, evaluation protocols of WMA technologies involving the use of field trials have been established to maximise the benefits of these trials. For example, Newcomb and Corrigan (2006) developed a *Material Test Framework for WMA Trials* which was adopted by the US National Asphalt Pavement Association (NAPA) and the Federal Highway Administration (FHWA). A protocol has also been more recently developed in South Africa. It is for this reason that a Protocol is being developed for application in Australia.

6.1.4 Summary

A large number of demonstration or validation trials of WMA technologies have been established in the USA to demonstrate the benefits of WMA technology compared to HMA, and to improve the quality and efficiency of construction (i.e. improved workability, improved compaction and more consistent field density). The major application has been overlays using high RAP-content mixes and severe construction conditions (e.g. construction in cold/wet environments). There have also been further developments and improvements in the WMA technologies using water (e.g. foam technologies using water injection nozzles) and emulsions to reduce the amount of water added to the system in order to address the concern of moisture susceptibility issues associated with the use of the water-based WMA products.

These trials had demonstrated that most WMA technologies associated with chemical and organic additives could be successfully implemented with minor modifications to the asphalt plant and, in the case of several products, successful paving could still occur at low temperatures.

Some of the trials also addressed various concerns regarding the use of WMA, including incomplete drying of the aggregate (especially with absorptive limestones), the potential for increased moisture susceptibility when utilising WMA processes that involve the use of water, the effects of chemical additives on the long term performance of the binder, the ability of WMA to provide enough radiant energy to heat the reclaimed asphalt component in mixes containing RAP, and the general lack of information regarding the long term performance of new asphalt mix designs (e.g. with high RAP content or rubber asphalt).

Consequently, laboratory trials have focussed more on moisture susceptibility, rut resistance and durability. Many demonstration and validation trials established in the USA are also being subjected to both accelerated loading trials and long-term performance monitoring.

The amount of published material relating to demonstration or validation trials in Australia is very limited. Similarly, whilst it is clear that industry has established a large number of trials, presumably mainly for local government applications, details of these trials are very sketchy and little or no material has been published.

7 CONCLUSIONS

This report has presented details of a major element of Austroads Project TT1454, *The Performance of Warm Mix Asphalt Pavements*, viz. the planning and conduct of a comprehensive field assessment of a range of WMA and HMA surfacings in order that their performance could be compared and the draft WMA Evaluation Protocol for the conduct of validation trials assessed and appropriate changes made. Issues addressed include the establishment of the validation sites, including the experimental design, a description of the site, details of the asphalt mixes tested, and the performance of the surfacings after almost two years of trafficking.

The structural (strength) and function (roughness, rutting, texture) performance of the validation sites after almost two years of trafficking was excellent, with no discernible difference between the WMA and HMA ‘control’ sections and no discernible difference between the various WMA mixes, including mixes containing additives, those incorporating various percentages of RAP and those manufactured using a foaming process.

A comparison of the cracking in the original surface of the most heavily-trafficked (slow) lane prior to overlay and in December 2010 and in March 2012 (almost two years after the sites were opened to traffic) revealed that the extent of cracking after almost two years of trafficking, compared to the extent of cracking prior to patching and overlay, was small and also that almost all of the cracking that was observed appeared to be reflection cracking.

No cracking was observed in the middle lane whilst some minor (shear) cracking observed in one section of the fast lane could be attributed to differential movement under the pavement compared to the movement under the concrete kerb and channel.

The results of the validation trial only apply to the WMA surfacings manufactured with the particular technologies and binders trialled and for the traffic and environmental conditions experienced. Further work is required to assess the structural performance of WMA pavements and any likely impacts on the structural design procedures currently documented in the Austroads guidelines.

In terms of the draft WMA Evaluation Protocol, the trial conducted under the Austroads project was far more detailed, in terms of demands, than a production/demonstration trial and much more in line with the requirements for a validation/implementation trial. The main difference was that, whilst the validation trial involved various asphalt mixes (binders, aggregate types, RAP, etc.), it was only one application (one pavement structure, one traffic type – albeit different traffic in each of three lanes – and one environmental condition). In addition, only thin (nominally 40 mm thick) surfacings were tested. Further work is required to assess the structural performance of structural layers incorporating WMA and any likely impacts on the structural design procedures currently documented in the Austroads guidelines.

However, it is considered that, in terms of the ‘field evaluation’ component of the draft WMA Evaluation Protocol, the requirements would be applicable to any validation trial (e.g. thin asphalt surfacing, structural asphalt layer, accelerated pavement testing, etc.).

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APPENDIX A LOCATION AND TEMPERATURE DATA

Table A 1: Location and temperature data, 20 April 2010, slow lane

Site company/ Mix type	Operator 1			Operator 2		
	Chainage (m)	Auger temp. (°C)	Mat temp. (°C)	Chainage (m)	Auger temp. (°C)*	Mat temp. (°C)
C HMA	0	175	154.4	28	147	144
	28	147	147.5	74	142	135
	74	157	157.3	106	135	145
	106	138	139.3	142	137	149
	140	142	131.7	157	121	124
	160	129	125.3			
*Average***		*148*	*143*		*136*	*139*
C WMA(1) 0% RAP	194	127	116.2	197	123	120
	245	129	114.8	245	124	121
	300	126	115.6	300	124	120
				335	129	120
*Average***		*127*	*116*		*125*	*120*
Intersection (not included in validation trial)						
B HMA	536	169	152.8	486	168	166
	580	160	150	536	168	162
	620	163	163	580	163	163
	655	163	156.4	618	164	153
				655	158	163
*Average***		*164*	*156*		*164*	*161*
B WMA 0% RAP	700	134	128.6	706	139	134
	757	135	123.5	757	131	125
	795	131	129.8	795	134	130
	840	146	138.4	840	137	137
	910	157	143.4	900	136	117
*Average***		*146*	*133*		*135*	*129*
A HMA	985	162	149.7	914	146	143
	1036	162	144.3	985	157	160
	1065	149	141.5	1036	155	150
				1070	143	142
				840	137	137
*Average***		*158*	*145*		*148*	*146*
A WMA 0% RAP	1145	122	115.8	1120	122	116
	1176	129	119.7	1176	124	122
	910	157	143.4	1225	121	113
	1225	123	118.6	1262	126	119
	1270	127	121.8			
*Average***		*132*	*124*		*123*	*118*

* IR gun cal +1 (not corrected).

** Rounded to nearest whole number.

Note: Ambient temperature ~ 18–20 °C; clear, no rain.

Table A 2: Location and temperature data, 21 April 2010, middle lane

Site company/ Mix type	Operator 1			Operator 1		
	Chainage (m)	Auger temp. (°C)	Mat temp. (°C)	Chainage (m)	Auger temp. (°C)*	Mat temp. (°C)
B HMA	0	168	155.3	0	161	159
	45	161	149.8	45	160	152
	90	161	146	90	160	156
	125	158	148.8	128	155	147
*Average****		*162*	*150*		*159*	*154*
B WMA 10% RAP	162	148	121.0	162	144	
	220	131	116.0	217	133	123
	265	135	123.4	315	137	130
	315	144	**			
	344	135	125.6			
*Average****		*139*	*122*		*138*	*127*
Intersection (not included in validation trial)						
A HMA	486	169	**	486	166	155
	534	176	162.5	534	169	162
	568	178	164.5	568	168	168
		162	160.8	625	163	163
	700	150	157.9	689	141	126
*Average****		*167*	*161*		*161*	*155*
A WMA 10% RAP		121	110	742	120	111
	770	125	116	780	121	115
		133	120	840	120	119
	880	128	110	880	124	118
*Average****		*127*	*114*		*121*	*116*
C HMA	910	164	155	910	166	168
	940	178	170	950	170	168
	990	171	160	998	169	168
	1040	162	147	1034	161	152
*Average****		*169*	*158*		*167*	*164*
C WMA(1) 50% RAP	1115	134	129	1120	145	120
	1140	129	120	1150	131	125
	1190	137	126	1190	129	124
	1220	137	129	1238	131	132
		136	128	1275	129	118
				1320	117	
*Average****		*135*	*126*		*130*	*124*

* IR gun cal +1 (not corrected).

** Insufficient, only small amount added.

*** Rounded to nearest whole number.

Note: Ambient temperature ~ 18-20 °C; clear, no rain.

Table A 3: Location and temperature data, 26 April 2010, fast lane

Site company/ Mix type	Operator 1			Operator 2		
	Chainage (m)	Auger temp. (°C)	Mat temp. (°C)	Chainage (m)	Auger temp. (°C)*	Mat temp. (°C)
A WMA 0% RAP	0	131	122.6	28	147	144
	40	120	115	74	142	135
	105	124	115.9	106	135	145
	150	123	114.6	142	137	149
*Average****		*125*	*117*		*140*	*143*
A WMA 10% RAP	200	120	112.2	157	121	124
	250	125	116.4	197	123	120
	290	122	115.4	245	124	121
	320	135	124.8	300	124	120
				335	129	120
*Average****		*126*	*117*		*124*	*121*
Intersection (not included in validation trial)						
C HMA	520	170	164.8	486	168	166
	600	170	162.5	536	168	162
	640	165	160.7	580	163	163
	685	180	172.2	618	164	153
				655	158	163
*Average****		*171*	*165*		*164*	*161*
C WMA(2) 0% RAP	705	145	139.8	706	139	134
	790	150	145.2	757	131	125
	830	146	158.2	795	134	130
	865	135	129.8	840	137	137
				900	136	117
*Average****		*144*	*143*		*135*	*129*
B HMA	910	169	158.5	914	146	143
	960	175	168.9	985	157	160
	1025	170	161.7	1036	155	150
	1070	178	167.2	1070	143	142
	1120	135	123.3			
*Average****		*165*	*156*		*150*	*149*
B WMA 0% RAP	1180	140	140.6	1120	122	116
	1235	149	140.6	1176	124	122
	1275	135	126.8	1225	121	113
	1300	145	**			
*Average****		*142*	*136*		*122*	*117*

* IR gun cal +1 (not corrected).

** Insufficient, only small amount added.

*** Rounded to nearest whole number.

Note: Ambient temperature ~ 18-20 °C; clear, no rain.

INFORMATION RETRIEVAL

Austroads, 2012, **Field Validation of Warm Mix Asphalt Pavements**, Sydney, A4, pp. 45. **AP-T214-12**

Keywords: warm mix asphalt, surfacings, hotmix asphalt, validation, Melbourne, roughness, rutting, cracking, texture, deflection, recycled asphalt pavement, foam asphalt, validation trial

Abstract:

This report describes the planning and conduct of a validation trial of three warm mix asphalt surfacings (chemical additive, polymer additive, foaming) and a hotmix asphalt ‘control’ surfacing at a site in Melbourne, Australia. Issues addressed include the establishment of the validation site, the experimental design, a description of the site, details of the mixes tested, the condition parameters monitored, and the performance of the surfacings after two years of trafficking. Performance after two years of trafficking was excellent and also independent of asphalt mix type, type of warm mix asphalt, and the percentage of RAP (0-50%) incorporated into the mix. Details of the laboratory testing program, the results and an interpretation of the data are the subject of a companion report.