Implications of Climate Change for Paved Roads and Road Safety in Southern Canada

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Presented by

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Based on Collaborative Research with

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Introductory comments:

The design and operation of transport infrastructure reflects the diverse range of environmental conditions observed across the globe.

Examples:

- Construction of the Taklamakan Desert Highway, China, in a region with migrating sand dunes and temperatures as low as -20$^{\circ C}$ and as high +40$^{\circ C}$
- Use of a corduroy base in muskeg areas
- Identification of most appropriate asphalt grade by region (e.g., Superpave Performance Grade of 70-10 in Southeast California vs. 58-22 or 52-16 in the Vancouver area)

Introductory comments:

Climatic sensitivities are due to extended or repeated exposure to particular atmospheric events or conditions

Examples:

- Shippers' decisions about rail versus marine for bulk commodities in the Great Lakes Region may be affected by observed or anticipated drops in water level
- Municipalities' decisions about pavements may be affected by observed or anticipated rutting due to extended periods of high temperatures in summer

Introductory comments:

Weather sensitivities are due to episodic exposure to particular atmospheric events or conditions

Examples:

- Focus on response strategies for specific conditions, e.g., road closure, winter road maintenance activities, implementation of optional telework day

Introductory comments:

Assessments of the implications of climate change for transportation in Canada began ~ 20 years ago

Chronology of synthesis reports:

- IBI Group (1990) *The Implications of Long-term Climate Change on Transport Infrastructure in Canada*. Climate Change Digest CCD90-22, Environment Canada.
- Andrey, J. and Snow, A. (1999) Transportation sector. *In Canada Country Study: Climate Impacts and Adaptations*, Volume VII, National Sectoral Volume, Chapter 8, Environment Canada, pp. 405-447.
- Andrey, J. et al. (2004) Transportation. In Climate Change Impacts and Adaptation: A Canadian Perspective, D.S. Lemmon and F.J. Warren (eds), Natural Resources Canada, pp. 131-150. http://www.adaptation.nrcan.gc.ca/perspective/index_e.php

Introductory comments:

Key sensitivities have been identified, and understanding is improving

- Northern Canada has been identified as the region where climatic changes and associated transportation-related impacts are expected to be greatest.
- Domestic marine (Great Lakes – St. Lawrence system) and coastal infrastructure in Eastern Canada are of concern because of lower water levels, and higher water levels (as well as storm surges), respectively.
- The design and operation of transportation infrastructure in Southern Canada is an area to be managed carefully.

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- Increasingly, the role of governments is to establish standards for the design, construction, operation and maintenance of public infrastructure.
- Transport infrastructure exists to facilitate safe mobility.
- The performance of such infrastructure is addressed through a life-cycle cost effectiveness framework.

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- Life-cycle cost effectiveness provides a means by which decisions can be made with respect to the construction, maintenance and rehabilitation of sections of the network.
- The goal is to maximize life-cycle cost effectiveness, i.e. to spend public dollars in a responsible way.
- In other words, as roads are built and as they deteriorate over time, decision-makers must determine the type of design/intervention and the best timing for rehabilitation.

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- A variety of measures for pavement performance/deterioration exist:
  - Ride quality, e.g., riding comfort index
  - Surface distress, i.e., ruts, cracks, patches, potholes
  - Structural adequacy, e.g., as measured through deflection testing
  - Surface friction and drainage, because of their importance for safety

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Low-Temperature Transverse Cracking

- Affects ride quality and facilitates the movement of water and fine particles through the pavement structure, thereby accelerating deterioration.
- Cracks run perpendicular to centre line and are spaced periodically.
- Associated with low winter temperatures and/or rapid cooling and is affected by age hardening.

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High-Temperature Rutting

- Occurs in the wheel paths of an asphalt concrete pavement due to densification and permanent deformation under high loads, i.e. truck traffic
- Is normally expressed as depression depth relative to the plane of the pavement surface
- Caused by unstable asphalt mixes due to high temperature and/or pavement properties, i.e., asphalt content or binder viscosity
- Also affected by conditions during the first few years after construction, e.g. conditions that interfere with pavement hardening

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Freeze-Thaw Indices

- Frost heave (rise in a pavement surface caused by the freezing of pore water and/or creation of ice lens in the underlying layers) and cracking are important climate-related processes.
- Freezing/frost indices correlate with frost depth and can be used to set winter weight premiums.
- Thawing indices are used to determine the best timing of spring load restrictions to prevent road damage, e.g., when the asphalt layer is above freezing but the unbound (base) layers are still melting

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Combined Effects of Environmental Conditions on Pavement Life

- The Mechanistic-Empirical Pavement Design Guide software can be used to estimate the combined effects of climate and traffic on the timing of required maintenance
- Separate calculations are made for roughness, cracking and rutting.

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Overall Approach

- Calculation of **weather indicators (17 sites)** and **pavement performance measures (6 sites)** for baseline and future scenarios using output from Atmosphere-Ocean GCMs (Canadian-CGCM2Ax and Hadley-HadCM3B21) that was downscaled (LARS-WG)

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Locations Analyzed

- Vancouver, Kelowna
- Calgary, Edmonton
- Regina, Winnipeg
- Thunder Bay, North Bay, Muskoka
- Windsor, Toronto, Ottawa
- Montreal, Quebec
- Fredericton, Halifax, St. John's

Coloured font for locations included in both analyses

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Future Climates ... 2050s

- Temperature increase expected at all 17 locations in all months (except possibly Jan&Feb for Vancouver and Kelowna)
- Changes in precipitation more variable from model to model, location to location and month to month, but overall increase

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Results of Climate Change Analysis Performance-Grade Asphalt Selection

- For baseline, recommended PG grades vary, e.g., Vancouver 52-16 vs. Edmonton 52-46 vs. Toronto 58-28
- Estimates of the 7-day maximum temperature at 20 mm below surface and the minimum temperature at the pavement surface by the 2050's indicate the need to INCREASE THE HIGH PG RATING at several sites.

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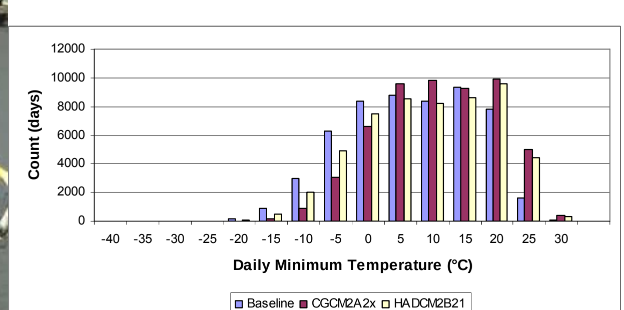
Results of Climate Change Analysis Performance-Grade Asphalt Selection



Daily minimum air temperature statistics for Windsor site under baseline and future scenarios.
Source: Mills et al., 2007. *The Road Well Travelled* …

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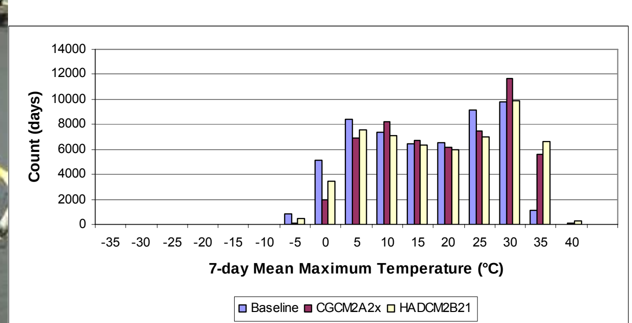
Results of Climate Change Analysis
Performance-Grade Asphalt Selection



7-day mean maximum air temperature statistics for Windsor site under baseline and future scenarios.
Source: Mills et al., 2007. *The Road Well Travelled …*

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Results of Climate Change Analysis
Freezing and Thawing Indices

- Indices based on methods developed for Minnesota
- Later dates for freeze up, earlier dates of thaw and more inter-annual variability, leading to SHORTER SEASON FOR WINTER WEIGHT PREMIUMS and the need for MORE VIGILANCE IN DETERMINING WHEN TO IMPLEMENT and ENFORCE SPRING LOAD RESTRICTIONS

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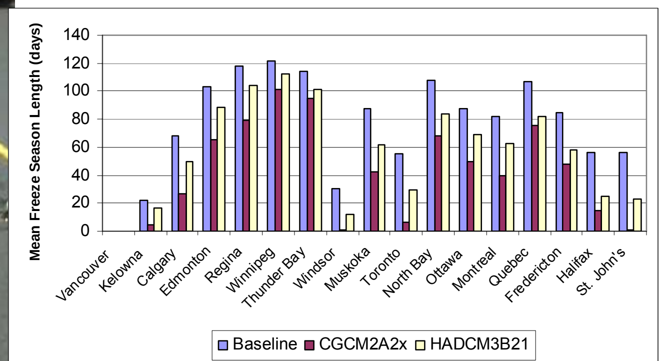
Results of Climate Change Analysis
Freezing and Thawing Indices



Source: Mills et al., 2007. *The Road Well Travelled …*

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Results of Climate Change Analysis
Pavement Deterioration and Performance

- The model used for the analysis continues to be improved
- RUTTING and CRACKING (longitudinal and alligator) INCREASED UNDER CLIMATE CHANGE but LOW-TEMPERATURE, TRANSVERSE CRACKING WAS REDUCED
- modestly earlier maintenance predicted

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- A summary of the work we've done:

  Mills, B., S.L. Tighe, J. Andrey, J.T. Smith, S. Parm and K. Huen. 2007. *The Road Well-Traveled: Implications of climate change for pavement infrastructure in southern Canada*. Final report prepared for the Climate Change Impacts and Adaptation Program, Natural Resources Canada. http://www.adaptation2005.ca/abstracts/pdf/mills.pdf

- Related studies
  - http://www.adaptation.nrcan.gc.ca/projdb/index_e.php?class=121 [Canadian]
  - http://www.nap/catalog/12/12179.html [US]

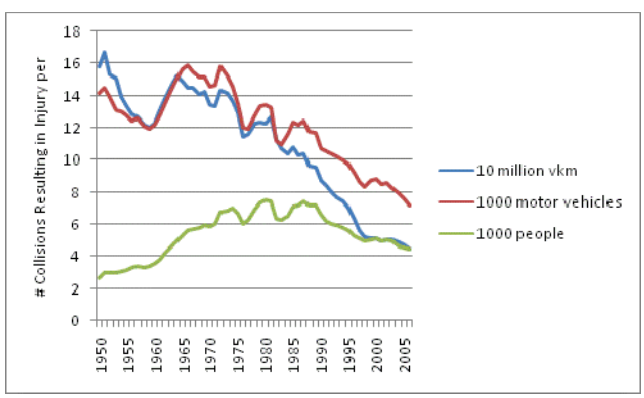
Implications of Climate Change for Paved Roads in Southern Canada

Summary of Key Points

- Methods exist to monitor and model the impacts of present and future climates on paved roads
- There is a need to incorporate longer time climate series (observed or synthetic) into decision making
- There is also a need for careful monitoring of road conditions, where weather variability calls into question past practices
- Considerable ongoing work in other countries

Implications of Climate Change for Road Safety

Road Safety Trends in Canada



Data extracted from Transport Canada and Environment Canada website for various years

Trends in Auto Travel in Canada

	Population (millions)	Registered Road Vehicles (millions)	Auto-mobility (person/veh) (km/veh)
1950	13.7	2.6	5.3 9000
1973	22.6	10.2	2.2 11,000 4900
2006	32.6	20.0	1.6 16,000

Road Safety Patterns

• Urban collisions tend to be less serious than those that occur in rural areas.

ELSEVIER

Accident Analysis and Prevention 38 (2006) 122–127

ACCIDENT ANALYSIS & PREVENTION

www.elsevier.com/locate/aap

Urban–rural differences in motor vehicle crash fatality and hospitalization rates among children and youth

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• Still, approximately 60% of casualty (fatality and non-fatal injury) collisions in Canada occur in urban areas

Weather-Related Driving Hazards

Weather-related condition	Driving hazard(s)
Ice, snow or frost on road surface	Decreased friction
Fog, glare, dust	Decreased visibility
Precipitation or blowing snow	Decreased friction and visibility
High or gusty winds	Vehicle handling
Extreme temperature or changes in pressure	Biophysical effects on drivers

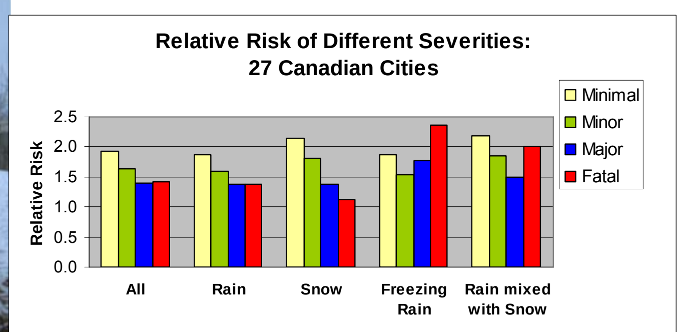
Data

- Transport Canada records on ~ 2 million casualties over 2 decades, 1984-2002
- Environment Canada's hourly, 6-hourly and daily weather observations at primary stations

Incidence of Weather	Cities Included in Study
Precipitation occurs > 15% of the time, snow more often than rain	Chicoutimi-Jonquiere, Sherbrooke, Quebec City St. John's, Sudbury
Precipitation occurs ~ 15% of the time, mostly rain	Vancouver, Richmond, Victoria
Precipitation occurs 10-15% of the time, snow more often than rain	London,Thunder Bay, Winnipeg, Regina, Saskatoon, Calgary, Edmonton
Precipitation occurs 10-15% of the time, rain more often than snow	Halifax, Moncton, Saint John, Fredericton, Montreal, Gatineau, Ottawa, Oshawa, Toronto, Brampton, Windsor
Precipitation occurs < 10% of the time, rain more often than snow	Kamloops

Andrey, J. et al., 2005. Toward a national assessment of the travel risks associated with inclement weather. Institute for Catastrophic Loss Reduction http://www.iclr.org/research/publications_climate.htm

Precipitation-Related Crash Risk



* High confidence in for all precipitation and rain, except for fatalities; moderate confidence for snow; low confidence for freezing rain and rain mixed with snow (see ICLR http://www.iclr.org/research/publications.htm)

Relative Risk over Time

- Relative risk of casualty during rainfall has decreased over the past two decades from an average of 1.8 to 1.5
- Relative risk of casualty during snowfall has remained steady at about ~ 2.0

Andrey, J. (In Press) Long-term trends in weather-related crash risks. *Journal of Transport Geography*

Extrapolations into the Future

- The horse race, as described by the founding editor of *Accident, Analysis and Prevention*, Frank A. Haight
- Cdn initiatives, e.g., *Road Safety Vision 2010*
- Uncertain projections for auto use and trucking given economic restructuring, climate change mitigation, fossil fuel prices, etc.
- Society's willingness to accept mobility restrictions or protective requirements
- Trends in urbanization, land use, demographics
- Changes in safety associated with climate change – ceteris paribus—likely to be small, as relative risk during heavy rain is similar to moderate snow (1.8)

Related Issue of Winter Maintenance

- Need for monitoring for wet-weather/hydroplaning potential and possibly more driver training for wet or extreme rainfall conditions
- Need for careful monitoring of conditions leading to ground frosts or freezing, and timely application of road salt, e.g., through maintenance decision-support systems
- Preliminary analysis of future road salt budget for City of Ottawa by B. Mills (unpublished) suggests that—assuming similar practices into the future—SALT USE WOULD DECREASE by only minimal amounts in Jan-Feb but by 20-35% Nov-Dec and Mar-Apr.

Method used by B. Mills for Salt Projections

Baseline (1951-2000)
Daily Climate Data

Monthly Climate Change
Scenarios (2050s)
HadCM3B21 CGCM2A2x

LARS Weather Generator
(synthetic daily time series)

Winter Severity-Salt Use Model (Suggett et al., 2006)

$$\ln(salt) = -5.54 + 2.39(s) - 0.09(t) + 0.73(zr) + 1$$

ln(salt) = natural logarithm of daily salt use (tonnes/lane-km)
s = proportion of days with trace or greater snowfall
t = absolute difference between mean daily temperature and -6.5°C
zr = proportion of days with freezing rain or drizzle.

Comparison of baseline and scenario results

Concluding comments:

The issues examined here—paved road infrastructure, road safety, and related activities such as setting spring load restrictions and decisions about winter maintenance—will require some adaptation in standards and practices to avoid unnecessary costs or collisions.

The good news is that data and methods exist to facilitate wise decisions, and these adaptations are within the range of current practices globally.

The issue not discussed here—and one that will be equally important—pertains to changes in travel demand, as a function of economics, land use planning and climate change mitigation.