Effects of Climate Change on Road Network Resilience

Professor Susan Tighe, Ph.D, P.Eng
Norman W. McLeod Chair in Sustainable Pavement Engineering
Director Centre for Pavement and Transportation Technology

Seminar Challenges for resilient road networks
Santiago Chile
October 18, 2016
Presentation Overview

• Introduction
• Climate Change
• Natural Disasters
• Road build-in resilience strategies
• Closing Remarks
Pavement Asset Design and Management Guide

• Leading the Development of the Transportation Association of Canada (TAC) design guide

• Resulted in many positive changes to Canadian standards and specifications
Pavement Asset Design and Management Guide

- Includes a new chapter on Climate Change and Sustainability
- Focuses on provincial, municipal and city needs

[Reid and Hein 2016]
Climate Change
Disaster Types in Ontario 1900 – 2013

When does flooding occur?

## Assessment of Damage

<table>
<thead>
<tr>
<th>Load type</th>
<th>Pavement damage reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood depth</td>
<td>Absorption of water</td>
</tr>
<tr>
<td>Flood duration</td>
<td>Absorption of water</td>
</tr>
<tr>
<td>Flood velocity</td>
<td>Force of water</td>
</tr>
<tr>
<td>Flood debris</td>
<td>Pavement surface texture reduction</td>
</tr>
<tr>
<td>Flood contaminants</td>
<td>Absorption or adhesion of contaminants carried by water</td>
</tr>
</tbody>
</table>
Climate Change Impacts

THE ROAD WELL-TRAVELED:
Implications of Climate Change for Pavement Infrastructure in Southern Canada

Brian N. Mills¹, Susan L. Tighe², Jean Andrey³, James T. Smith³, Suzanne Farm² and Ken Huen¹

¹ Environment Canada, Adaptation & Impacts Research Division, Waterloo, Ontario
² University of Waterloo, Department of Civil & Environmental Engineering, Waterloo, Ontario
³ University of Waterloo, Department of Geography, Waterloo, Ontario

FINAL TECHNICAL REPORT
March 2007
Analysis of Performance Related Data

1. Influence of climate and climate change alone

2. Influence of structure type and baseline traffic volume

3. Combined influence of traffic growth and climate change

<table>
<thead>
<tr>
<th>PROVINCE</th>
<th>British Columbia</th>
<th>Alberta</th>
<th>Manitoba</th>
<th>Ontario</th>
<th>Quebec</th>
<th>Newfoundland</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTPP Site Identification</td>
<td>62-1005</td>
<td>81-1804</td>
<td>83-6450</td>
<td>87-1006</td>
<td>89-1021</td>
<td>85-1808</td>
</tr>
<tr>
<td>Climatic Region</td>
<td>Wet-freeze</td>
<td>Dry-freeze</td>
<td>Wet-freeze</td>
<td>Wet-freeze</td>
<td>Wet-freeze</td>
<td>Wet-freeze</td>
</tr>
<tr>
<td>Climate station reference</td>
<td>1108447 Vancouver International Airport</td>
<td>3012205 Edmonton International Airport</td>
<td>5029222 Winnipeg International Airport</td>
<td>6198733 L.B. Pearson International Airport</td>
<td>7025250 P.E. Trudeau International Airport</td>
<td></td>
</tr>
<tr>
<td>Latitude (degrees)</td>
<td>49.2</td>
<td>53.5</td>
<td>50.0</td>
<td>43.7</td>
<td>45.5</td>
<td></td>
</tr>
<tr>
<td>Longitude (degrees)</td>
<td>-120.1</td>
<td>-113.5</td>
<td>-97.2</td>
<td>-79.6</td>
<td>-73.6</td>
<td></td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>4.3</td>
<td>723.3</td>
<td>238.7</td>
<td>173.4</td>
<td>35.7</td>
<td></td>
</tr>
<tr>
<td>Traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-way AADTT**</td>
<td>1240</td>
<td>1420</td>
<td>498</td>
<td>2744</td>
<td>1912</td>
<td></td>
</tr>
<tr>
<td>Percentage of truck traffic in design lane</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Pavement Structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer 1: Asphalt (cm)</td>
<td>9.7</td>
<td>8.4</td>
<td>5.1</td>
<td>4.1</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Layer 2: Asphalt (cm)</td>
<td>-</td>
<td>-</td>
<td>5.6</td>
<td>10.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Layer 3: Base (cm)</td>
<td>23.9</td>
<td>32.8</td>
<td>11.4</td>
<td>18.0</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>Layer 4: Subbase (cm)</td>
<td>31.0</td>
<td>24.6</td>
<td>10.7</td>
<td>79.2</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>Pavement Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>Crushed gravel</td>
<td>Crushed gravel</td>
<td>Crushed gravel</td>
<td>Crushed gravel</td>
<td>Crushed gravel</td>
<td></td>
</tr>
<tr>
<td>Subbase</td>
<td>River-run gravel</td>
<td>River-run gravel</td>
<td>River-run gravel</td>
<td>A-4</td>
<td>Crushed gravel</td>
<td></td>
</tr>
<tr>
<td>Subgrade**</td>
<td>SM</td>
<td>SM</td>
<td>SM</td>
<td>ML</td>
<td>SP</td>
<td>GW</td>
</tr>
</tbody>
</table>

*Mills, 2007*
Analysis of Performance Related Data

- Extreme minimum daily temperature (thermal cracking indicator)
- Seven-day average maximum daily temperature (rutting indicator)
- Freezing and thawing indices (indicator of frost and thaw depths)
Management Needs

UNIVERSITY OF WATERLOO
200 University Avenue West, Waterloo, ON, Canada  N2L 3G1
519-888-4567 | uwaterloo.ca

Planning and Programming
- Traffic and Environmental data information
- Assess network deficiencies
- Budgets
- Establish priorities
- Schedule projects
- Priorities

Design
- Information on materials, traffic, costs, environment, etc.
- Design alternatives
- Analysis
- Optimization
- Sustainability
- User costs

Construction
- Environment during construction
- Specifications
- Contracts
- Schedules
- Construction operations
- Quality control/quality assurance
- Records

Maintenance, Preservation and Rehabilitation
- Standards
- Treatments
- Schedules
- Operations
- Budget control
- Records
- Impact on performance
- User costs

In-Service Evaluation
- Periodic monitoring of structural adequacy, roughness, surface distress, and surface friction
- Assess performance
- Prioritize

End of Service Life
- Recycling and reuse of materials for reconstruction
- Salvage Value
- Records
- Restoration
- Zero Waste Management

---

“Working” Management

Database

Information

Research

(TAC, 2013)
Alberta (Edmonton) site (50% reliability)

Years to reach maintenance limit

- Baseline
- CGCM2A2x
- HadCM3B21

Climate Change Scenario

- IRI
- Longitudinal cracking
- Alligator cracking
- Transverse cracking
- AC rutting
- Total rutting

(Mills, 2007)
Pavement Predictions

![Bar chart showing AC Rutting predictions for different provinces in Canada.](image)

- **British Columbia**: AC Rutting (baseline) = 2 mm, AC Rutting (CGCM2A2x) = 3 mm
- **Alberta**: AC Rutting (baseline) = 6 mm, AC Rutting (CGCM2A2x) = 9 mm
- **Manitoba**: AC Rutting (baseline) = 3 mm, AC Rutting (CGCM2A2x) = 5 mm
- **Ontario**: AC Rutting (baseline) = 4 mm, AC Rutting (CGCM2A2x) = 5 mm
- **Quebec**: AC Rutting (baseline) = 4 mm, AC Rutting (CGCM2A2x) = 5 mm
- **Newfoundland**: AC Rutting (baseline) = 2 mm, AC Rutting (CGCM2A2x) = 3 mm

*Source: Mills, 2007*
Pavement Predictions

International Roughness Index (IRI) (m/km)

- British Columbia
- Alberta
- Manitoba
- Ontario
- Quebec
- New foundland

IRI (baseline) vs. IRI (CGCM2A2x scenario)

(Mills, 2007)
Climate Change Impacts on Pavement

- Changes occurring in minimum daily temperature
- Changes occurring in maximum daily temperature
- Changes occurring in freezing and thawing indices
- Changes occurring in precipitation, duration and intensity
- All of these changes are impacting infrastructure
- Reconsider current design methods, maintenance and rehabilitation practices
- Manage implications
What is a Natural Disaster?
Role of Engineers and Scientists

- Many of these could possibly be avoided by better design, construction, safety systems, early warning and planning.
- Scientists and engineers try to prevent damage by warning people the natural disaster is coming.
- Try to monitor the event and try to prevent damage.
- Develop plans for emergencies
Key Sustainability Issues

• Virgin Material Usage
• Alternative Material Usage
• Program for In-Service Monitoring and Management
• Air Quality/Emissions
• Water Quality
• Noise
• Energy Usage
Research Methodology

- Technical
- Economic
- Sustainable
- Costs/Benefits
Quantify All Costs/Benefits

Serviceability

Cost

Environmental Impacts

Conventional Pavement

Pervious Pavement

Recycled Pavement/Using By-Products

(Tighe, 2010)
Long Life Design

• Resilience is the ability to deal with changes in general

• Resilience in pavement engineering design to ensure it withstands hazard with minimum damage of pavement

• Build-in pavement resilience from material revolution view

• Pavement resilience from post disaster using pavement management to better manage future road
Closing Remarks

• Understand climate change must be examined for long life infrastructure
• Adoption of new materials and designs
• Evaluate potential threats related to climate change and plan for them
• Proactive design and management
Acknowledgements

• Undergraduate and Graduate Students
• Ministry of Transportation Ontario (MTO)
• Natural Sciences and Engineering Research Council of Canada (NSERC)
• Ontario Hot Mix Producers Association (OHMPA)
• Cement Association of Canada
• Partners in Norman W. McLeod Chair
• CPATT Partners
Questions/Comments

Professor Susan Tighe, Ph.D, P.Eng
Norman W. McLeod Chair in Sustainable Pavement Engineering
Director Centre for Pavement and Transportation Technology

sltighe@uwaterloo.ca