The benefits of Long-Term Pavement Performance (LTPP) research to funders

Tim Martin a,*, Lith Choummanivong a

Abstract

Long-term pavement performance (LTPP) monitoring has been conducted in Australia for over 20 years. This research was funded by Austroads (representing federal, state and territory road agencies, local government and the New Zealand road agency) to promote improved practice and capability for the road agencies. The LTPP monitoring program measured performance by rutting, roughness, cracking and deflection. Initially the program involved a range of designated flexible pavement sites under varying conditions of environment and traffic. Many of these LTPP sites were included in the Strategic Highway Research Program (SHRP) of the United States (US). All sites were monitored in accordance with the SHRP protocols. Later long-term pavement performance maintenance (LTPPM) sites were included in the program to: (i) assess the impact of surface maintenance treatments on changes to pavement conditions (works effects, WE); and, (ii) assess the impact of maintenance on road deterioration (RD).

A range of RD and WE models were developed using the LTPP/LTPPM observational data in combination with experimental data collected from Australia’s Accelerated Loading Facility (ALF) that separately investigated the impact on RD of increased axle load and various typical surface maintenance treatments. The RD models cover the deterministic prediction of functional surface distress (rutting, roughness and cracking) and the loss of traffic load capacity (strength). The WE models cover the deterministic prediction of the impact of a range of typical surface treatments on improved surface conditions. The RD models are currently being used to develop probabilistic distress predictions based on the variability found in the observational data. The future use of probabilistic predictions of RD outcomes will allow road agencies to better quantify the risks involved in managing the pavement infrastructure.

* Corresponding author. Tel.: +61 3 9881 1564; fax: +61 3 9887 8104.
E-mail address: tim.martin@arrb.com.au
Both the RD and WE models are currently being installed in the pavement management systems (PMS) of both state and local government road agencies to provide efficient maintenance allocation and resourcing at a road network level. In the process of developing the RD and WE models, a number of support tools were also developed such as a tool for determining the independent variable representing climate, based on GPS locations, and a tool for estimating deterioration rates from time-series data. The RD and WE models are also being used to estimate the marginal cost of road wear when pavements are subject to increased axle load to increase road freight efficiency.

A dedicated research program generally involves a long-term evolutionary process, however, when it is clearly focused on achieving measurable and practical outcomes, such as improving the practices and capabilities of road agencies, the benefits can be clearly defined and quantified when bench-marked against current and past practices. The LTPP/LTPPM research program is annually reviewed and assessed to ensure that the sites that no longer yield useful data are replaced by sites that provide new observational data with respect to environment, traffic and pavement material conditions.

© 2016 The Authors. Published by Elsevier B.V. Peer-review under responsibility of Road and Bridge Research Institute (IBDiM).

Keywords: Long-term pavement performance (LTPP) monitoring; analysis of observational and experimental data; road deterioration and works effect model development; sealed and unsealed road performance

1. Introduction

1.1. Context

Australia’s population is around 24 million and it has 907,520 km of road network length as estimated by the Department of Infrastructure and Regional Development (2013). Some 332,860 km (37%) of this network are sealed roads with nearly 87% of these roads being a sprayed bitumen seal over an unbound crushed rock base. The remaining 13% of the sealed roads are mainly surfaced with asphalt. The bulk of the road network (63%) is therefore unsealed comprising the following: (1) unsealed roads with a gravel wearing surface; (2) formed unsealed roads; and, (3) unformed unsealed roads.

The prediction of sealed and unsealed pavement performance is a critical element in using well-structured pavement management systems (PMS) for estimating the maintenance and capital funding requirements for road networks. In the past many of the performance prediction models used by PMS in Australia were based on data collected in Brazil, the Caribbean and Kenya from 1971 to 1984 (Cox 1990). Most of these models were not likely to be suited to Australian conditions of construction, maintenance, climate and traffic as sprayed bitumen sealing over an unbound crushed rock base occurs mainly in Australia, New Zealand and South Africa, while the performance of unsealed roads is highly dependent on the local conditions of materials and climate.

Earlier Australian sealed pavement performance deterioration models were time dependent models developed by Potter (1982) with no explanatory variables for changes in traffic and maintenance effects.

1.2. Aims of Study

The overall objectives of the Australian long-term pavement performance (LTPP) study were as follows:

1. The enhancement of road asset management strategies through the use of improved pavement performance models, such as road deterioration (RD) and works effects (WE) models, based on an improved understanding of pavement behaviour. This is the same approach used by the United States (US) Strategic Highway Research Program (SHRP) for the observation of pavement performance by regular monitoring (SHRP-LTPP).

2. The comparison of the results of accelerated loading on test pavements with actual road pavement performance. This was the accelerated loading facility (ALF) LTPP experimental program (ALF-LTPP).

3. The investigation of the quantitative influence that various maintenance surface treatments have on long pavement performance. This was the long-term pavement performance maintenance (LTPPM) program.

Later on the LTPP study used the outcomes of accelerated load testing with the ALF to separately investigate the influence of increased heavy vehicle axle loading on long-term pavement performance.
2. History of the LTPP Studies in Australia

2.1. LTPP study of arterials road performance

In 1987 LTPP monitoring commenced in the United States as part of the General Pavement Studies (GPS) under the SHRP (Crawley 1997). In 1994/95 Austroads took the opportunity to participate in the SHRP by establishing and funding its own LTPP monitoring program through a project later known as AT1064 Long-term Performance Monitoring to Develop Consistent Performance Models as part of the National Strategic Research Program (NSRP). This project initially established 21 arterial road SHRP-LTPP sites that were part of the Australian SHRP-LTPP study. The project also monitored 12 arterial road ALF-LTPP sites that were initially subject to ALF testing. These sites included granular, asphalt and concrete pavements in both rural and urban locations. The LTPP sites monitored the impact of traffic loading and climate on pavement performance. Between 1994/95 and 2000/01 monitoring and reporting was conducted annually at these sites and reported by Koniditsiotis et al. (1995a; 1995b; 1996a; 1996b; 1997) and Clayton and Styles (2001).

The Australian Asphalt Pavement Association (AAPA) and the Australian Stabilisation Industry Association (AustStab) were also actively involved in the study by providing LTPP test sites of specific interest to them. This involvement ensured that a wider range of pavement types were included in the study.

The LTPP sites were not established to specifically monitor the influence of maintenance treatments on pavement performance. Historically little has been known about the quantitative effect of maintenance treatments on the pavement performance as noted by Markow and Brademeyer (1984), Paterson (1990), and Shahin et al. (1994). Ideally, to obtain specific information about the influence of maintenance on pavement performance, the LTPP pavement sections should be homogeneous with respect to the other variables that affect pavement performance (Sadek et al. 1996). In other words, the sites should be specifically designed so that only the variable of interest (i.e. maintenance) is varied at each site. This approach was adopted by the creation of a long term pavement performance maintenance (LTPPM) sites program as part of project AT1064 also funded by Austroads. Sites that had some existing surface distress (cracking) and were due for resealing were considered as suitable LTPPM sites as they gave the opportunity to apply different maintenance treatments along their lane length.

In 1998/99 eight LTPPM sites were initially established in Australia (four in Victoria, two in Queensland, one in NSW and one in Tasmania) to study the influence of various maintenance treatments on pavement performance under normal traffic loading conditions. Since 1998/99 monitoring and reporting of the LTPPM test sites has been underway on an annual basis.

![Fig. 1. Typical LTPPM layout of sub-sections](image1.png)

![Fig. 2. Typical LTPP signage](image2.png)

Figure 1 shows a typical layout of an LTPPM site which is comprised of five sub-sections each 200 m long with a different surface maintenance treatment over the same pavement base. The maintenance treatments range from a high quality geotextile reseal to minimum maintenance. Because all sections are in the same lane they are subject to the same traffic loading and climatic conditions. The LTPPM sites are similar to the Specific Pavement Studies (SPS) of the US SHRP as the LTPPM sites are aimed at studying the specific impact of maintenance on pavement performance.
The LTPP site length was 12 m for most ALF-LTPP sites, 12 m being the length of the ALF test pavement. The SHRP-LTPP sites were 150 long and the other LTPP sites varied in length from 100 m to 200 m, depending on local conditions. All active LTPP and LTPPM site start and finish locations were defined by GPS coordinates, and highly visible signs, as shown in Figure 2, were installed in 2005.

In 2004/05 additional LTPP sites were sought and identified to provide pavement performance data on sprayed seal unbound granular pavements which are dominant pavement type used on Australian rural arterial roads. These additional LTPP sites were based on gaining access to State Road Agency (SRA) historical time series performance data on defined lane segments. Over 850 candidate sites were submitted for review from which 69 additional LTPP sites were selected as suitable. These additional sites covered three defined climatic zones; dry, temperate and wet. All sites had an AADT value less than 25,000 vehicles/day, as documented in Austroads (2006).

However, no further time series data for the additional sites was sought from the SRAs because the condition data was of lower quality than that for the existing LTPP sites. This was mainly because the road condition data was collected by network condition surveys and the matching of data on the identified lane segments from consecutive surveys often proved to be problematic.

Table 1 provides the breakdown of the LTPP and LTPPM sites by study type, pavement type, jurisdiction, climate and traffic load. The traffic load on the sites varies from 0.02 to 2.30 MESA/lane/year and the climate index, TMI, varies from -24 (dry) to 100 (wet). Both rigid and flexible pavements are represented.

<table>
<thead>
<tr>
<th>State</th>
<th>Test section(1)</th>
<th>Site type (2)</th>
<th>Road name</th>
<th>TMI</th>
<th>Pavement type(3)</th>
<th>Traffic load(4)</th>
<th>Status(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New South Wales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NSW) LTPP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSW03</td>
<td>ALF</td>
<td>Federal Highway, Collector</td>
<td>5</td>
<td>JPCP/LM</td>
<td>0.63</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>NSW17</td>
<td>ALF</td>
<td>Foreshore Road, Botany</td>
<td>42</td>
<td>CRCP/CR</td>
<td>1.45</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>NSW20</td>
<td>ALF</td>
<td>Pacific Motorway, Somersby</td>
<td>49</td>
<td>AC/M</td>
<td>1.26</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>NSW24</td>
<td>ALF</td>
<td>Pacific Highway, Tomago</td>
<td>37</td>
<td>SS/BCR</td>
<td>2.30</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>NSW25</td>
<td>ALF</td>
<td>Pacific Highway, Tomago</td>
<td>37</td>
<td>SS/BCR</td>
<td>2.30</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ABBR2</td>
<td>NA(5)</td>
<td>Monaro Highway, Cooma</td>
<td>19</td>
<td>SS/GS/HL</td>
<td>0.31</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>VC01</td>
<td>SHRP</td>
<td>Western Ring Rd, Tullamarine</td>
<td>13</td>
<td>AC/CTCR</td>
<td>0.53</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VC02</td>
<td>SHRP</td>
<td>Western Ring Rd, Jacana</td>
<td>13</td>
<td>AC/CTCR</td>
<td>0.53</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VC03</td>
<td>SHRP</td>
<td>Western Ring Rd, Broadmeadows</td>
<td>13</td>
<td>AC/CTCR</td>
<td>0.41</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VC04</td>
<td>SHRP</td>
<td>Western Ring Rd, Glenroy</td>
<td>14</td>
<td>AC/CTCR</td>
<td>0.41</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VC05</td>
<td>SHRP</td>
<td>Western Ring Rd, Fawkner</td>
<td>14</td>
<td>AC/CTCR</td>
<td>0.40</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VC20</td>
<td>ALF</td>
<td>Hume Highway, Benalla</td>
<td>-5</td>
<td>SS/UBCR</td>
<td>0.74</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>VCA01</td>
<td>NA</td>
<td>Metropolitan Ring Rd, Thomastown</td>
<td>15</td>
<td>AC/CTCR</td>
<td>0.28</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VCA02</td>
<td>NA</td>
<td>Western Ring Rd, Sunshine West</td>
<td>2</td>
<td>AC/CTCR</td>
<td>0.49</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VCA03</td>
<td>NA</td>
<td>Western Ring Rd, St Albans</td>
<td>5</td>
<td>AC/CTCR</td>
<td>0.44</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>VCA04</td>
<td>NA</td>
<td>Eastern Freeway, Donvale</td>
<td>22</td>
<td>AC/CTCR</td>
<td>0.22</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>QL02</td>
<td>SHRP</td>
<td>Bruce Highway, Beerburrum</td>
<td>73</td>
<td>AC/CR</td>
<td>0.49</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>QL04</td>
<td>SHRP</td>
<td>Warrego Highway, Ipswich</td>
<td>5</td>
<td>AC/CR/CTSB</td>
<td>0.85</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>QL13</td>
<td>ALF</td>
<td>Bruce Highway, Beerburrum</td>
<td>70</td>
<td>AC/CTCR</td>
<td>0.58</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>QL14</td>
<td>ALF</td>
<td>Bruce Highway, Beerburrum</td>
<td>70</td>
<td>AC/CTCR</td>
<td>0.58</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>ABBR1</td>
<td>NA</td>
<td>Rainbow Beach Road, Rainbow Beach</td>
<td>28</td>
<td>SS/BEC</td>
<td>0.04</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>SA02</td>
<td>ALF</td>
<td>South Eastern Freeway, Callington</td>
<td>-15</td>
<td>AC/CR</td>
<td>0.02</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>SA03</td>
<td>ALF</td>
<td>South Eastern Freeway, Callington</td>
<td>-15</td>
<td>AC/CR</td>
<td>0.02</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>SA05</td>
<td>ALF</td>
<td>South Eastern Freeway, Callington</td>
<td>-15</td>
<td>AC/CR</td>
<td>0.02</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>SA06</td>
<td>NA</td>
<td>Port River Expressway, Port Adelaide</td>
<td>-11</td>
<td>AC/CTSB</td>
<td>0.80</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>SA07</td>
<td>NA</td>
<td>Dukes Highway, Cooke Plains</td>
<td>-24</td>
<td>SS/UBCR</td>
<td>0.71</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>SA10</td>
<td>ALF</td>
<td>South Eastern Freeway, Callington</td>
<td>-15</td>
<td>AC/CR</td>
<td>0.02</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>ACT01 – P1</td>
<td>NA</td>
<td>Uriarra Road, Stromlo</td>
<td>6</td>
<td>SS/UBCR</td>
<td>0.12</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT01 – C1</td>
<td>NA</td>
<td>Uriarra Road, Stromlo</td>
<td>6</td>
<td>SS/UBCR</td>
<td>0.12</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT02 – C2</td>
<td>NA</td>
<td>Drakeford Drive, Kambah</td>
<td>5</td>
<td>AC/UBCR</td>
<td>0.15</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT02 – C3</td>
<td>NA</td>
<td>Drakeford Drive, Kambah</td>
<td>5</td>
<td>AC/UBCR</td>
<td>0.08</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT03 – C1</td>
<td>NA</td>
<td>Isabella Drive, Macarthur</td>
<td>5</td>
<td>AC/UBCR</td>
<td>0.15</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>Test section(1)</td>
<td>Site type</td>
<td>Road name</td>
<td>TMI</td>
<td>Pavement type(2)</td>
<td>Traffic load(3)</td>
<td>Status(4)</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>-----------------------</td>
<td>-----</td>
<td>------------------</td>
<td>-----------------</td>
<td>-----------</td>
</tr>
<tr>
<td>ACT03 – C2</td>
<td>NA</td>
<td>Isabella Drive, Macarthur</td>
<td>5</td>
<td>AC/UBCR</td>
<td>0.15 A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT04 – P1</td>
<td>NA</td>
<td>Yamba Drive, Isaacs</td>
<td>5</td>
<td>AC/UBCR</td>
<td>0.17 A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT04 – P2</td>
<td>NA</td>
<td>Yamba Drive, Isaacs</td>
<td>5</td>
<td>AC/UBCR</td>
<td>0.17 A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT05 – C1</td>
<td>NA</td>
<td>Yarra Glen, Curtin</td>
<td>5</td>
<td>DS/AC</td>
<td>0.46 A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT05 – C2</td>
<td>NA</td>
<td>Yarra Glen, Curtin</td>
<td>5</td>
<td>DS/AC</td>
<td>0.46 A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT06 – P1</td>
<td>NA</td>
<td>Monaro Highway, Fyshwick</td>
<td>6</td>
<td>DS/AC</td>
<td>0.35 A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>ACT06 – P2</td>
<td>NA</td>
<td>Monaro Highway, Fyshwick</td>
<td>6</td>
<td>DS/AC</td>
<td>0.35 A</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

**Victoria**

LTTPM1  LTTPM Stud Road, Dandenong North 31 AC/UBCR 0.56 A

LTTPM2  LTTPM Western Highway, Gerang Gerung -24 SS/UBCR 0.53 A

LTTPM3  LTTPM Princes Highway West, Heywood 13 SS/UBCR 0.41 I

LTTPM4  LTTPM South Gippsland Highway, Woodside 3 SS/UBCR 0.11 A

**Queensland**

LTTPM5  LTTPM Bruce Highway, North of Ingham 100 SS/UBCR 0.24 A

LTTPM6  LTTPM Flinders Highway, West of Townsville 12 SS/UBCR 0.21 I

**NSW**

LTTPM7  LTTPM Great Western Highway, Blacktown 40 AC/UBCR 0.56 A

**Tasmania**

LTTPM8  LTTPM Esk Main Road, Fingal 13 AC/CTCR 0.11 A

Notes:


CTCR: cement-treated crushed rock; CTSB: cement-treated sub-base.

3. Traffic load in millions equivalent standard axles (MESA)/lane/year.

4. A = Active; I = Inactive.

5. NA = these LTPP sites were not established as part of the former ALF-LTPP or SHRP-LTPP studies, but were later included to broaden the pavement types.

From Table 1, a total of 39 LTPP and 8 LTTPPM sites have been established since 1994/95. As the LTTPPM sites each contained five sub-sections, there were up to 79 LTPP and LTTPPM sections being monitored.

Currently 25 LTPP and 6 LTTPPM sites (55 sections) are monitored as there was a net loss of 24 sections on the arterial roads due either to major rehabilitation works or lane re-alignment over the 21 years of monitoring. In 2013/14 two new LTPP sites were established in South Australia (SA06 and SA07).

2.2. LTPP study of local road performance

The local roads deterioration study (LRDS) commenced in 2000 to develop road deterioration (RD) models suitable for unsealed and sealed local road conditions. The study gained endorsement from the Australian Local Government Association (ALGA), State Road Agencies (SRAs), Austroads and the Institute of Public Works Engineering Australia (IPWEA).

Over 200 organizations (Local Government Authorities (LGAs), SRAs and others) participated in the study by providing 500 sealed and 100 unsealed test sites established across Australia. Table 2 shows the breakdown of these sites by road type and jurisdiction.

All funding for the study, which included field monitoring, data assembly, analysis and model development, came from the LGAs who provided the sealed and unsealed local road sites. These sites were monitored by ARRB across Australia.

The LRDS aimed to develop both sealed and unsealed mechanistic-empirical deterministic RD models suitable for Australian local road conditions, using all the data collected during the monitoring period from 2002 to 2009 from all Australian states and territories.
Table 2. Breakdown of sealed and unsealed test sites by state and territory.

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>No. of participating organizations</th>
<th>No. of sealed sites</th>
<th>No. of unsealed sites</th>
<th>Total no. of sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>New South Wales</td>
<td>59</td>
<td>118</td>
<td>20</td>
<td>138</td>
</tr>
<tr>
<td>Victoria</td>
<td>53</td>
<td>144</td>
<td>25</td>
<td>169</td>
</tr>
<tr>
<td>Queensland</td>
<td>41</td>
<td>64</td>
<td>22</td>
<td>86</td>
</tr>
<tr>
<td>Western Australia</td>
<td>37</td>
<td>66</td>
<td>13</td>
<td>79</td>
</tr>
<tr>
<td>South Australia</td>
<td>24</td>
<td>47</td>
<td>20</td>
<td>67</td>
</tr>
<tr>
<td>Tasmania</td>
<td>17</td>
<td>34</td>
<td>-</td>
<td>34</td>
</tr>
<tr>
<td>ACT</td>
<td>1</td>
<td>6</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>4</td>
<td>21</td>
<td>-</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>236</td>
<td>500</td>
<td>100</td>
<td>600</td>
</tr>
</tbody>
</table>

As agreed by the participating organizations, the key performance parameters (dependent variables) used for the sealed (s) and unsealed (u/s) RD models were:

- strength (s), as assessed by FWD deflection
- rutting (s), as assessed by an MLP
- cracking (s), as assessed by visual inspection
- roughness (s and u/s), as assessed by an MLP (s) and a road and level survey (u/s)
- gravel loss (u/s), as assessed by a road and level survey
- shape loss (u/s), as assessed a road and level survey.

Deterministic modeling needs a substantial long-term data collection to capture all the possible variations to the input independent variables. The pavement performance observational data was collected by field surveys on each sealed and unsealed local road site. For the unsealed road sites, the condition data (transverse and longitudinal profile) was measured at two-monthly intervals over a 12 month period to estimate roughness changes and gravel and transverse shape loss. For the sealed road sites, road condition data (roughness, rutting, cracking and surface deflection), was measured at two-yearly intervals over a period of five years.

The participating organizations provided historical road use data covering traffic information such as the average daily traffic (ADT), the percentage of heavy vehicles (%HV) and the pavement history data of each of the nominated sites such as their construction, rehabilitation and surface sealing/resealing dates.

The rainfall and temperature data from each site’s nearest meteorological station were extracted from the Bureau of Meteorology (2009) database to estimate TMI values representing local climatic conditions.

3. Approach to Establishing and Monitoring LTPP Sites

3.1. LTPP site establishment criteria

Establishment of LTPP sites at the commencement of the study required compliance with the following basic criteria and information documented by Roberts and Martin (1996):

- Selection of a designated pavement lane that is reasonably homogeneous over the designed length of the site, based on known geotechnical and pavement material information.
- The overall condition of the subgrade, that is, a declaration that the subgrade is either ‘stable (non-reactive)’ or ‘unstable (reactive)’.
- Information allowing estimation of the local climate of the road segment as represented by the Thornthwaite Moisture Index (TMI) as defined by Thornthwaite (1948). This information includes annual rainfall and annual minimum and maximum daily temperature data.
- Valid construction and maintenance history so that the pavement and surface age can be determined.
- Categorization of the type of pavement surfacing, e.g., sprayed seal surfacing with nominal stone size, number and type of seals (i.e., single, double, geotextile, etc.).
The thickness of pavement layers and a description of the materials comprising the pavement structure and a declaration of whether some of these materials are moisture sensitive.

Inventory data covering the road name or identity number, start and finish running chainage and GPS coordinates of start and finish locations, lane location and width, direction of traffic flow, road classification (local, arterial, sub-arterial, etc.) and classification of location (rural or urban).

Road use data, updated on a regular basis, covering annual average daily traffic (AADT, vehicles/day), percentage heavy vehicles (%HV) and classification of heavy vehicles with the estimated equivalent standard axles for each heavy vehicle classification.

Road use data is ideally captured on a regular and extended basis using either a weigh-in-motion (WIM) device or a traffic classification device located near the LTPP site to accurately estimate the traffic load.

3.2. Monitoring protocols and equipment

The following road conditions and other variables impacting on pavement performance were assessed and recorded on each LTPP site:

- Lane rutting, based on the measured transverse profile of the lane, using a Walking Profilometer (WP) prior to 2002 and after 2002 using an ARRB MLP driven at highway speed and collected at the same time as the roughness measurements.
- Lane roughness in International Roughness Index (IRI) units (m/km) was continuously measured in the inner and outer wheel path of the lane and reported at 50 m to 100 m intervals along each site using the same equipment used for measuring lane rutting above.
- Surface deflection measured at 10 m intervals along the lane on the outer wheel path and between wheel paths of the lane using a falling weight deflectometer (FWD).
- The surface distress, such as cracking and loss of surfacing, was initially assessed by visual observation and later in the program either by digital imaging or by automatic distress detection devices driven at highway speed.
- Annual traffic load assessment was made using either WIM devices or traffic surveys.
- Any maintenance practices conducted at the site that would impact on the visible surface conditions.
- Annual meteorological data (rainfall and temperature).

The above road condition data was collected in accordance with the SHRP protocols for the FWD testing (1989) and the SHRP protocols (1990a) for LTPP monitoring of condition data and WIM studies (1990b). These protocols required the roughness and rutting measurements to be repeated five times on each LTPP site to confirm consistency and repeatability of the measurements. Similar monitoring protocols were used for the LTPPM sites.

Initially all LTPP sites were condition monitored on an annual basis. However, where LTPP sites were found to demonstrate low rates of deterioration, the monitoring frequency was extended up to a five year interval.

4. Outcomes of the LTPP Studies

4.1. LTPP study of arterial road performance

The main outcomes of the LTPP study to date are as follows:

- The development of guidelines for the establishment and monitoring of LTPP and LTPPM sites, developed by Clayton (2000).
- The development of a National database, using Microsoft Access, for archiving LTPP and LTPPM pavement performance data. The pavement performance data is available for download free of charge at the LTPP website (URL: http://www.arrb.com.au/ltpp/) for sharing with road agencies, researchers and the general public. In 2014 the LTPP website had over 2600 hits seeking performance data.
- An annual summary report and newsletter updating the performance of the LTPP and LTPPM sites monitored in the previous 12 months distributed to all stakeholders.
Analysis of the pavement performance observed during ALF trials was generally comparable with in-service pavement performance, particularly for unbound pavements with sprayed bituminous seals. The effect of the inter-relationship between factors such as environment, age and mix of traffic loadings on pavement performance cannot be fully addressed by accelerated pavement testing.

Analysis of data collected during ALF trials for the impact of various surface maintenance treatments combined with the observational data from the LTPP and LTTPM sites, facilitated the development of rutting and roughness progression factors and the calibration of the HDM-4 RD models for rutting and roughness under Australian conditions as reported by Martin (2004).

A comparison between the asphalt pavement performance of the LTPP sites and the US SHRP-LTPP sites demonstrated that these pavements showed similar rates for roughness and strength deterioration under similar traffic and climatic conditions as documented in Austroads (2009).

The development of interim works effect (WE) models for a wide range of surface treatments based on using before and after treatment condition data at the LTPP and LTTPM sites in combination with specific SRA before and after surface treatment data as documented in Austroads (2007).

The development of interim network-level functional RD models for roughness, rutting and cracking of flexible pavements using ALF maintenance experimental data and the data from the impact of increased axle mass loading and observational data from the LTPP and LTTPM sites, as documented in Austroads (2010a).

The development of interim network-level structural RD models for flexible pavements using observational data from the LTPP and LTTPM sites, as documented in Austroads (2010b).

The above RD models, along with the above Austroads work to develop interim WE models, were installed in the PMS used by the SRAs in NSW and Victoria.

A new probabilistic modelling approach using data condensation technology, known as a stochastic information packet (SIP), was trialed in a proof-of-concept study to explore the possibility of adopting the approach in a PMS by Kadar et al. (2015). The study used a two-step process by conducting SIP operations (i.e. pavement modelling) in an Excel environment (step 1) and then importing the results into the PMS to trigger intervention condition limits for developing treatment strategies (step 2).

The above RD and WE models form the basis of the analysis in the freight axle mass limits investigation tool (FAMLIT) used to estimate the marginal cost of road wear due to increased axle mass limits on heavy vehicles, as documented in Austroads (2014). The marginal cost of road wear is expected to be incorporated into a heavy vehicle road pricing scheme as part of a heavy vehicle road reform initiative across Australia.

There has recently been preliminary development of RD models into the rapid deterioration phase to demonstrate and quantify the impact of deferred maintenance intervention on pavement surface conditions, as documented in Austroads (2015). These models have been based on performance data provided by the SRAs involved with the LTPP and LTTPM research.

The calibration of HDM-4 and development of the RD models was able to draw on related research projects funded by Austroads and others. Long-term climate change modelling up to the year 2099 by Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO) (2001) led to the development of a simple Excel based spread sheet model to predict the Thornthwaite Moisture Index, TMI, for any location in Australia based its GPS coordinates, as documented in Austroads (2010c). This allowed a relatively easy assessment of TMI for modelling purposes. The determination of the under-lying rates of roughness and rutting deterioration from time series data were assessed by a heuristic approach, as documented by Martin (2008). The approach was independently validated by Byrne (2007) using a minimum message length (MML) data mining technique.

The annual report allows a review of the LTPP and LTTPM sites to be monitored and their monitoring frequency.

4.2. LTPP study of local road performance

The LRDS produced the following RD models, for sealed and unsealed roads, documented by Martin et al. (2013), which can be directly installed into a PMS:

- Sealed local roads RD models for rutting, roughness, cracking and strength based on the structure of the RD models derived from the LTPP and LTTPM research.
• Unsealed local roads RD models for roughness, gravel loss of surface sheeting and transverse shape loss of the pavement to initiate grader blading.

Recently a related study on the impact of road maintenance on unsealed road performance was conducted and completed on a sample of unsealed roads in Victoria. This study developed interim WE models for the impact of grader blading and granular resheeting on unsealed roads, as documented by Dias et al. (2014). This work was funded by a joint cooperative between Austroads, ARRB and the LGA.

Further work on similar WE modelling in 2015 and 2016 is underway on samples of unsealed roads in Queensland and NSW by means of the same joint cooperative funding arrangement.

5. Benefits of the LTPP Studies

5.1. Cost of the studies and other considerations

The LTPP and LTPPM study is estimated to have cost $5.3 million (dollars of the day) over the 21 years from 1994/95 to 2015/16. The LRDS cost $4 million (dollars of the day) over the 10 years from 2001/02 to 2011/12, giving a total of $9.3 million spent on Australian LTPP studies.

While the study costs are significant in the Australian context, it is a relatively low cost compared to the value of the Australian road infrastructure (federal, state and local) which is estimated to be around $230 billion, excluding bridges, as noted by Roads Australia (2015). The annual maintenance and rehabilitation expenditure on Australia’s roads is around $14 billion, according to Infrastructure Partnerships Australia (2011).

5.2. Benefits of the studies

The reliable prediction of pavement performance is a key element when using a PMS to estimate future network funding requirements, the allocation of this funding throughout the network and the programming of the identified type of work determined to keep the network at a safe level of service and performance to the users. A documented network level study, such as one conducted by Martin and Thoresen (1998), has shown that managing pavement deterioration to the lowest rate possible can produce annual road agency savings in maintenance and rehabilitation works of up to 39%. However, even if a more modest saving in annual road agency costs of 5% ($700 million) was achieved, the benefit cost ratio derived from the LTPP and LTPPM studies would exceed 70.

Other benefits accrue due to having a LTPP and LTPPM database readily accessible to the public. As most road agency maintenance work is contracted out to providers, the LTPP and LTPPM database and the resulting RD and WE models are a useful resource for contractors and consultants bidding and planning road maintenance works.

The LTPP and LTPPM studies have also been a focal point and data source for a number of related studies such as the identification of under-performing pavements, the impact of climate change on the road infrastructure and pavement performance prediction beyond the usually experienced linear rates of deterioration. As the program and scope of the LTPP and LTPPM study is reviewed annually, it remains focused on issues of relevance and avoids unnecessary expenditure on research of low return.

References


Bureau of Meteorology, 2009. Climate data: Australia, CD ROM, BoM, Canberra, ACT, Australia.


Infrastructure Partnerships Australia, 2011. Road Maintenance: Options for Reform, Infrastructure Partnerships Australia, Sydney, NSW, Australia.


