Axle loads; Equivalent Axles or Load Spectrum?

Joint Nordic/Baltic Symposium on Pavement Design and Performance Indicators

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**ESAL; Equivalent Single Axle Loads**

- One of the main deliverables of the AASHO Roads Test 1958 – 1960

- A method of aggregating all traffic loads into their equivalent number of standard single axle loads.
  - Single axle
  - 18 000 lbs (18 kips) axle load
  - Dual tyre

- Widely used in many countries for many years

- LEF: Load Equivalency Factor
- EDF: Equivalent Damage factor
- (ESWL: Equivalent Single Wheel Load)
The original AASHO Equations

\[
LEF = \frac{W_x}{W_{18}} = \left(\frac{L_{18} + L_{2S}}{L_X + L_{2X}}\right)^{4,79} \times \left(\frac{10^{G/\beta_X}}{10^{G/\beta_{18}}}\right) \times \left(L_{2X}\right)^{4,33}
\]

\[
G = \log\left(\frac{4,2 - p_t}{4,2 - 1,5}\right) \quad \beta_X = 0,3 + \left(\frac{0,081 \times (L_X + L_{2X})^{3,23}}{(SN + 1)^{5,19} \times L_{2X}^{3,23}}\right)
\]

where:  
- \(L_X\) = the axle load (lbs)  
- \(L_{2X}\) = code for axle configuration  
  - Single axle: \(L_{2X} = 1\)  
  - Tandem axles: \(L_{2X} = 2\)  
  - Triple axles: \(L_{2X} = 3\) (from 1986)  
- \(SN\) = structural number of the pavement  
- \(p_t\) = terminal serviceability index
Original LEF is a function of:

- the axle load
- the axle configuration
- the structural number of the pavement
- the terminal serviceability index

The LEF equation is since 1960-ies presented in many variants

The most simplified version:
the fourth power law

\[ LEF = \left( \frac{W_x}{18} \right)^4 \]

Not very useful because:
applicable only to single axles with dual tyres, based on serviceability index as the performance parameter
Minnesota: the MnRoad Project

The Serviceability Model

\[ EDF = \left( \frac{FA}{18 \times 0.552} \right)^{4.15} + m_1 \times \left( \frac{SA}{18} \right)^{4.15} + m_2 \times \left( \frac{TA}{18 \times 1.85} \right)^{4.15} \]

The Roughness (IRI) Model

\[ EDF = \left( \frac{FA}{18 \times 0.523} \right)^{3.85} + m_1 \times \left( \frac{SA}{18} \right)^{3.85} + m_2 \times \left( \frac{TA}{18 \times 1.85} \right)^{3.85} \]

EDF = equivalent damage factor (per vehicle)
FA = front axle load, single axle, single tyre (lbs)
SA = single axle load, dual tyre (lbs)
TA = tandem axle load, dual tyre (lbs)
m_1 = no of single axles per vehicle (front axle excluded)
m_2 = no of tandem axles per vehicle (dual tyres)
The exponent:

Minnesota, Mn Road
Serviceability index: exponent = 4,15
Roughness index, IRI: exponent = 3,85
Increase in rutting: exponent = 2,98 (single axles)
                     exponent = 3,89 (tandem axles)

Cantebury, New Zealand:
27 mm asphalt surface om 275 mm granular base course.
Pavement deterioration based on rutting:
Exponent varied from 3 to 9
   7th International Symposium on Heavy Vehicle Weights & Dimensions, Delft, The Netherlands, Europe, 2002
Distress and damage factors for flexible pavements,
Norwegian Public Roads Administration, publication no 66

\[
LEF = k_{at} \times k_{wt} \times k_{ld} \times k_{tp} \times \left( \frac{P}{P_0} \right)^\alpha
\]

- \(k_{at}\) expresses the effect of axle type, including the axle spacing
- \(k_{wt}\) expresses the effect of wheel type (single vs dual tyres, wide base, etc)
- \(k_{ld}\) expresses the effect of suspension system (leaf spring or air)
- \(k_{tp}\) expresses the effect of tyre inflation pressure
- \(P\) the load on one axle (each axles in tandem or triple axle configuration are looked at separately)
- \(P_0\) the reference load on one single axle
- \(\alpha\) the exponent (value depends on the type of distress)
  - fatigue cracking: \(\alpha = 2,0\)
  - roughness: \(\alpha = 4,0\)

- A subtask of the BUAB project was to analyse 54 different types of heavy vehicles with respect to their road friendliness.
- Road friendliness: the ratio between the payload and the LEF sum of the vehicle.
- The types of vehicles in the study represent heavy vehicles in the AUTOSYS database of the Norwegian Directorate of Public Roads:
  - 5 busses
  - 8 trucks
  - 13 semitrailers
  - 28 full trailers

[Diagram showing road friendliness data]

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Load spectra

- ME-PDG (AASHTO 2002 Design Guide)

- Quite complex, requires a lot of data
  - Vehicle class distribution (10 heavy vehicle classes)
  - Axle load distribution single axles for each vehicle class
  - Axle load distribution, tandem axles for each vehicle class
  - Axle load distribution, triple axles for each vehicle class
  - Average number of single axles per vehicle (for each vehicle class)
  - Average number of tandem axles per vehicle (for each vehicle class)
  - Average number of triple axles per vehicle (for each vehicle class)
  - Tyre pressure, distance between axles, etc. etc.
The FHWA classification is not fully comparable with the European truck and trailer combinations

Table 1. FHWA commercial vehicle classification schema.

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Schema</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td><img src="image" alt="4" /></td>
<td>Buses</td>
</tr>
<tr>
<td>5</td>
<td><img src="image" alt="5" /></td>
<td>Two-axle, six-tire, single-unit trucks</td>
</tr>
<tr>
<td>6</td>
<td><img src="image" alt="6" /></td>
<td>Three-axle single-unit trucks</td>
</tr>
<tr>
<td>7</td>
<td><img src="image" alt="7" /></td>
<td>Four- or more than four-axle single-unit trucks</td>
</tr>
<tr>
<td>8</td>
<td><img src="image" alt="8" /></td>
<td>Four- or less than four-axle single trailer trucks</td>
</tr>
<tr>
<td>9</td>
<td><img src="image" alt="9" /></td>
<td>Five-axle single trailer trucks</td>
</tr>
<tr>
<td>10</td>
<td><img src="image" alt="10" /></td>
<td>Six- or more than six-axle single trailer trucks</td>
</tr>
<tr>
<td>11</td>
<td><img src="image" alt="11" /></td>
<td>Five- or less than five-axle multi-trailer trucks</td>
</tr>
<tr>
<td>12</td>
<td><img src="image" alt="12" /></td>
<td>Six-axle multi-trailer trucks</td>
</tr>
<tr>
<td>13</td>
<td><img src="image" alt="13" /></td>
<td>Seven- or more than seven-axle multi-trailer trucks</td>
</tr>
</tbody>
</table>

The BWIM classification: truck and trailer combinations are included in the 8 – 10 FHWA classes
FHWA Vehicle Classification

Traffic Volume Adjustment Factors

AADTT distribution by vehicle class

- Class 4: 14.8
- Class 5: 18.8
- Class 6: 8.7
- Class 7: 0.9
- Class 8: 5.8
- Class 9: 13.4
- Class 10: 37.5
- Class 11: 0.0
- Class 12: 0.0
- Class 13: 0.0

Total: 100.0

Load Default Distribution:
- Level 1: Site Specific Distribution
- Level 2: Regional Distribution
- Level 3: Default Distribution

Note: AADDT distribution must total 100%.
## Average number of axles per vehicle

<table>
<thead>
<tr>
<th>Class</th>
<th>Single</th>
<th>Tandem</th>
<th>Tridem</th>
<th>Quad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 4</td>
<td>1.69</td>
<td>0.33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Class 5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Class 6</td>
<td>1.01</td>
<td>0.99</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Class 7</td>
<td>1.48</td>
<td>0.75</td>
<td>0.34</td>
<td>0</td>
</tr>
<tr>
<td>Class 8</td>
<td>3.01</td>
<td>0.37</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Class 9</td>
<td>2.48</td>
<td>0.41</td>
<td>0.57</td>
<td>0</td>
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<tr>
<td>Class 10</td>
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<td>1.52</td>
<td>0.17</td>
<td>0</td>
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<td>Class 11</td>
<td>4.29</td>
<td>0.26</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>Class 12</td>
<td>3.52</td>
<td>1.14</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>Class 13</td>
<td>2.15</td>
<td>2.13</td>
<td>0.35</td>
<td>0</td>
</tr>
</tbody>
</table>
Axle load distribution, single axles

Forslag til aksellastfordeling, enkeltaksler

Aksellast, tonn

Kumulativ fordeling

FHWA 4, alle veger
FHWA 6, alle veger
FHWA 9, alle veger
FHWA 5, stamveger
FHWA 8, stamveger
FHWA 10, alle veger
FHWA 5, øvrige Rv
FHWA 8, øvrige Rv
HB 018
Axle load distribution, tandem axles

Forslag til lastfordeling, boggiaksler

Last, tonn

Kumulativ andel

FHWA 4
FHWA 6
FHWA Sverige
FHWA 10 konv.

FHWA 8 øvr.RV
FHWA 9

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Hourly distribution of heavy vehicles, BWIM Sweden 2004
Equivalent Axles or Load Spectrum?

In the short term:

- All pavement design systems have some calibration against pavement service lives or observed pavement deterioration.

- A lot of experience is connected to ESWL. Even ME-PDG presents ESWL in design project (temporary text files) as information.

- In pavement design the expected future traffic loads should be based on the same principles that were used for calibration.

If you get the correct results from wrong input data, you would most certainly get the wrong results from the correct input data!
Equivalent Axles or Load Spectrum?

In the long run:

Use of load spectra is preferred

- Load spectra require a large number of data
- Equivalent axles require a large number of coefficients to give the correct results
- ESWL is a relatively inaccurate simplification of the influence of traffic loads on pavement performance.
- WIM and BWIM data favour the use of load spectra
- Load spectra are easily adaptable to new trends in truck and trailer design as well as axle configurations