Estimating the marginal cost of road wear on Australia’s sealed road network

Dr Tim Martin, Thorolf Thoresen, Mathew Clarke & Will Hore-Lacy
Introduction

• Council of Australian Government (COAG) road reform plan involves exploring infrastructure pricing models for heavy vehicles so that
  - road network can be used more productively (more payload)
  - expand road access in a way that the additional cost can be recovered

• ARRB using Austroads/NTC research funding has investigated estimating the marginal road infrastructure costs resulting from additional units of road usage, focusing on higher loads on different axle group loads on heavy vehicles

• The outputs of this research will feed into the COAG Road Reform Plan (CRRP) project.
Impact of Loads on Costs

• This research project aims to investigate the relationship between varying vehicle loads and road wear costs.

Varying Loads

Different Road Classifications

Impact on Road Wear Costs

Change in road wear cost per vehicle trip
Definitions of marginal cost (MC)

- We are interested in the marginal road infrastructure cost resulting from additional units of road usage, focusing on higher loads on a vehicle.

  - **Short-run-marginal-cost (SRMC)** takes into account the cost of maintaining a road within a defined condition limit (roughness) with no road strengthening beyond initial design value – “Constrained” approach

  - **Long-run-marginal-cost (LRMC)** takes into account the cost of maintaining a road within a defined condition limit (roughness) and allows road strengthening beyond initial design value – “Unconstrained” approach

**Note:** marginal costs on heavy vehicle road users was not estimated
Basis for estimating road wear costs

• Used a pavement life-cycle costing model, Freight Axle Mass Limits Investigation Tool (FAMLIT) to estimate present value PV wear of maintenance and rehabilitation costs over a 50 year period
• Converted PV wear into equivalent annual uniform costs (EAUC)
• Considered sealed road network of three pavements types
  - sealed granular pavements (GN)
  - asphalt pavements (AC)
  - sealed cement stabilised pavements (CS)
• Simulated road network of 17 road types (traffic level, location, climate) of new (N) and in-service (S) pavement types
Assumptions of life-cycle costing

- No growth of heavy vehicle numbers
- Unconstrained funds for maintenance and rehabilitation funding
- Rehabilitation work (thickness/depth requirements) triggered by roughness limits (varied with road type) to reset roughness
- Wear costs estimated on one kilometre long lane section (AUD/lane-km)
Deterioration models considered for road wear estimation

• Strength/roughness deterioration (SSD) model – roughness is a function of traffic load, climate and annual strength

• Rutting/roughness deterioration (RRD) model – roughness is a function of traffic load, climate and initial strength

  - rehabilitation intervention can also be triggered by excess rutting

  - accounted for increased routine and periodic maintenance with increased traffic loads

• Compared estimates with SSD and RRD models, used RRD because it better reflects reality
Traffic loading

• Based on annual weigh-in-motion (WIM) data for axles groups and AADT estimates for road types
• Standard axle repetitions (SAR) for road wear of axle groups used;
  - GN pavements SAR = 4
  - AC pavements SAR = 5
  - CS pavements SAR = 12
Loading scenarios

• Considered six axle groups loaded from tare weight to > GML;
  - single axle single tyre (SAST), single axle dual tyre (SADT)
  - tandem axle single tyres (TAST), tandem axle dual tyres (TADT)
  - triaxle dual tyres (TRDT), quad axle dual tyres (QADT)

• Loading scenario summary:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>SAST (tonne)</th>
<th>SADT (tonne)</th>
<th>TAST (tonne)</th>
<th>TADT (tonne)</th>
<th>TRDT (tonne)</th>
<th>QADT (tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference load</td>
<td>5.4</td>
<td>8.15</td>
<td>9.17</td>
<td>13.76</td>
<td>18.45</td>
<td>22.53</td>
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<tr>
<td>Load increment</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Axle load offset</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5.5</td>
<td>9</td>
<td>9.75</td>
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<tr>
<td>Tare weight</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>6.5</td>
<td>10</td>
<td>10.75</td>
</tr>
<tr>
<td>Base GML</td>
<td>6</td>
<td>9</td>
<td>11</td>
<td>16.5</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Maximum load</td>
<td>12</td>
<td>15</td>
<td>20</td>
<td>26.5</td>
<td>35</td>
<td>45</td>
</tr>
</tbody>
</table>
Incremental load wear cost - methodology & assumptions

- Example of Model Mechanics - SRMC

- Additional 1 tonne carried → Impact on road pavement → Intervention brought forward → PV of future road costs increases

Illustrative example:

Roughness

Intervention required

Road returned to reset value

\( M^1, M^2, M^3, M^4 \)  
\( \text{Time} \)

\( M \)  
Increase in mass from GML

General Mass limits (GML)

Maintenance Intervention
Incremental load wear cost - methodology & assumptions

- Development of cost curves
- Regression analysis
Load-wear-costs (LWC) and marginal costs (MC) as a function of axle load

\[ LWC = EAUC = a_0 + (TMI + TMIOFFSET)^{a_1} + a_2 \times (Axle \ Load - Offset)^{a_3} \]

The annual marginal cost, \( MC_{ann} \) (c/tonne-km/yr) is the first derivative of EAUC with respect to axle load:

\[ = a_2 \times a_3 \times (Axle \ Load - Offset)^{(a_3 - 1)} \]

The marginal cost per axle group pass, \( MC_{axle} \) (c/tonne-km):

\[ = MC_{ann} \times \text{number of axle group passes per year} \]

where:

- \( a_0, a_1, a_2 \) and \( a_3 \) = regression coefficients;
- Axle Load = tonne;
- TMI = Thornthwaite Moisture Index;
- TMIOFFSET = minimum TMI value plus one;
- Offset = axle group reference base tonnes before incremental axle loads were varied

* Determined by non-linear least squares regression analysis
Load-wear-costs (LWC) and marginal costs (MC) as a function of SAR

\[ \text{LWC} = \text{EAUC} = a_0 + (\text{TMI} + \text{TMI OFFSET}) a_1 + a_2 \times (\text{SAR-km} - \text{Offset}) \]

The annual marginal cost, \( \text{MC} \) (c/SAR-km) is the first derivative of EAUC with respect to SAR-km:

\[ \text{MC} = \frac{\partial \text{EAUC}}{\partial \text{SAR-km}} = a_2 \]

where:

- \( a_0, a_1 \) and \( a_2 \) = regression coefficients; SAR-km = annual pavement wear per lane-km; Offset = axle group reference base SAR-km before incremental axle loads were varied

\* Determined by non-linear least squares regression analysis
Examples of LWC and MC results

• High daily traffic rural granular pavement (RT1 – HRGN)
• High daily traffic urban asphalt pavement (RT2 – HUAC)
• Low daily traffic rural granular pavement (RT3 – LRGN)
• Above roads represent 63% of sealed road network
SRMC and LRMC re-defined

- SRMC1 used rehabilitation thickness needed (< minimum rehabilitation thickness) to return pavement strength to no greater than initial strength
- SRMC1 used full reset roughness after rehabilitation (not realistic)
- SRMC2 used minimum practical rehabilitation thickness, but pavement strength as a consequence was increased
- SRMC2 is not in accordance with SRMC definition
- LRMC1 allowed rehabilitation thickness to be whatever it needed to be to cater for the increased load
LWC based on SRMC1 & SRMC2 approach for RT1
SRMC1 & SRMC2 estimation for RT1
LWC based on SRMC2 approach for RT2

RT2 - HUAC (N) (TML=20)

- SRD model: SRMC2
- RRD model: SRMC2

EAUC ($) vs Load (tonne) on Tandem axle (TADT)
SRMC2 estimation for RT2

RT2 - HUAC (N) (TMI=20)

SRMC2: SRD model
SRMC2: RRD model

Load (tonne) on Tandem axle (TADT)

SRMC (c/tonne-km/pass)
LWC based on SRMC2 and LRMC1 approach for RT1

![Graph showing EAUC ($) vs Load (tonne) on Tandem axle (TADT) for RT1- HRGN (TMI=0). The graph compares RRD model: LRMC1 and RRD model: SRMC2, with a GML indicated.]
LWC based on SRMC2 and LRMC1 approach for RT2

RT2 - HUAC (N) (TMI=20)

- RRD model: LRMC1
- RRD model: SRMC2

EAUC ($) vs. Load (tonne) on Tandem axle (TADT)
LWC based on SRMC2 and LRMC1 approaches for RT3

![Graph showing LWC based on SRMC2 and LRMC1 approaches for RT3. The graph plots EAUC ($) against Load (tonne) on Tandem axle (TADT). The graph includes two lines: one for RRD model: LRMC1 and another for RRD model: SRMC2. There is a vertical line indicating GML.](image)
LWC relationship variation with axle groups for RT2
LWC estimation with SAR

EAUC vs Million SAR- km/year

- RT3 - LRMC1
- RT2 - LRMC1
- RT1 - LRMC1

EAUC ($) vs Million SAR-km/year

0 5000 10000 15000 20000 25000 30000

0 0.5 1 1.5 2 2.5

Million SAR-km/year
LRMC1 estimates based on SAR-km

- LRMC1 estimates constant for each road type
- Summary of LRMC1 estimates for RT1, RT2 & RT3

<table>
<thead>
<tr>
<th>Road type</th>
<th>LRMC1 (c/SAR-km)</th>
<th>% Sealed road network</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT1</td>
<td>0.801</td>
<td>24</td>
</tr>
<tr>
<td>RT2</td>
<td>0.569</td>
<td>2</td>
</tr>
<tr>
<td>RT3</td>
<td>41.9</td>
<td>37</td>
</tr>
</tbody>
</table>
Summary

• Definition of SRMC had to be redefined to reflect reality of maintenance and rehabilitation practice
• SRMC and LRMC estimates are virtually equal for most load increases on axle groups
• SRMC/LRMC estimates expressed in terms of c/SAR-km are applicable to all axle groups on a given road type
• SRMC/LRMC estimates of c/SAR-km increase as road types have lower levels of traffic (resulting primarily from the design strength)