2015 North Dakota Asphalt Conference

NDDOT Implementation of AASHTO Flexible Pavement Design

Part I – ADT & ESALs – Nickie Reis, P&AM
Part II – Structural Numbers – Tom Bold, M&R

March 31 - April 1, 2015
Part I – ADT & ESALs – Nickie Reis, P&AM

Part II – Structural Numbers – Tom Bold, M&R
Process of going from traffic counts to ESALs
(Equivalent Single Axle Load)
It all begins with Traffic!

- Without a quality traffic count everything is based on assumptions or best estimates.
- A traffic count doesn’t do much good if it has incorrect data.
Traffic Counts

• NDDOT collects traffic using portable Automatic Data Recorders (ADRs) to obtain 24 hour data at class locations.

• NDDOT also uses permanent Automatic Traffic Recorders (ATRs) that collect traffic data every day throughout the year.

• Both methods collect traffic based on Class FHWA scheme “F” 13 vehicle classification tree.

• Classification scheme is how the ATR’s and the portable counters “see” the various truck axle configurations.
FHWA 13 Vehicle Classification (Scheme F)
(Scheme F) without Classes 1-4

<table>
<thead>
<tr>
<th>Classification Type</th>
<th>Vehicle Type</th>
<th>No. of Axles</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>7 or more</td>
</tr>
</tbody>
</table>
Equivalent Single Axle Load (ESAL)

• **ESAL**- is the relationship between axle weight and pavement damage.
• The reference axle load is an 18,000-lb. single axle with dual tires.
• Developed by the American Association of State Highway Officials (AASHO) Road Test.
Loaded ESAL Values by Truck type

Based on AASHTO Guide for Design of Pavement Structures 1993 – Appendix D

Assumed Pt= 2.5 & Sn=2

- The Sn changes based on the cross section of the existing roadway
- 4 inches of Asphalt and 10 inches of Base would represent a Sn=2

---

### Class 7

<table>
<thead>
<tr>
<th>Weight (lb 000s)</th>
<th>Total</th>
<th>ESALS (Flex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>58</td>
<td>.613</td>
</tr>
<tr>
<td>42</td>
<td></td>
<td>.594</td>
</tr>
</tbody>
</table>

Total ESALs = **1.207**

### Class 10

<table>
<thead>
<tr>
<th>Weight (lb 000s)</th>
<th>Total</th>
<th>ESALS (Flex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>88</td>
<td>.198</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td>1.08</td>
</tr>
<tr>
<td>42</td>
<td></td>
<td>.594</td>
</tr>
</tbody>
</table>

Total ESALs = **1.872**
Loaded ESAL Values by Truck type

Based on AASHTO Guide for Design of Pavement Structures 1993 – Appendix D

Assumed Pt= 2.5 & Sn=2

- The Sn changes based on the cross section of the existing roadway
- 4 inches of Asphalt and 10 inches of Base would represent a Sn=2

### Class 9

<table>
<thead>
<tr>
<th>Weight (lb 000s)</th>
<th>ESALS (Flex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.198</td>
</tr>
<tr>
<td>34</td>
<td>1.08</td>
</tr>
<tr>
<td>34</td>
<td>1.08</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.358</strong></td>
</tr>
</tbody>
</table>

### Class 13

<table>
<thead>
<tr>
<th>Weight (lb 000s)</th>
<th>ESALS (Flex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.198</td>
</tr>
<tr>
<td>34</td>
<td>1.08</td>
</tr>
<tr>
<td>34</td>
<td>1.08</td>
</tr>
<tr>
<td>13</td>
<td>0.278</td>
</tr>
<tr>
<td>12.5</td>
<td>0.238</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.874</strong></td>
</tr>
</tbody>
</table>
## Loaded ESALs by Vehicle Class Distribution

<table>
<thead>
<tr>
<th>Class Type</th>
<th>% Type</th>
<th>Truck Volume</th>
<th>Number of Trucks</th>
<th>Flex ESAL Rate (loaded)</th>
<th>Flexible ESALS Per Type</th>
<th>Weight (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 5</td>
<td>5</td>
<td>1000</td>
<td>50</td>
<td>1.768</td>
<td>88.4</td>
<td>32,000</td>
</tr>
<tr>
<td>Class 6</td>
<td>2</td>
<td>1000</td>
<td>20</td>
<td>1.278</td>
<td>25.56</td>
<td>46,000</td>
</tr>
<tr>
<td>Class 7</td>
<td>1</td>
<td>1000</td>
<td>10</td>
<td>1.207</td>
<td>12.07</td>
<td>58,000</td>
</tr>
<tr>
<td>Class 8</td>
<td>12</td>
<td>1000</td>
<td>120</td>
<td>2.848</td>
<td>341.76</td>
<td>66,000</td>
</tr>
<tr>
<td>Class 9</td>
<td>66</td>
<td>1000</td>
<td>660</td>
<td>2.358</td>
<td>1556.28</td>
<td>80,000</td>
</tr>
<tr>
<td>Class 10</td>
<td>6</td>
<td>1000</td>
<td>60</td>
<td>1.872</td>
<td>112.32</td>
<td>88,000</td>
</tr>
<tr>
<td>Class 11</td>
<td>1</td>
<td>1000</td>
<td>10</td>
<td>6.478</td>
<td>64.78</td>
<td>92,000</td>
</tr>
<tr>
<td>Class 12</td>
<td>1</td>
<td>1000</td>
<td>10</td>
<td>5.988</td>
<td>59.88</td>
<td>105,500</td>
</tr>
<tr>
<td>Class 13</td>
<td>6</td>
<td>1000</td>
<td>60</td>
<td>2.874</td>
<td>172.44</td>
<td>105,500</td>
</tr>
</tbody>
</table>

Total= 2433.49 ESALs
Difference in Assuming all trucks are in a certain vehicle Class

- 1000 trucks x 2.358 ESALs (Class 9) = 2358 ESALs
- 1000 trucks x 2.874 ESALs (Class 13) = 2874 ESALs
- Difference between Class 13 & Class 9
  \[ 2874 - 2358 = 516 \text{ ESALs} \]
- 516 ESALs x 365 days in a year x 20 years equals a difference of \(3,766,800\) ESALs.
- By not knowing what class of trucks that are on the roadway can have a significant impact on the design.
Traffic Estimate

• After the traffic count is taken and ESALs calculated a growth rate is applied.
• There are no set standard growth rates.
• Growth rates are usually based on traffic history, economic activity in the area & local knowledge of future traffic generators.
• The information then gets sent to materials for their part.
Part I – ADT & ESALs – Nickie Reis, P&AM

Part II – Structural Numbers – Tom Bold, M&R
(or, NDDOT AASHTO Pavement Design Inputs)
Highway Performance Class & Investment Strategies
AASHTO Flexible Pavement Design Equation

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{1094} + 2.32 \times \log_{10}(M_R) - 8.07
\]
Predicted Damage over the Design Period (Accumulated ESALs)

= 

Pavement Structure Required Based on:

- Available Foundation Soil Strength
- Condition at the End of the Design Period
- Acceptable Level of Risk

AASHTO Flexible Pavement Design Equation

\[
\left\{ \log_{10}(W_{18}) - Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left( \frac{\Delta PSI}{4.2-1.5} \right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07 \right\}
\]
Design Input Factors

\[ \log_{10} W_{18} = Z_R \times S_o + 9.36 \times \log_{10} (SN + 1) - 0.20 + \frac{1094}{(SN + 1)^{5.19}} \frac{\Delta PSI}{4.2 - 1.5} + 2.32 \times \log_{10} (M_R) - 8.07 \]

\[ W_{18} = \text{Accumulated ESALS} \]

\[ Z_R = \text{Reliability Factor} \]

\[ S_o = \text{Standard Deviation} \]

\[ SN = \text{Structural Number} \]

\[ \Delta PSI = \text{Serviceability Index} \]

\[ M_R = \text{Subgrade Resilient Modulus} \text{ (in psi)} \]
Traffic Counts & Future Growth Rate

\[ \log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}(\frac{\Delta PSI}{4.2-1.5})}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07 \]

\[ W_{18} = \text{Total Accumulated Flexible ESALs for Pavement Design Period} \]

- Predicted Number of 18,000 lb. Axle Loadings (1 - 18kips = ESAL)
  - \( T/2 \times 365 \times \left[ \frac{(1+i)^n - 1}{i} \right] \)

Where:
- \( T = \text{Two-Way Daily Flexible ESALs} \)
- \( i = \text{Growth Rate} \)
- \( n = \text{Design Period, (20 years for flexible pavements)} \)
**Z_R = Reliability**

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10} \left( \frac{\Delta PSI}{4.2 - 1.5} \right)}{1094} + 2.32 \times \log_{10}(M_R) - 8.07
\]

\[Z_R = \text{Reliability Factor (Risk)}\]

<table>
<thead>
<tr>
<th>NDDOT Performance Class</th>
<th>New Construction (Reliability %)</th>
<th>Rehabilitation (Reliability %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate</td>
<td>90%</td>
<td>85%</td>
</tr>
<tr>
<td>Interregional Corridor</td>
<td>85%</td>
<td>80%</td>
</tr>
<tr>
<td>State Corridor</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>District Corridor</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>District Collector</td>
<td>70%</td>
<td>70%</td>
</tr>
</tbody>
</table>
$S_0 = \text{Standard Deviation}$

$\log_{10}(W_{18}) = Z_R \times S_0 + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{1094} + 2.32 \times \log_{10}(M_R) - 8.07 + 0.40 + \frac{1}{(SN+1)^{5.19}}$

$S_0 = \text{Standard Deviation}$

- Combined Standard Error of the Traffic Prediction and Performance Prediction
- NDDOT uses 0.49
SN = \textit{Structural Number}

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN + 1) - 0.20 + \log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right) + 2.32 \times \log_{10}(M_R) - 8.07
\]

SN = \textit{Structural Number}

- Indicative of the total pavement thickness required
  \[
  SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots
  \]
  where: \( a_i = i^{th} \text{ layer coefficient} \)
  \( D_i = i^{th} \text{ layer thickness (inches)} \)
  \( m_i = i^{th} \text{ layer drainage coefficient} \)
\[ \log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{1094} + 2.32 \times \log_{10}(M_R) - 8.07 \]

**SN = Structural Number**

\[ SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \ldots \]

- \( a_i = i^{th} \) Layer Coefficient
  - New HBP Superpave Material
    - 20 yr. Accumulated Design ESALS
      - \( < 400,000 \) FAA 40 = 0.34
      - 400,000 to \( < 1,000,000 \) FAA 42-43 = 0.36
      - 1,000,000 to 3,000,000 FAA 44 = 0.38
      - \( > 3,000,000 \) FAA 45 = 0.40
  - New Cold In-Place Recycling = 0.25
**SN = Structural Number**

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}(\frac{\Delta PSI}{4.2 - 1.5})}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07
\]

**Structural Overlays**

\[
SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \ldots
\]

- \(a_1\) = \(i^{th}\) Layer Coefficient
  - New HBP Superpave Material
    - **20 yr. Accumulated Design ESALS**
      - \(< 400,000\) FAA 40 = 0.34
      - 400,000 to \(< 1,000,000\) FAA 42-43 = 0.36
      - 1,000,000 to 3,000,000 FAA 44 = 0.38
      - \(> 3,000,000\) FAA 45 = 0.40
  - \(a_2\) = \(i^{th}\) Layer Coefficient
    - Existing HBP Material
      - = 0.25
Bituminous Recommendations

Performance Graded Binders

• Selection Based on Project Type & ESALs

  • New or Reconstruction
    • Lower lifts – PG 58-28
    • Upper Lifts – PG 58-34, 64-28/34, 70-28, 76-28

  • Overlays
    • PG 58-28, 64-28, 70-28, 76-28

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20 yr. Accumulated Design ESALS

< 400,000
400,000 to < 1,000,000  PG 58-XX
1,000,000 to 3,000,000
>3,000,000  PG 58-XX & Above
SN = Structural Number

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) + 0.20 + \frac{\log_{10}\left(\frac{\Delta P S I}{4.2 - 1.5}\right)}{1094} + 0.40 + \frac{2.32 \times \log_{10}(M_R)}{(SN+1)^{5.19}} - 8.07
\]

SN = \[a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots\]

- \(a_i = \text{i}^{\text{th}}\) Layer Coefficient
  - **New & Existing Base Materials**
    - **Aggregate Base:**
      - Sand Base = 0.06
      - Class 3 = 0.08
      - Class 5 = 0.10
    - Emulsified Base = 0.10 to 0.20
    - Blended Base = 0.10
    - New Cement Treated Base = 0.18
    - New Cement Treated Subgrade = 0.12
SN = Structural Number

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{1094 \times \frac{0.40}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07
\]

\[
SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots
\]

- \(D_i\) = \(i^{th}\) Layer Depth Thickness
  - Existing Materials
    - Pavement
      - Milestone Cores Obtained by District Personnel
      - RIMS Historical Data
    - Base
      - Field Aggregate Depth Checks
      - RIMS Historical Data
SN = Structural Number

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}(\frac{\Delta PSI}{4.2-1.5})}{1094} + 2.32 \times \log_{10}(M_R) - 8.07
\]

\[SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots\]

- \(D_i\) = \(i^{th}\) Layer Depth Thickness
  - New Materials
    - Pavement
      - 1:3 Ratio (HBP : Base)
      - Design Thickness is Rounded to the Nearest ½ inch
    - Base
      - Thicker Bases Perform Better
      - Typical Base Thickness – 8”, 12”, 15”, 18”, etc.
**SN = Structural Number**

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{1094} + 2.32 \times \log_{10}(M_R) - 8.07
\]

\[
SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots
\]

- \( m_i = i^{th} \text{ Drainage Coefficient} \)
  - Aggregated Bases Generally Provide Some Level of Drainage
  - NDDOT Uses Drainage Coefficient of 1.0
\[ \Delta PSI = Serviceability \]

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN + 1) - 0.20 + \frac{\Delta PSI}{4.2 - 1.5} + 2.32 \times \log_{10}(M_R) - 8.07
\]

\[ p_o - p_t = \Delta PSI \]

\[ p_o = 4.5 \text{ (Initial Serviceability)} \]

\[ p_t = 2.5 \text{ (Terminal Serviceability)} \]

\[ \Delta PSI = 2.0 \text{ (Serviceability Index)} \]
\[ M_R = \text{Subgrade Modulus} \]

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}(\Delta PSI)}{0.40 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07
\]

\( M_R = \text{subgrade resilient modulus} \) (in psi)

- FWD Field Data or Historical Data
- Typical NDDOT Design – 4,000psi to 7,000psi
Flexible Pavement Design

NDDOT Approach Summary:

- **Traffic**
  - ESALs – *Counts & Classifications of Vehicles*
  - Estimation of Growth Rate – *Predicting Future Corridor Usage*

- **Pavement Structure**
  - Subgrade Strength – *FWD / Field Data Analysis*
  - Existing Section - *Field Investigation or Historical Data*
  - Design Reliability – *Highway Performance Class System*
  - Materials – *Structural Coefficients*

- **Bituminous Recommendation**
  - Based on Project Type and ESALs – *Pavement Design*
Questions?