Project Scope

- To review existing City of Toronto pavement design procedures
- Evaluate the existing standards using mechanistic – empirical methodologies
- Consolidate the design standards and procedures of the former municipalities
- Develop new pavement structural design guidelines
Seminar Goals

- Why is this study important?
- How was the study completed?
- What is the outcome of the study?
- How will this study affect you?

Agenda

- Study background
- Brief introduction to pavement design
- Introduction to the M-E PDG
- Use of the new pavement design guidelines
Background

- 5,200 centreline kilometres of roadways
- 250 centreline kilometres of laneways
- Network is over 100 years old
Functional Classification

- Arterial Roads
  - Primary, Secondary, Local, Major, Minor, etc
- Collector Roads
  - Industrial, Residential
- Local
  - Industrial, Residential
- Lanes

Existing Pavement Types

- Two primary pavement types throughout the City:
  - Asphalt Concrete over Aggregate Base
  - Asphalt Concrete over Concrete Base
Existing Pavement Standards

- The City of Toronto comprises 7 former cities and municipalities
  - East York
  - Etobicoke
  - Metro
  - North York
  - Scarborough
  - Toronto
  - York
Expanding the Realm of Possibility

Lack of Commonality

- Etobicoke Arterial
  - 40 mm HL1
  - 225 mm HL8(HS)
  - 40 mm Granular A
  - 260 mm Granular B

- Scarborough Arterial
  - 40 mm HL1
  - 125 mm HL8
  - 50 mm Granular A
  - 400 mm Granular B

Pavement Design Methodologies
Pavement Design Methods

- There are many different design procedures in use around the world.
- The theory behind the design procedures varies immensely between agencies.
- A variety of different techniques exist and they are generally categorized as:
  - Empirical
  - Mechanistic
  - Mechanistic-Empirical

State of Practice/Art

State-of-Practice  State-of-the-Art

Empirical  Mechanistic  Mechanistic-Empirical

Common Practice??
Empirical Design

- Empirical design is based on correlations with existing experience
- Most widely used design method because people have developed confidence in the existing methods
- You need a lot of existing data to have confidence in the results
- Results are limited to the scope of the testing

Empirical – Basic Methods

- Early trial and error methods
- Successful designs are copied and repeated
- Designs often related to pavement thickness and compared using equivalent granular thickness (EGT) or granular base equivalency (GBE)
- Typical GBE or EGT factors
  - 1 mm HMA ~ 2 mm base ~ 3 mm subbase
Empirical – More Advanced

- Most common empirical design procedure in North America is the 1993 AASHTO Guide for Design of Pavement Structures
- Been validated for Ontario and widely used across Canada
- Based on in-service pavements therefore empirically based
- No procedure for innovative/improved technologies

Brief History of the AASHTO Design Guide

- AASHO Road Test (1958-60)
- 1972 – Revised Interim Guide
- 1981 - Revised Interim Guide for PCC
- 1998 Supplement to the AASHTO Guide (PCC)
- 2002 Guide to utilize mechanistic principles
Expanding the Realm of Possibility

AASHO Road Test (late 1950’s)

A fleet of 70 to 126 vehicles
Driven by Army personnel continuously between 18 and 19 hours a day, six days a week
Close to 320 Army personnel were utilized at the peak of the project.

141 accidents and two driving fatalities occurred during the two-year test period.

Figure 11 - Map of AASHO Road Test.
Evaluation of Road Condition

- Road was evaluated in terms of the **Pavement Serviceability Rating** (PSR)
  - "The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve"

\[
\begin{array}{ccccccc}
   & 5 & 4 & 3 & 2 & 1 & 0 \\
Satisfactory & Yes & Very Good & Good & Fair & Poor & Very Poor \\
No & Undecided & & & & & \\
\end{array}
\]

Results of the AASHO Road Test

- A better understanding of the difference in damage caused by different types and weights of trucks (ESALs)
- A better understanding of what users consider to be a good performing roadway (PSI)
- Design equations to relate the traffic with the damage seen on the roads

\[
\begin{align*}
\log_{10}(D_{eq}) &= Z_x^* S_x^* + 3.35 \log_{10}(D+1) - 0.06 + \frac{\log_{10}(\frac{D_{eq}}{1.0})}{1.624 \times 10^7} + (4.22 - 0.32 p)^* \log_{10} \left[ \frac{S_{eq}^{30} - 1.122}{(Z_x/6)^{0.7}} \right] \\
\end{align*}
\]
Using the AASHTO Data Today

- What has changed since the AASHO Road Test?
  - Significant changes to the types of materials used in pavement construction
  - Increase in traffic volume and vehicle weight
  - Large advancements in the construction practices
  - Other design factors (ie. drainage, friction, etc…)

- Our understanding of the materials and the mechanisms of the deterioration is greatly advanced

Mechanistic Design

- Relates stress/strain states to failures
- If modeled correctly can be very accurate
- Long history of existing mechanistic models
  - Boussinesq
  - Burmister
  - Linear Elastic Analysis
  - Finite Element Analysis
Pavement Response Under Load

Axle Load

Surface $\varepsilon_{\text{SUR}}$ $\delta_{\text{SUR}}$

Base/Subbase $\varepsilon_{\text{SUB}}$

Why Not Use Mechanistic Design?

- Pavement systems are VERY complicated to try and model
  - Asphalt concrete is a non-homogenous thermal-viscoelastic material and has properties that change with age
  - Variability in materials along a project
  - A pavement is only as good as it is constructed
  - A pavement is designed for predicted traffic
- Early attempts to predict service life were very poor
- Relationships between stress/strain and failure modes are still being developed (ride quality, structural failure, rutting, etc…)
Mechanistic-Empirical Design

- Mechanistic Design uses models to predict the effect of materials, traffic, and environment on the expected performance.
- Empirical calibration ensures that it matches what is seen in the field.
- A large data set is used to calibrate pavement models used to predict various methods of pavement deterioration.
- The larger amount of data and mechanistic component allows for a more accurate reliability component.
Mechanistic-Empirical Pavement Design Guide (M-E PDG)

- Uses advanced inputs to predict the mechanisms of failure (structural and functional).
- Correlated with field results to ensure the models are accurate.

M-E PDG Design Inputs

- Climate Conditions
- Traffic Conditions
- Layer Materials and Thickness
Expanding the Realm of Possibility

### Integrated Climatic Model

- Precipitation
- Temperature
- Frost
- Wind
- Solar Radiation
- Water Table Depth

- HMA $E^*$ w/time & temperature
- Base $M_R$ w/moisture & frost
- Soil $M_R$ w/moisture & frost

### Truck Traffic Inputs

- Moving away from Equivalent Single Axle Loads (ESALs)
- M-E PDG models the damage caused by individual axle loads for each pavement section
- Traffic is also distributed by time of the year and by time of the day to better account for the relationship between climate and load.
M-E PDG Material Inputs

- No longer based on standard co-efficients for each material class (SN coefficients, GBE coefficients)
- Detailed material properties and performance characteristics are needed
  - Layer moduli
  - Gradation
  - Mix Volumetrics
  - Drainage

Mechanistic Models

- All inputs are combined to predict stress-strain relationships for all load combinations at different times of the day and year
- Models used for predicting distresses include:
  - Finite element analysis for flexible pavements
  - Neural network for rigid pavements
- Results in a prediction of performance for a potential cross-section
National Calibration of Models

- The models were calculated based on research sites all over the U.S.A. and Canada.
- Advanced testing and routine monitoring was completed as a part of the Long Term Pavement Performance (LTPP) project.
- Test sites were located on states built and monitored by State and Provincial Agencies.
- It was recommended that local calibration be considered to ensure that models matched local conditions, materials, loads, and construction practices.
Flexible Distress Prediction

The following distresses are predicted for flexible pavements:

- Thermal (transverse) cracking
- Bottom-Up fatigue (alligator) cracking
- Top-Down fatigue (longitudinal) cracking
- Rutting
- IRI

Typical Prediction Outcome

Bottom Up Cracking - Alligator

![Graph showing typical prediction outcome for bottom-up cracking.](image-url)
Rigid Distress Prediction

The following distresses are predicted for rigid pavements:

- Faulting
- Slab cracking
- Joint load transfer
- IRI

Figure 3. Predicted Faulting
M-E PDG Calibration for The City of Toronto

Climate Inputs

- A composite station was necessary to combine information from the 4 available weather stations

- Depth of water table was assumed to be constant for all locations
## Traffic Inputs

<table>
<thead>
<tr>
<th>FHWA Class</th>
<th>Truck Type</th>
<th>Local (Residential)</th>
<th>Local (Commercial/Industrial.)</th>
<th>Local (Residential Throughway)</th>
<th>Collector (Residential)</th>
<th>Collector (Commercial/Industrial.)</th>
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## Traffic Inputs

<table>
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<tr>
<th>FHWA Class</th>
<th>Configuration</th>
<th>Minor Arterial (Non-Truck Route)</th>
<th>Minor Arterial (Truck Route)</th>
<th>Major Arterial (Non-Truck Route)</th>
<th>Major Arterial (Truck Route)</th>
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<td>Total</td>
<td></td>
<td>100 %</td>
<td>100 %</td>
<td>100 %</td>
<td>100%</td>
</tr>
</tbody>
</table>
Construction Material Inputs

- Standard pavement mixtures are used throughout the city.
- Typical mix design reports were available for volumetric and mix properties.

Subgrade Material Inputs

- The subsoils within the City limits comprise predominately till and delta sands.
Empirical Model Calibration

- A calibration of the M-E PDG was performed as a part of this project.
- Testing was completed on 117 sections composed of:
  - 67 Flexible
  - 41 Composite
  - 6 JPCP
- Visual surveys and laser profiler testing were completed on all sections

Calibration Results

- The distresses were predicted and then compared to the measured distresses
- Not all of the performance models were designed for municipal pavements.
- The traditional distresses used for a structural analysis (ie. alligator cracking) were centered around the national calibration models.
Calibration Highlights

- Thermal (transverse) cracking
  - Dependent on binder type
  - PGAC has helped mitigate
  - Reflection cracking is not easily modeled

- Bottom-Up fatigue (alligator) cracking
  - Most reliable model
  - Basis of previous design methodologies

- Top-Down fatigue (longitudinal) cracking
  - Difficult distress mechanism to accurately predict

Calibration Highlights

- Rutting
  - The rutting predicted was significantly worse than that measured in the City of Toronto
  - Rutting issues encountered are related to the asphalt mix volumetrics

- Roughness (IRI)
  - Roughness measured tended to be significantly higher than predicted
  - IRI models were calibrated based on highway conditions and do not include municipal road hardware effects
Roughness Calibration…

- Pavement roughness is used to ensure that the road is safe to drive at reasonable speeds.
- IRI model didn’t predict street hardware and traffic calming devices.

M-E PDG and Existing Toronto Pavement Sections
Pavement Design with the M-E PDG

- The designs were based on:
  - Common City of Toronto materials
  - Experience of design and construction staff
  - Functional classifications
  - Limiting fatigue cracking

Evaluation of Existing Sections

- The M-E PDG was used to evaluate the existing cross-sections used by the former municipalities
- The Toronto specific design inputs were used
- The results of the analysis were the expected truck traffic

![Graph showing predicted alligator cracking percentage against annual average daily traffic (AADT)]
Evaluation of Existing Sections (Arterial Roads)

Two Arterial Sections
- **Etobicoke Arterial**
  - 40 mm HL1
  - 225 mm HL8(HS)
  - 40 mm Granular A
  - 260 mm Granular B

- **Scarborough Arterial**
  - 40 mm HL1
  - 125 mm HL8
  - 50 mm Granular A
  - 400 mm Granular B
Evaluation of Existing Sections (Collector Roads)

![Graph showing predicted design truck volume (AADTT) for different road sections and design types.]

Issues with Existing Designs

- **East York Collector**
  - 50 mm HL3
  - 50 mm HL8
  - 150 mm Granular A
  - 225 mm Granular B

- **North York Collector**
  - 35 mm HL1
  - 175 mm HL8
  - 50 mm Granular A
  - 100 mm Granular B
Evaluation of Existing Sections (Composite Pavements)

Development of New Guidelines

- New designs were based on the existing designs and experience with them
- Some things were reduced:
  - Fewer materials
  - Less variability in material thickness
- Some things added:
  - More flexibility in traffic levels
  - Some consideration of subgrade type
Granular Material

- Existing guidelines use:
  - Granular A – 40-150 mm
  - Granular B – 100-400 mm
- The granular material is used to:
  - Provide frost protection
  - Allow adequate drainage
  - Provide suitable construction platform

Recommended Granular Material

- Granular A is recommended at 50 mm
- Granular B Type II is recommended to provide adequate angularity and support

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>Granular A</th>
<th>Granular B Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Arterial (Truck Route)</td>
<td>50 mm</td>
<td>350 mm</td>
</tr>
<tr>
<td>Major Arterial (Non-Truck Route)</td>
<td>50 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>50 mm</td>
<td>250 mm</td>
</tr>
<tr>
<td>Collector</td>
<td>50 mm</td>
<td>250 mm</td>
</tr>
<tr>
<td>Local</td>
<td>50 mm</td>
<td>250 mm</td>
</tr>
</tbody>
</table>
Asphalt Material

- The designs focus on four common mixes:
  - HL-1
  - HL-3
  - HL-8
  - HL-8 (HS)
- Thickness was provided for different traffic levels within functional classifications

Optimum AC Thickness (fatigue)

![Graph showing predicted alligator cracking (%) area vs. AC thickness (mm)]
Asphalt Thickness (traffic)

Traffic Volume for Major Arterial Non- Truck Route (AADT)

Updated Pavement Designs

Notes:
How to Use the New Guidelines

Pavement Design Procedure

1. Determine the functional classification
2. Determine traffic parameters
3. Determine subgrade support value
4. Use design matrix table to select pavement sections
5. Life cycle cost analysis
6. Recommended pavement design
### General Functional Classifications

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Locals</th>
<th>Collectors</th>
<th>Minor Arterials</th>
<th>Major Arterials</th>
<th>Expressways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic movement versus property access</td>
<td>Property access primary function</td>
<td>Traffic movement primary consideration, some property access</td>
<td>Traffic movement primary consideration, subject to property access</td>
<td>Traffic movement primary consideration; no property access</td>
<td></td>
</tr>
<tr>
<td>Typical daily motor vehicle traffic volume (both directions)</td>
<td>≤ 2,500</td>
<td>2,500 - 5,000</td>
<td>5,000 - 10,000</td>
<td>10,000 - 20,000</td>
<td>&gt; 20,000</td>
</tr>
<tr>
<td>Minimum number of peak period lanes (excluding bicycle lanes)</td>
<td>One (one-way streets) or two</td>
<td>Two</td>
<td>Two</td>
<td>Two</td>
<td>Four</td>
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<tr>
<td>Minimum right-of-way width, m</td>
<td>15 - 30</td>
<td>20 - 27</td>
<td>20 – 30°</td>
<td>20 – 45°</td>
<td>&gt; 45°</td>
</tr>
<tr>
<td>Legal speed limit, km/h</td>
<td>40 - 50</td>
<td>40 - 60</td>
<td>50 - 60</td>
<td>60 - 80</td>
<td>&gt; 80</td>
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<td>Accommodation of pedestrians</td>
<td>Sidewalks on one or both sides</td>
<td>Sidewalks on both sides</td>
<td>Sidewalks on both sides</td>
<td>Pedestrians prohibited</td>
<td></td>
</tr>
<tr>
<td>Accommodation of cyclists</td>
<td>Special facilities as required</td>
<td>Walk curb lane or special facilities desirable</td>
<td>Cyclists prohibited</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface transit</td>
<td>Generally not provided</td>
<td>Permitted</td>
<td>Preferred</td>
<td>Preferred</td>
<td>Express buses only</td>
</tr>
<tr>
<td>Surface transit daily passengers</td>
<td>Not applicable</td>
<td>9,000</td>
<td>10,000 - 20,000</td>
<td>&gt; 20,000</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Heavy truck restrictions (e.g., seasonal or night time)</td>
<td>Restrictions permitted</td>
<td>Restrictions permitted</td>
<td>Generally no restrictions</td>
<td>Generally no restrictions</td>
<td>No restrictions</td>
</tr>
<tr>
<td>Typical spacing between traffic control device, m</td>
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<td>215 - 400</td>
<td>215 - 400</td>
<td>215 - 400</td>
<td>Not applicable</td>
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<tr>
<td>Typical right-of-way width, m</td>
<td>15 - 22</td>
<td>20 - 27</td>
<td>20 – 30°</td>
<td>20 – 45°</td>
<td>&gt; 45°</td>
</tr>
</tbody>
</table>
Determine the Traffic

- The type of vehicles greatly affect the service life of a vehicle.
- The traffic data needed for the design guidelines includes:
  - AADT
  - Commercial Vehicles

Traffic Data

- Refer to the City’s Traffic Management Centre (TMC), Volume Maps, or Turning Movement Summaries
  [Link](http://insideto.toronto.ca/wes/transportation/tmc/tdcsb/volumes/index.htm)
- If there is no traffic data, a traffic count request can be made through
  - Traffic Data & Safety Bureau
  - Traffic Management Centre
  - Transportation Services
Determine AADT from Intersection

- **8 Hour Traffic**
  - 1514 + 649 + 215 + 504 = 2882 Vehicles
- **Commercial Vehicles**
  - 437 + 42 + 20 + 105 = 704 C.V.
- **24% Commercial Vehicles**
- **AADT**
  - 2882 \times 2.1 = 6052
Subgrade Support

- The subgrade soil is the native material that the roadway is built on.
- The purpose of the pavement structure is to adequately protect the subgrade from the traffic loads.
- The subgrade support is defined in terms of the Resilient Modulus ($M_r$).

Subgrade Support Classes

- Cohesive soils
  - Tills, clays, silts, etc
  - Low to high frost susceptibility depending on the actual soil matrix
  - Fair subgrade support with an $M_r$ of 30 MPa

- sandy alluvium soils
  - Sand bars, beaches, and boulder fields of the lower lying Iroquois Plain
  - Low frost susceptibility
  - Good subgrade support with an $M_r$ of 50 MPa
### Select Appropriate Cross Section

For each functional classification, find the specific design by using the expected traffic and subgrade support value.

### Using the Design Matrix

- The design matrix is setup in groups of functional classes.
- For each functional classification, find the specific design by using the expected traffic and subgrade support value.

#### Functional Classification

<table>
<thead>
<tr>
<th>Traffic Class</th>
<th>Non-Track Routes (4% Commercial Vehicles)</th>
<th>Truck Routes (5% Commercial Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>20,000</td>
<td>25,000</td>
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<tr>
<td>30 MPa</td>
<td>40 mm HL-1</td>
<td>40 mm HL-1</td>
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<tr>
<td></td>
<td>60 mm HL-1 (HS)</td>
<td>50 mm HL-1 (HS)</td>
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<tr>
<td></td>
<td>50 mm Granular A</td>
<td>50 mm Granular A</td>
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<td></td>
<td>250 mm Granular B *</td>
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<tr>
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<td>40 mm HL-1</td>
<td>40 mm HL-1</td>
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<td>60 mm HL-1 (HS)</td>
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<td>250 mm Granular B *</td>
<td>250 mm Granular B *</td>
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<td>435 mm Total</td>
<td>435 mm Total</td>
</tr>
</tbody>
</table>

### Notes

- Subgrade: PCC Concrete / Granular A / Granular B
- All Traffic & Subgrade: * Denotes 2 Granular B Types on specified in GPA 910
Composite Pavements

- Selected only by Functional Classification
- Pavement structure isn’t as sensitive to traffic volume.

<table>
<thead>
<tr>
<th>Composite Pavements</th>
<th>All Traffic &amp; Subgrade</th>
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</thead>
<tbody>
<tr>
<td><strong>Major Arterial</strong></td>
<td>40 mm HL-1</td>
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<td>50 mm HL-8 (HS)</td>
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<td>150 mm Granular ‘A’</td>
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<td>490 mm Total</td>
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<tr>
<td><strong>Minor Arterial - Bus/Truck Route</strong></td>
<td>40 mm HL-1</td>
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<td>50 mm HL-8 (HS)</td>
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<td>250 mm PCC Concrete</td>
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<tr>
<td></td>
<td>490 mm Total</td>
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<tr>
<td><strong>Local Collector - Bus/Truck Route</strong></td>
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<td></td>
<td>200 mm PCC Concrete</td>
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<td></td>
<td>400 mm Total</td>
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<tr>
<td><strong>Local Collector - Non Bus/Truck Route</strong></td>
<td>50 mm HL-1 or HL-3</td>
</tr>
<tr>
<td></td>
<td>150 mm PCC Concrete</td>
</tr>
<tr>
<td></td>
<td>150 mm Granular ‘A’</td>
</tr>
<tr>
<td></td>
<td>350 mm Total</td>
</tr>
</tbody>
</table>

Pavement Type Selection

- City of Toronto uses two pavement types:
  - Flexible (Asphalt) pavement
  - Composite (Asphalt and Concrete) pavement
- Many factors to consider
  - Long term performance
  - Short term performance
  - Serviceability
  - Life Cycle Cost
Life Cycle Cost

- A procedure to account for all costs over the whole life of a pavement
- Costs for both alternative pavement types are calculated and compared
- Recommended whole life
  - Arterial Roads – 100 years
  - Collector Roads – 75 years
- Recommended rehabilitation analysis period
  - 50 years (30 years minimum)

Life Cycle Cost Considerations

- Select appropriate whole life maintenance plan
- Calculate costs of all maintenance and rehabilitation activities for each alternative
- Calculate life cycle costs for each alternative
- Summarize and compare the Net Present Value for all alternatives
- If the life cycle cost is within 10 percent, they are considered equivalent (other factors must then be considered)
Whole Life Maintenance Plan

Composite Pavement Performance for Major and Minor Arterial Roads

Pavement Unit Costs

Pavement Material Unit Prices for 2005 and 2006

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Unit Price</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Std Dev</td>
</tr>
<tr>
<td>Hot-Mix Asphalt HLT PIGAC 80-20</td>
<td>$64.68</td>
<td>$3.76</td>
</tr>
<tr>
<td>Hot-Mix Asphalt HLT and HLT MOD PIGAC 80-20</td>
<td>$62.96</td>
<td>$9.27</td>
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<tr>
<td>Hot-Mix Asphalt HLL PIGAC 80-20</td>
<td>$62.24</td>
<td>$6.63</td>
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<tr>
<td>Hot-Mix Asphalt HLL(HS) PIGAC 80-20</td>
<td>$62.48</td>
<td>$8.00</td>
</tr>
<tr>
<td>Granular A Crushed Limestone</td>
<td>$27.11</td>
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<tr>
<td>Granular A Recycled Concrete</td>
<td>$36.71</td>
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<tr>
<td>Granular A (All items)</td>
<td>$36.98</td>
<td>$3.49</td>
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<tr>
<td>Granular B Crushed Limestone (Type I)</td>
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</tr>
<tr>
<td>Granular B Recycled Concrete</td>
<td>$21.93</td>
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<td>Granular B</td>
<td>$18.73</td>
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<tr>
<td>Granular B (All items)</td>
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<tr>
<td>Concrete Base 150 mm Thick</td>
<td>$32.00</td>
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<tr>
<td>Concrete Base 200 mm Thick</td>
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<tr>
<td>Concrete Base 250 mm Thick (Estimated)</td>
<td>$50.33</td>
<td>$5.70</td>
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</tbody>
</table>

Source: Transportation Infrastructure Asset Management and Programming Unit
Expanding the Realm of Possibility

Typical LCCA Format

DETAILED LIFE-CYCLE COST ANALYSIS
Composite Major and Minor Arterial Road per 1 km LCCA Maintenance Plan

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MAJOR ACTIVITY</th>
<th>INITIAL COST</th>
<th>MINOR ACTIVITY</th>
<th>INITIAL COST</th>
<th>TOTAL COST</th>
<th>DISCOUNT</th>
<th>PRESENT WORTH</th>
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<tr>
<td>0</td>
<td>Initial Construction</td>
<td>$1,054,350</td>
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<td></td>
<td>$1,054,350</td>
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<td>2</td>
<td>Crack Seal</td>
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<td>$3,000</td>
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<td>0.9500</td>
<td>$5,658</td>
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<td>3</td>
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<td>0.9500</td>
<td>$5,658</td>
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<tr>
<td>20</td>
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<td>$3,000</td>
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<td>$6,000</td>
<td>0.9500</td>
<td>$5,658</td>
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<tr>
<td>24</td>
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<td>$3,000</td>
<td>$6,000</td>
<td>0.9500</td>
<td>$5,658</td>
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<td>46</td>
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<td>$6,000</td>
<td>0.9500</td>
<td>$5,658</td>
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<tr>
<td>54</td>
<td>Crack Seal</td>
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<td>$3,000</td>
<td>$6,000</td>
<td>0.9500</td>
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<td>67</td>
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<td>0.9500</td>
<td>$5,658</td>
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<td>72</td>
<td>Crack Seal</td>
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<td>$6,000</td>
<td>0.9500</td>
<td>$5,658</td>
</tr>
<tr>
<td>77</td>
<td>Crack Seal</td>
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<td>$3,000</td>
<td>$6,000</td>
<td>0.9500</td>
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<tr>
<td>95</td>
<td>Crack Seal</td>
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<td>$6,000</td>
<td>0.9500</td>
<td>$5,658</td>
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<tr>
<td>99</td>
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<td></td>
<td>$3,000</td>
<td>$6,000</td>
<td>0.9500</td>
<td>$5,658</td>
</tr>
</tbody>
</table>

Sub-total $1,054,350
Salvage Value (7% of Construction Cost) **$80,332

Life-Cycle Cost for 68 Year Road Life $1,134,682

100 Year Life-Cycle
Breakdown Value (150 years 4.33% escalation) **$1,134,682

Total Life-Cycle Cost - 100 Years $1,134,682

CALCULATION OF DISCOUNT RATE
Annual Discount Rate = 9 %
Annual Inflation Rate = 3 %
Discount Rate **86

Preferred Alternative

- The pavement structural design should be based on
  - Life Cycle Cost Analysis
  - Operating Costs
  - Impact to the Public
  - Risk Analysis
General Considerations

- Flexible Pavements
  - Typically lower initial cost
  - Shorter service life
- Composite Pavements
  - Longer service life
  - More resistant to heavy loads
  - Typically less expensive to maintain

Design Example - 1

- Local Road Rehabilitation of Existing Flexible Pavement
  - Princess Anne Crescent and surrounding streets (Oldham Rd, Cheviot Pl, Orkney Cr, Byland Rd, Grimsby Ct)
- Road Classification:
  Local Residential Roads
- Traffic Level:
  AADT <2,500;
  <3% Commercial Vehicles
- Assumed sandy silt till subgrade; support 30 MPa
**Design Example 1 – Princess Anne Cr.**

### But We’re Not Reconstructing!

- Must consider appropriate rehabilitation strategies
  - Partial reconstruction (pulverize, regrade, new HMA)
  - Cold Recycling and Overlay
  - Full Reconstruction Flexible
  - Full reconstruction Composite
- Treatment selection should be based on LCCA
Design Example - 2

- Reconstruction of McNicoll Avenue (Program Year 2006/07)
  - From Pharmacy Ave to Warden Ave
- Road Classification: Minor Arterial Road
- Traffic Level: AADT ~ 16337 (2004); Non-Truck Route, Bus Route
- Assumed silty clay subgrade; support 30 MPa
Design Example 2 Summary

- Flexible Cross-section
  - 40mm HL-1
  - 95mm HL-8 (HS)
  - 50mm Granular A
  - 250mm Granular B – Type II
- Composite Cross-section
  - 40mm HL-1
  - 50mm HL-8 (HS)
  - 250mm PCC Concrete
  - 150mm Granular A

- Complete LCCA
- Other Considerations:
  - Urban cross-section with four lanes

Design Example 3

- New Development
  - Rouge Hills (single family -detached, semi and -row housing)
- Road Classification:
  - Local Residential Roads
- Traffic Level:
  - 2,500 AADT
- Assumed silty clay subgrade; support 30 MPa
## Design Example 3 – Rouge Hills

### All Traffic & Subgrade

<table>
<thead>
<tr>
<th>AADT</th>
<th>Local Residential (3% Commercial Vehicles)</th>
<th>Local Industrial (10% Commercial Vehicles)</th>
<th>Local Throughway (5% Commercial Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,500</td>
<td>50 mm HL-1 or HL-3</td>
<td>50 mm HL-1 or HL-3</td>
<td>50 mm HL-1 or HL-3</td>
</tr>
<tr>
<td>3,000</td>
<td>60 mm HL-8</td>
<td>60 mm HL-8</td>
<td>60 mm HL-8</td>
</tr>
<tr>
<td>4,500</td>
<td>50 mm Granular A</td>
<td>50 mm Granular A</td>
<td>50 mm Granular A</td>
</tr>
</tbody>
</table>

### Composite Cross-section

- Composite Cross-section
  - 50mm HL-1 of HL-3
  - 150mm PCC Concrete
  - 150mm Granular A

### Design Example 3 Summary

- **Flexible Cross-section**
  - 40mm HL-1
  - 60mm HL-8
  - 50mm Granular A
  - 250mm Granular B – Type II

- **Complete LCCA**
- **Other Considerations:**
  - Primarily residential use

---

**Expanding the Realm of Possibility**
Design Example - 4

- New Development
  - East Bayfront (condominium)
- Road Classification:
  - Local Throughway
- Traffic Level:
  - 4,500 AADT
- Assumed sand subgrade; support 50 MPa

### Design Example 4 – East Bayfront

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>20 MPa</th>
<th>50 MPa</th>
<th>30 MPa</th>
<th>50 MPa</th>
<th>30 MPa</th>
<th>50 MPa</th>
<th>30 MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>40 mm HL-1</td>
<td>30 mm HL-1</td>
<td>40 mm HL-1</td>
<td>30 mm HL-1</td>
<td>40 mm HL-1</td>
<td>30 mm HL-1</td>
<td>40 mm HL-1</td>
</tr>
<tr>
<td>Arterial</td>
<td>350 mm Granular B *</td>
<td>50 mm Granular A</td>
<td>150 mm Granular 'A'</td>
<td>50 mm Granular A</td>
<td>150 mm Granular 'A'</td>
<td>50 mm Granular A</td>
<td>150 mm Granular 'A'</td>
</tr>
<tr>
<td>Local Residential (CV/Commercial Vehicles)</td>
<td>2,500</td>
<td>3,000</td>
<td>4,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Industrial (CV/Commercial Vehicles)</td>
<td>2,500</td>
<td>3,000</td>
<td>4,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Throughway (CV/Commercial Vehicles)</td>
<td>2,500</td>
<td>3,000</td>
<td>4,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Subgrade is Granular B - Type II as specified in OPSS 1010*
Design Example 4 Summary

- Flexible Cross-section
  - 40mm HL-1
  - 60mm HL-8
  - 50mm Granular A
  - 250mm Granular B – Type II

- Composite Cross-section
  - 50mm HL-1 of HL-3
  - 150mm PCC Concrete
  - 150mm Granular A

- Complete LCCA
- Other Considerations:
  - Primarily residential use (access to condominiums)

Design Example 5

- Reconstruction of Carlaw Avenue (Program Year 2007)
  - From Commissioners Street to Lake Shore Blvd East South Branch

- Road Classification:
  Collector Road

- Traffic Level:
  AADT 6050 (2004); 24% Commercial (Major truck route)

- Assumed sand subgrade; support 50 MPa
Consider Annual Average Daily Truck Traffic (AADTT)

- There is no option for a Collector Road with 6050 AADT and 24% commercial vehicles
- Consider Annual Average Daily Truck Traffic (AADTT)
  - Truck & Buses 1450
- Similar truck traffic loading as minor arterial
  - 1500 AADTT (20,000 AADT with 7.5% commercial)
Design Example 5 – Carlaw Avenue

20,000

<table>
<thead>
<tr>
<th>35 MPa</th>
<th>50 MPa</th>
<th>30 MPa</th>
<th>50 MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>25,000</td>
<td>50,000</td>
<td>20,000</td>
<td></td>
</tr>
</tbody>
</table>

Major

40 mm HL-1
50 mm HL-8 (HS)

Minor Arterial

40 mm Granular A
50 mm Granular A
75 mm HL-8
60 mm HL-8

Collector

35 mm HL-8 (HS)
30 mm Granular A
75 mm Total

Local

50 mm Granular A
135 mm HL-8 (HS)
50 mm Granular A
250 mm Granular B – Type II

Design Example 5 Summary

- Flexible Cross-section
  - 40mm HL-1
  - 135mm HL-8 (HS)
  - 50mm Granular A
  - 250mm Granular B – Type II

- Composite Cross-section
  - 40mm HL-1
  - 50mm HL-8 (HS)
  - 250mm PCC Concrete
  - 150mm Granular A

- Complete LCCA

- Other Considerations:
  - Heavy truck route
  - Existing section shows significant rutting
Design Considerations

- There is more to pavement design than just the thickness of the layers
  - Asphalt Mix Design
  - Concrete Base Design
  - Recycled Crushed Concrete Base
  - Drainage
  - Sensitive Soils
  - Geotextiles
  - Perpetual Pavements
Asphalt Mix Design

- Asphalt mix design can have a very large impact on the performance of a pavement
- Common mixes used in Toronto
  - HL-1
  - HL-3
  - HL-8
  - HL-8 (HS)
- Premium Mixes
  - Superpave
  - SMA

Performance Graded Asphalt Cement (PGAC)

- Evolution of grading asphalt binder:
  - Penetration grades
  - Viscosity grades
  - PGAC
- For the City of Toronto temperatures:
  - Typical Surface Course – PG 64-28
  - Typical Binder Course – PG 58-28
  - Premium – PG 70-28
Superpave Mix Design

- Superpave vs. Marshall Mix Design
  - Same ingredients
  - Same construction
  - Just different mix design criteria

- Equivalent mixes:

<table>
<thead>
<tr>
<th>HL Designation</th>
<th>Comparable Superpave Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA</td>
<td>SMA</td>
</tr>
<tr>
<td>DFC</td>
<td>Superpave 12.5FC2</td>
</tr>
<tr>
<td>HL-1</td>
<td>Superpave 12.5FC1</td>
</tr>
<tr>
<td>HL-3</td>
<td>Superpave 12.5</td>
</tr>
<tr>
<td>HL-8/HL-8(HS)</td>
<td>Superpave 19.0</td>
</tr>
<tr>
<td>LSBC</td>
<td>Superpave 37.5</td>
</tr>
</tbody>
</table>

Tack Coat

- A tack coat is used to ensure that overlays properly adhere to underlying layers.
- Should be used for all tie-ins, and vertical surfaces
- Horizontal surfaces should be tack coated if construction is staged.
Concrete Base Construction

- Concrete Base
- When asphalt is removed during rehabilitation:
  - Inspect the exposed concrete slabs
  - Repair shattered slabs
  - Repair joints for poor load transfer

Recycled Crushed Concrete

- Recycled crushed concrete is a cost effective material that can be used as a base for roadways
- Typically graded to meet OPSS Granular A
- Can be substituted for Granular A on a 1:1 basis
- Proper quality control is necessary to ensure there are no excess fines
Pavement Drainage

- Poor drainage can greatly reduce the service life of a pavement
- In urban situations, continuous drains should be used whenever possible
- Stub drains may be considered in cases where permeable soils are present

Sensitive Subsoils

- Portions of the City have fine grained subgrade soils that are moisture sensitive and susceptible to frost heave
- Requires subgrade replacement or additional granular material for frost protection
Geotextiles

- Geotextiles are synthetic sheets (woven and non-woven) that are used typically to separate granular layers
- Adds tensile strength to layer
- Supports layers and improves drainage
- Tend to be expensive and should be considered on a project specific basis

Perpetual Pavements

- Perpetual pavements are designed to limit the stress and strains at the bottom of the asphalt layer
- Designed to withstand fatigue cracking
- Only requires occasional resurfacing for a long service life
- Pavements have been placed at an HMA thickness of 500mm
- Typically limited to freeway applications
Maintenance and Rehabilitation

- Not many new streets are being constructed anymore
- Most work done is either a reconstruction or a repair of an existing road
  - Preventative maintenance
  - Repair of utility cuts
  - Localized repairs
  - Resurfacing

Crack Treatments

- Prevents water and debris from entering individual cracks in the HMA pavement surface
**Patching**

- Address localized areas of distress
- Correct surface discontinuities
- Seal the pavement from moisture infiltration

**Resurfacing**

- Wearing course
- Level pavement
- Improve friction
- Seal pavement
- Fills ruts
Hot In-Place Recycling

- Reduce rutting
- Reduce roughness
- Improve friction
- Reduce distress

1. Vibratory dual steel drum rollers
2. Rubber-tired rollers
3. Static dual steel drum rollers

Mixing
Leveling and profiling
Scarifying
Optional addition of aggregate and/or beneficiating hot mix

Microsurfacing

- Level pavement surface
- Fill ruts
- Restore surface friction
Surface Seals

- Seal pavement surface
- Rejuvenate oxidized HMA
- Provide delineation
- Improve friction

Asphalt Chip Seal

- Wearing course
- Improve surface friction
- Seal pavement
- Eliminate dust

Optional sanding
Asphalt distributor

Power broom or sweeper
Rubber-tired rollers
Cover aggregate
Self-propelled aggregate spreader
Asphalt distributor

May be one unit
Questions?