

11th National Conference on Transportation Asset Management

July 10–12, 2016

Minneapolis Marriott City Center, Minneapolis, Minnesota

Impact of Climate Change on the Performance, Maintenance, and Life-Cycle Costs of Flexible Pavements

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Transportation Infrastructure**



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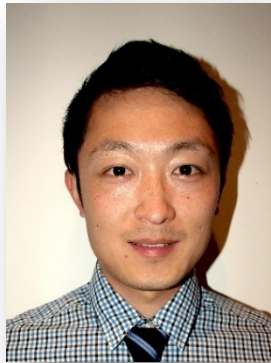
- Why did we study this?
 - ✓ Motivation
- How did we do it?
 - ✓ Methods
 - ✓ Data
- What did we learn?
 - ✓ Results
 - ✓ Impact of the international collaboration

Acknowledgements

**Nottingham Transportation Engineering Centre
University of Nottingham, U.K.**

NTEC
Nottingham Transportation
Engineering Centre

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FHWA, and Virginia Tech

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Why?

Introduction



VirginiaTech
Transportation Institute

Center for Sustainable
Transportation Infrastructure

NTEC

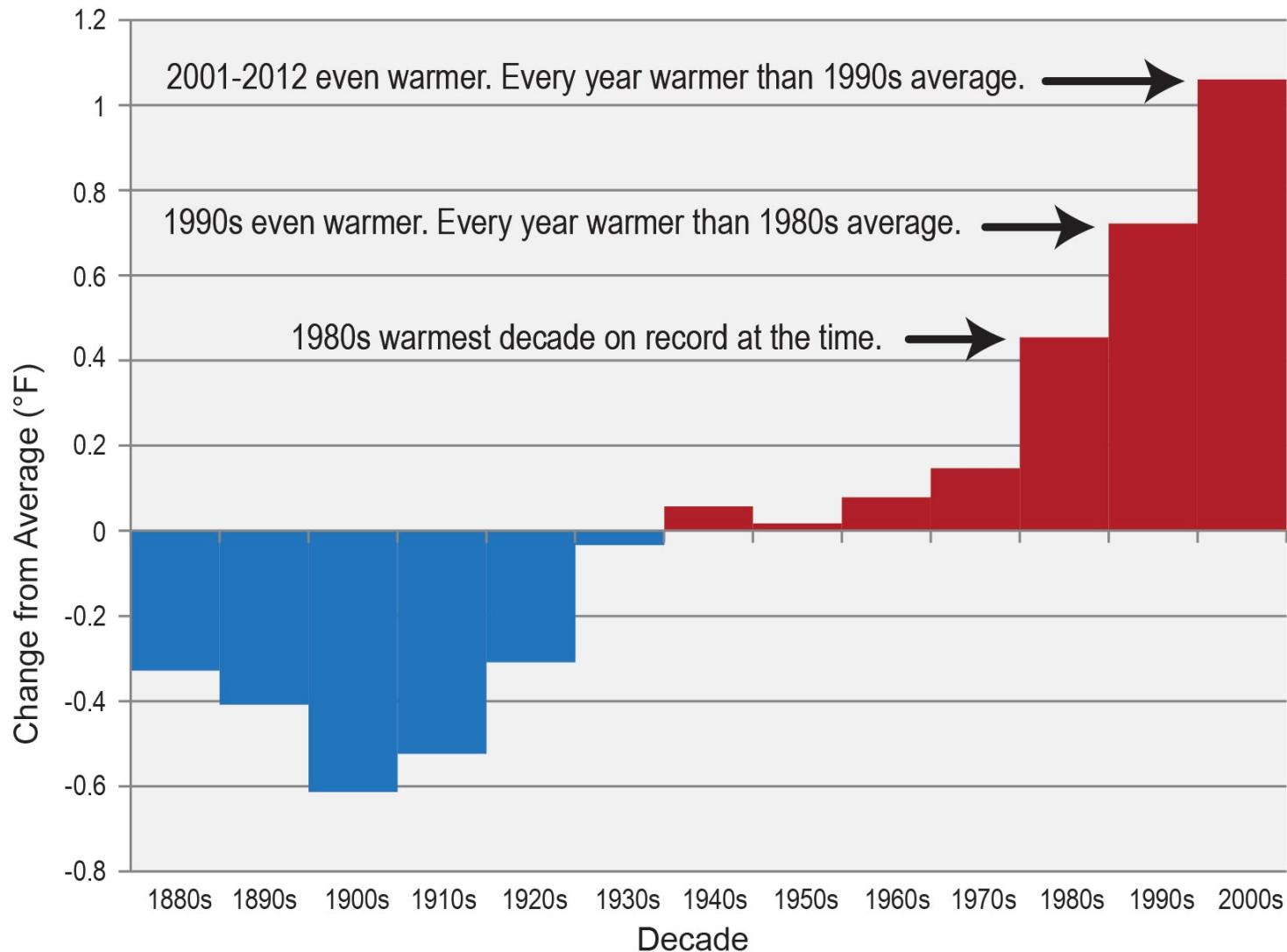
Nottingham Transportation
Engineering Centre



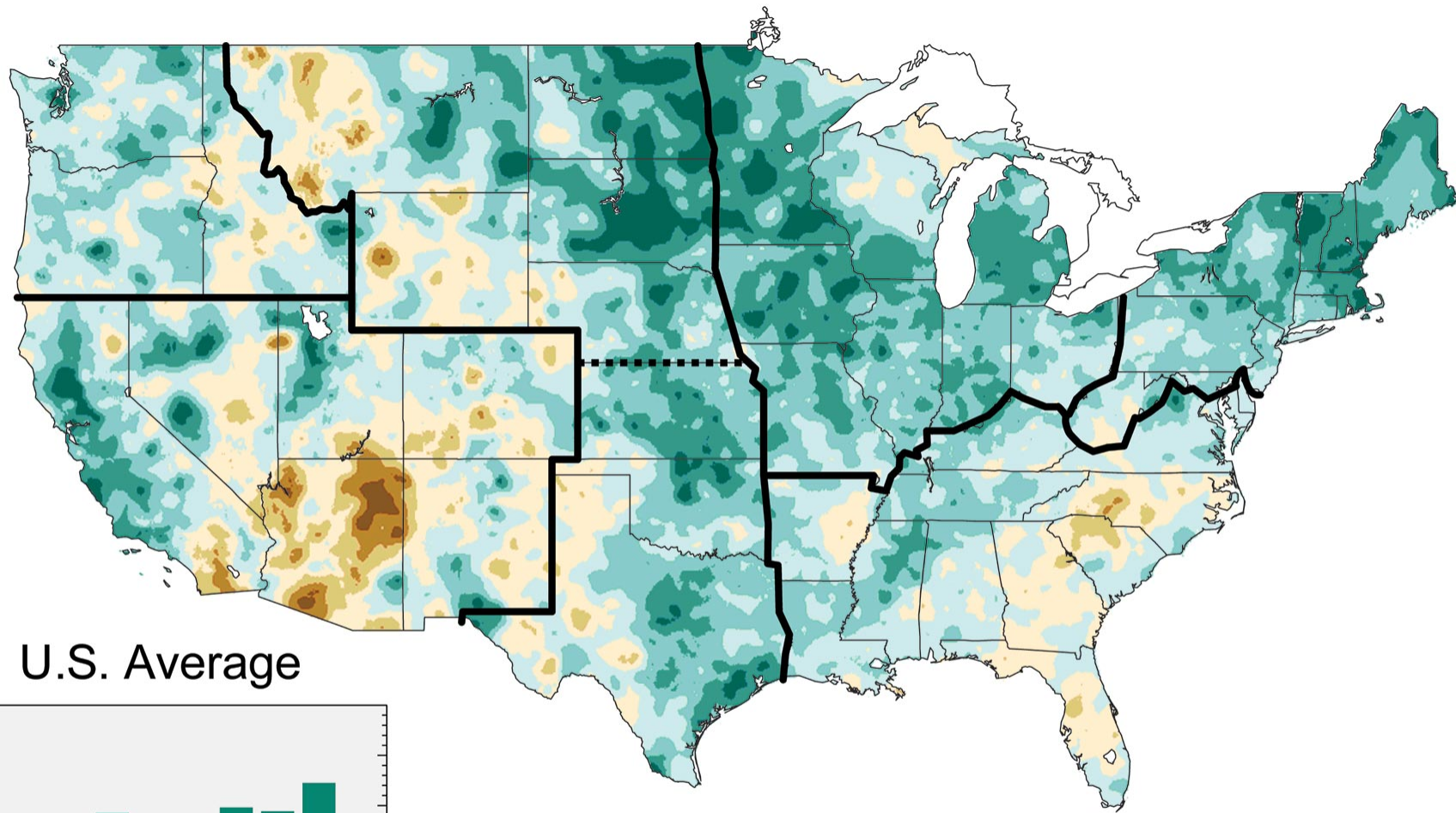
University of
New Hampshire

Our Climate is Changing

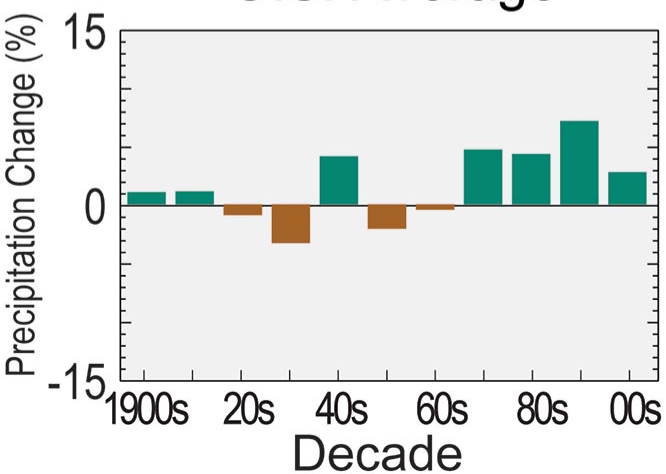
Global Temperature Change: Decade Averages



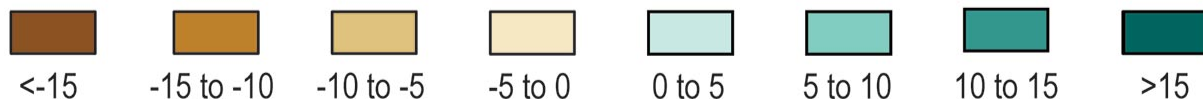
Observed U.S. Precipitation Change



U.S. Average



Precipitation Change (%)



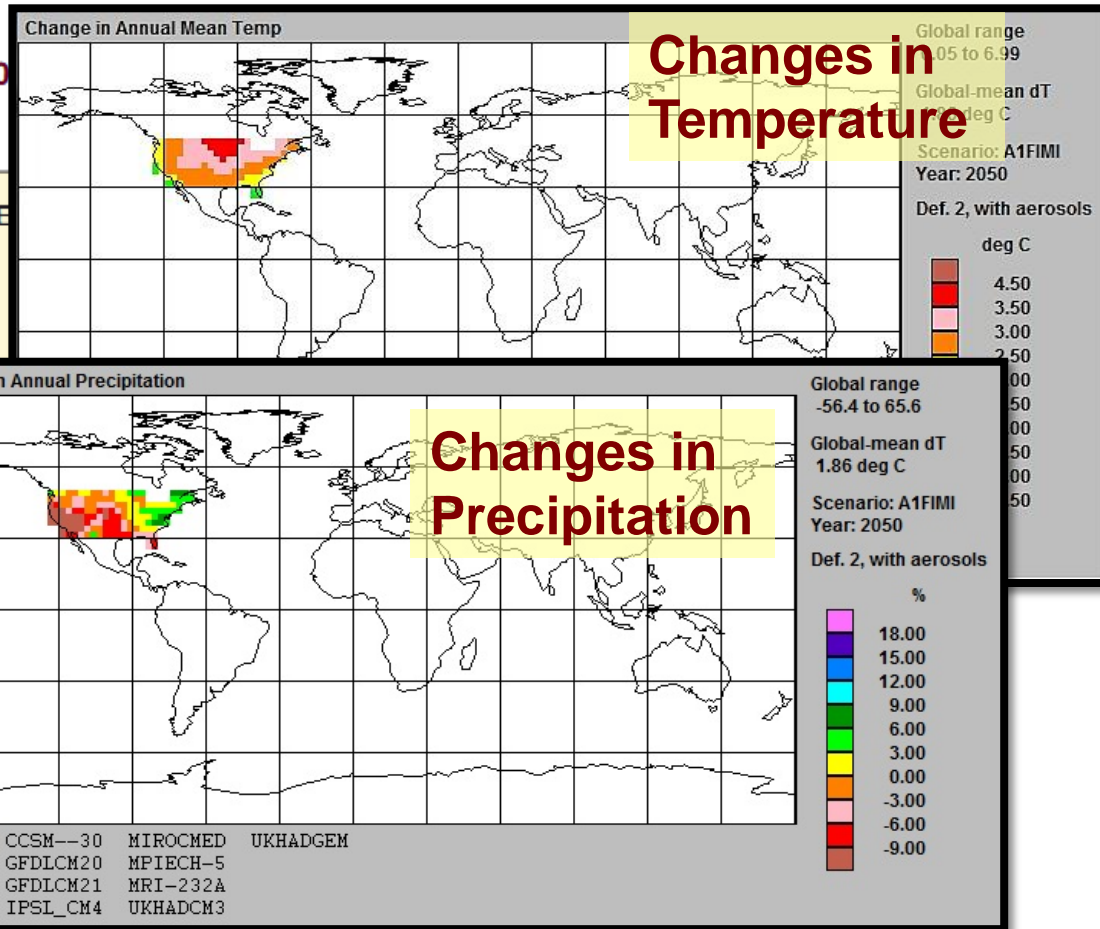
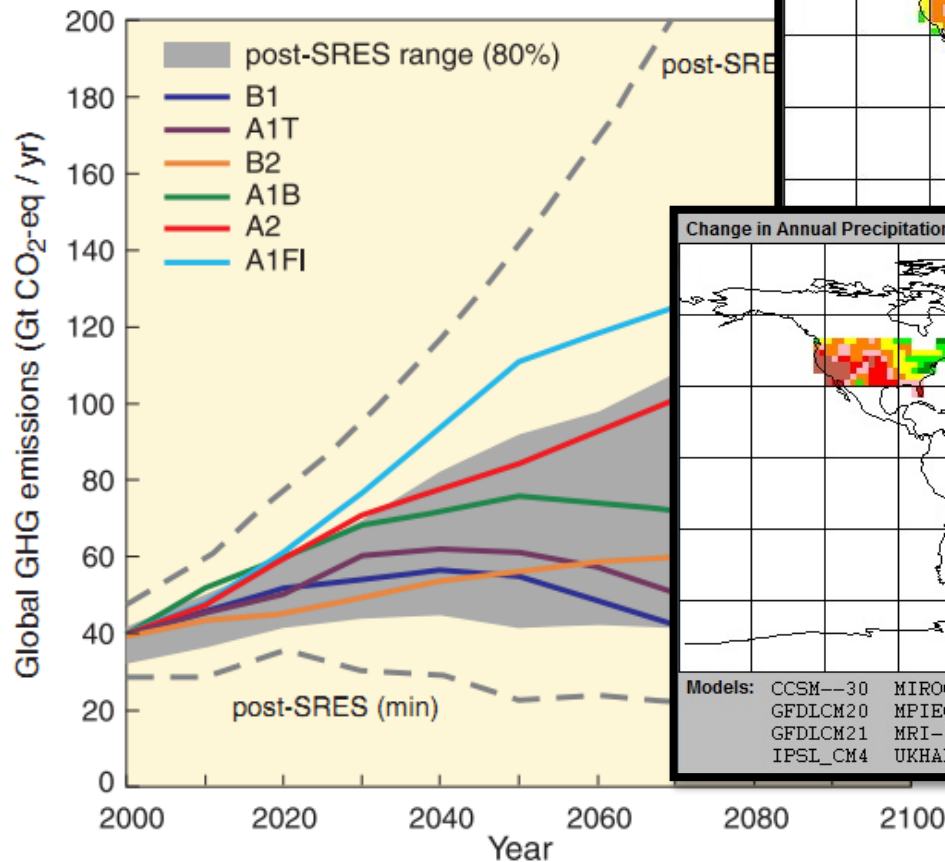
Extreme Weather

Trends in Flood Magnitude



Climate Change Scenarios

Scenarios for GHG emissions from 2000 to 2100
in the absence of additional climate policies



Examples of the Impact of Climate Change on the Infrastructure



- **Sea level rise** Increase damage to U.S. infrastructure including roads, buildings, industrial facilities, ports and coastal military installations
- **Storm surge**
- **Heavy downpours**
- **Increasing risks to Flooding** Exceeding the limits of flood protection infrastructure designed for historical conditions
- **Rapid melting of snowpack**
- **Extreme heat** Damaging transportation infrastructure such as roads, rail lines, and airport runways

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How?

Methods



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Objective

- To develop a framework to evaluate the (*long-term direct*) impact of climate change
- on the *performance, maintenance, and life-cycle costs* on flexible pavements



Responses to Climate Change

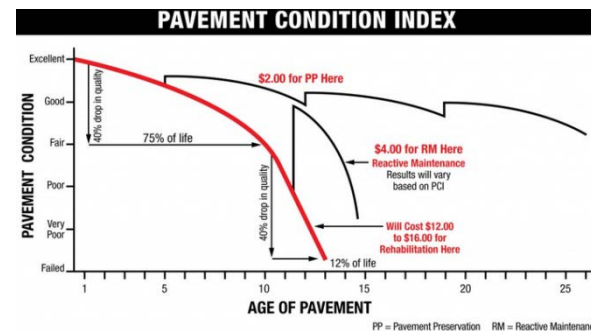
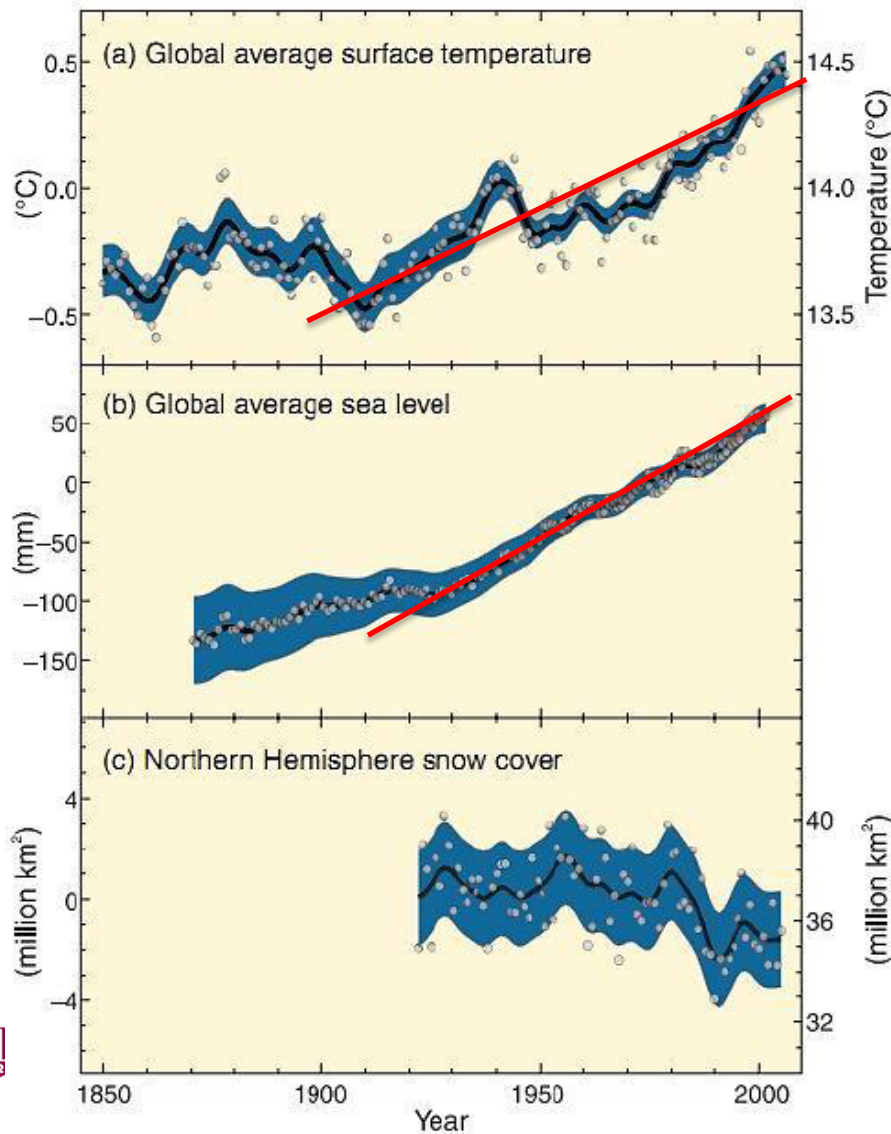


Adaptation - to address and prepare for impacts

Mitigation - to reduce future climate change, e.g., by cutting emissions

- current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences
- Adaptation actions often fulfill other societal goals, such as sustainable development, disaster risk reduction, or improvements in quality

Problem Formulation

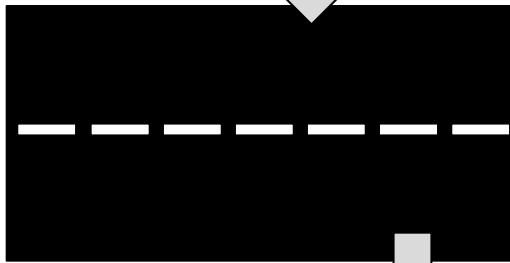


Specific Research Questions

1. To what extent can climate change impact the deterioration of a particular flexible pavement?
2. How will maintenance decisions be made to adapt to climate change? and
3. How will the consequent LCCA change due to climate change?

Approach Overview

Variable: climate change



Output 1: Pavement deterioration
Output 2: Maintenance decision-making
Output 3: Life-cycle costs

Task 1: Investigation of climate change

Task 2: Pavement deterioration modelling

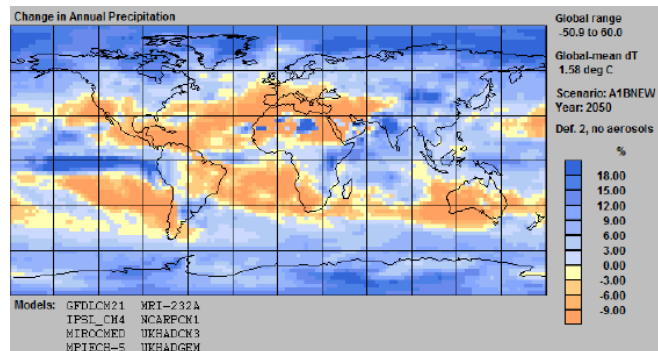
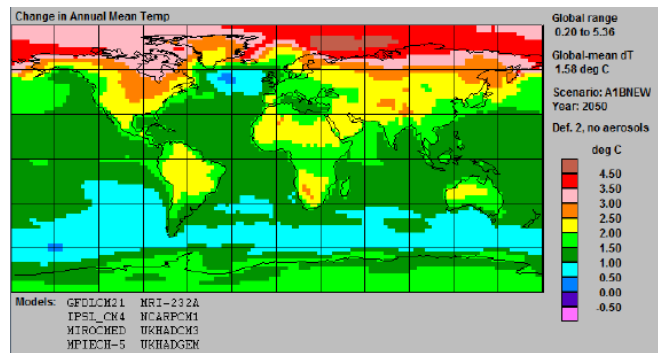
Task 3: Intervention strategies & maintenance effects

Task 4: Life-cycle cost analysis & maintenance optimization

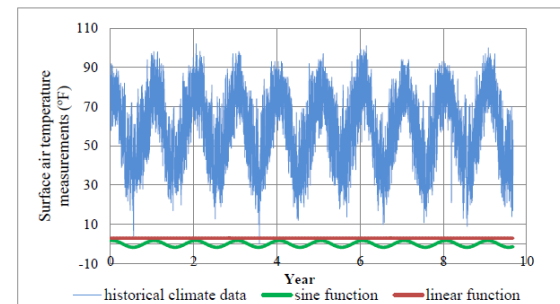


Methods

Climate change prediction: MAGICC/SCENGEN

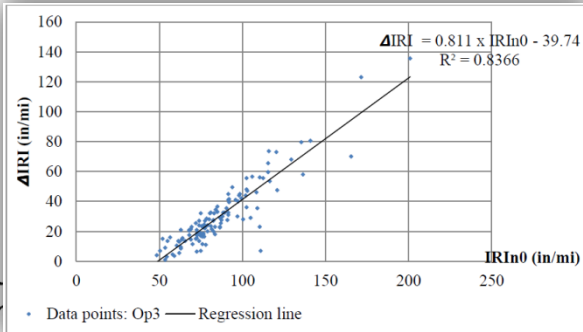
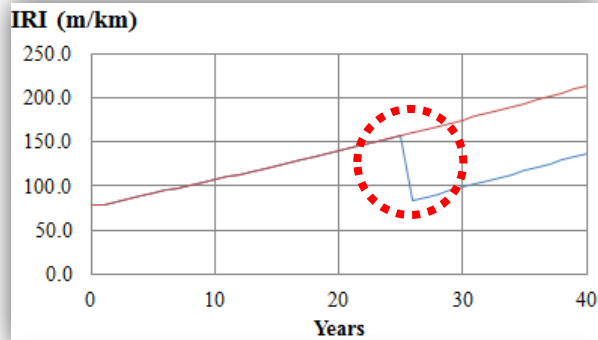


Pavement performance prediction: MEPDG

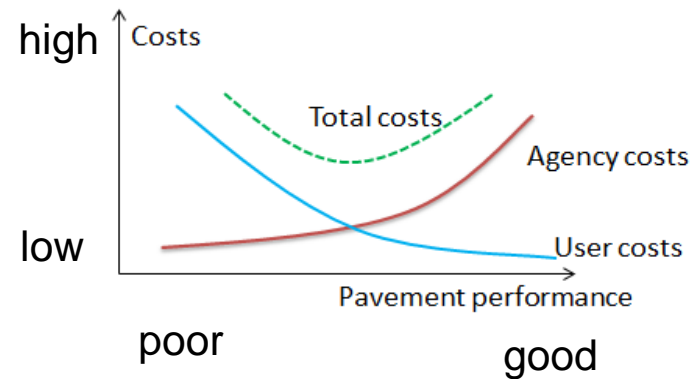


Methods (cont.)

Maintenance effects modelling



LCCA & maintenance optimization



	BL		
Year	Op1	Op2	Op3
1	0	0	0
2	1	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	1	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0

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What?

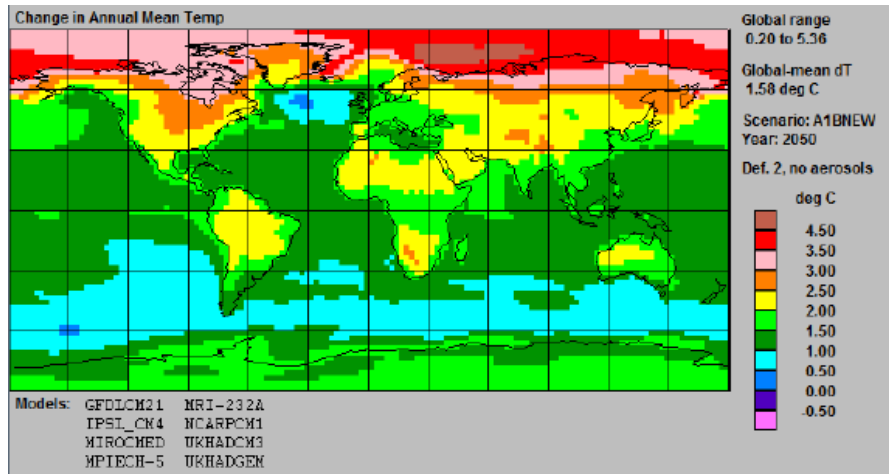
Results



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Climate Change Investigation



High emission

A1FI



A1B



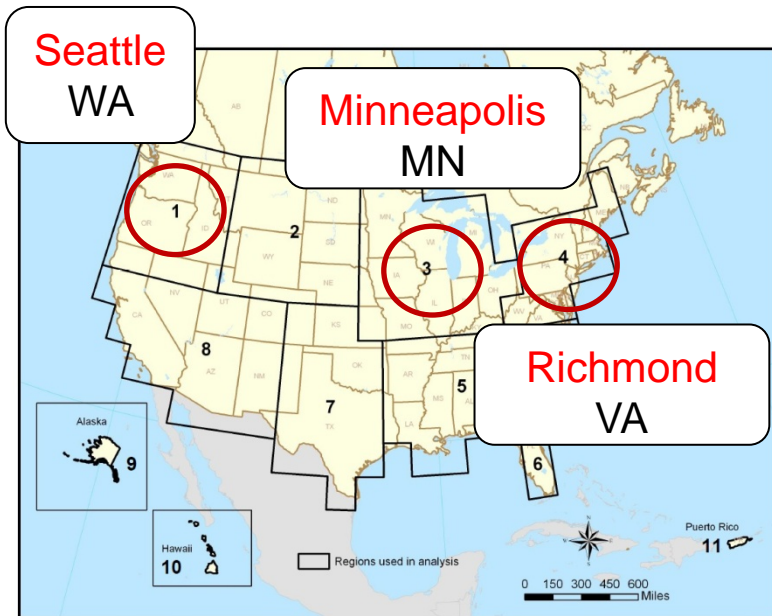
Medium
emission

B1



Low emission

Climate Change Simulation



Qiao, Y., Flintsch, G.W., Dawson, A., and Parry, T., "Examining the Effects of Climate Change on Pavement Deterioration and Service Life", TRR 2349, pp 100-1-7, 2013

T = temperature

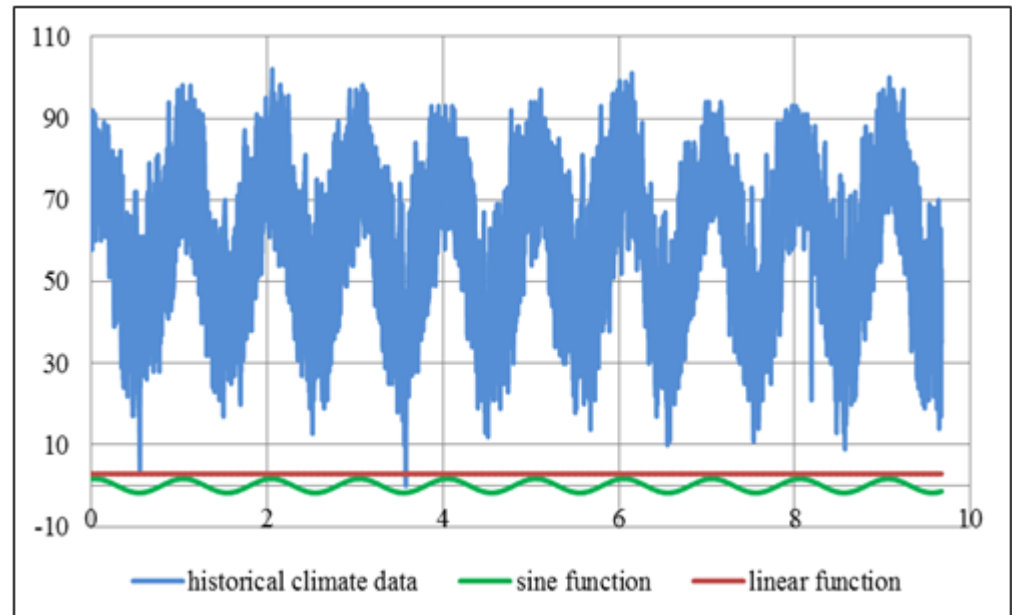
P = precipitation

W = wind speed,

S = percent sunshine

G = ground water level

TV = temperature variation



Impact on Pavement Performance

T = temperature

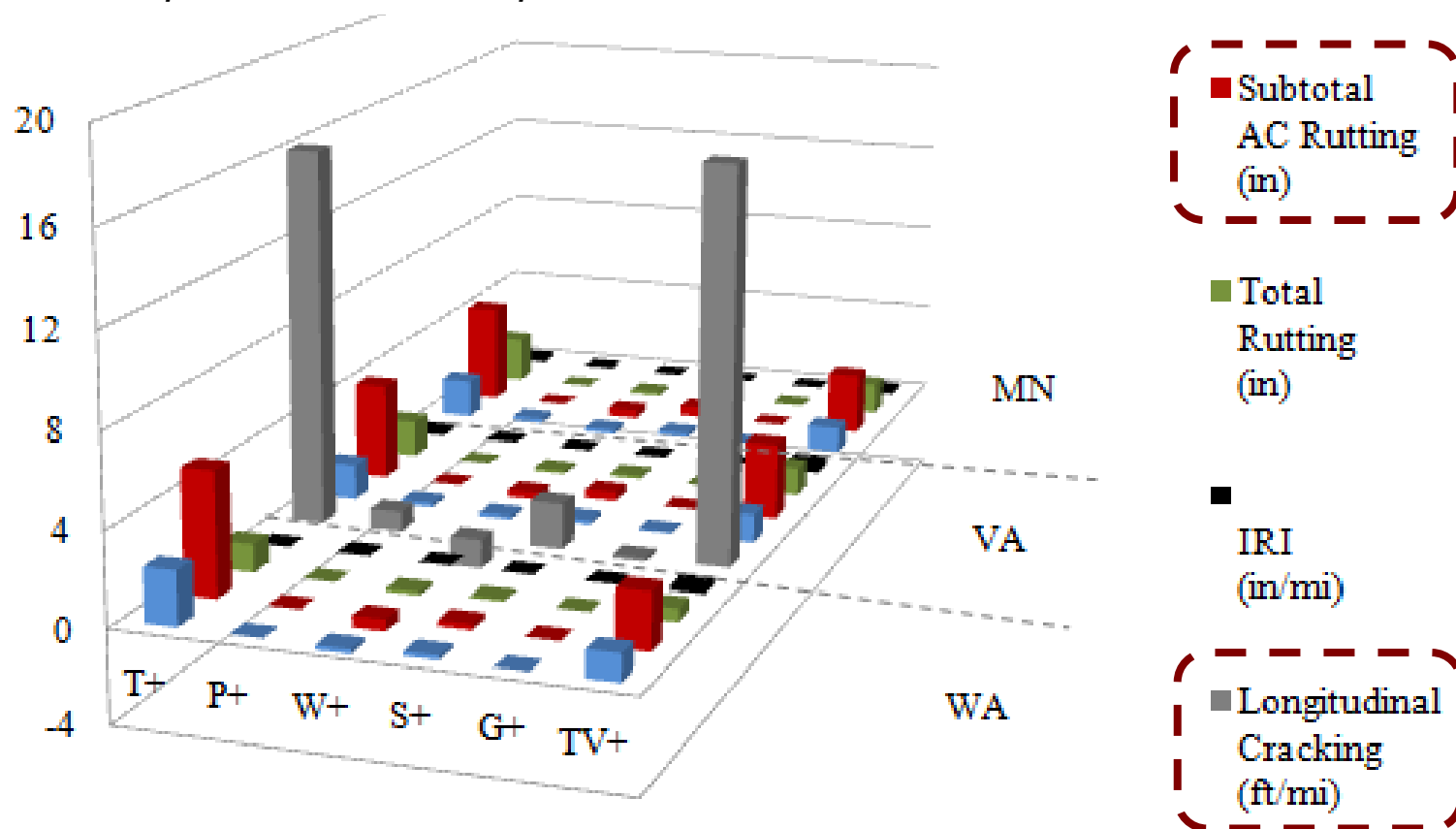
S = percent sunshine

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G = ground water level

W = wind speed,

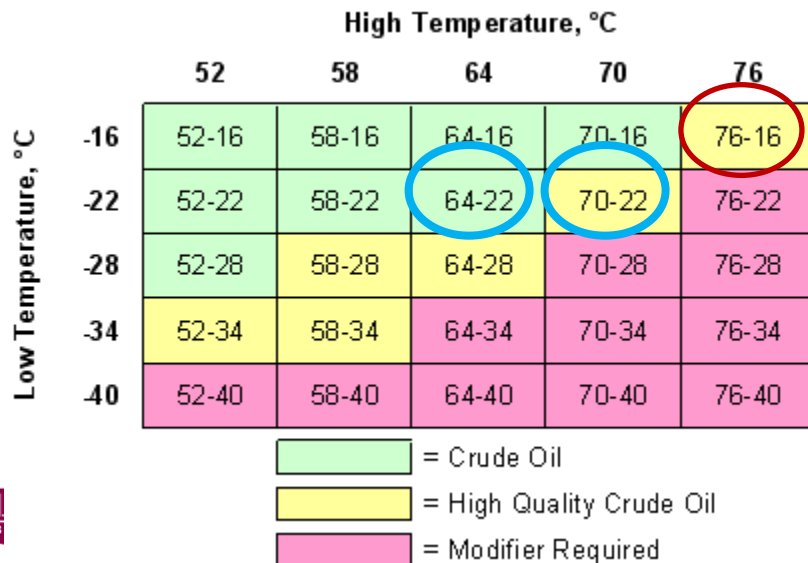
TV = temperature variation



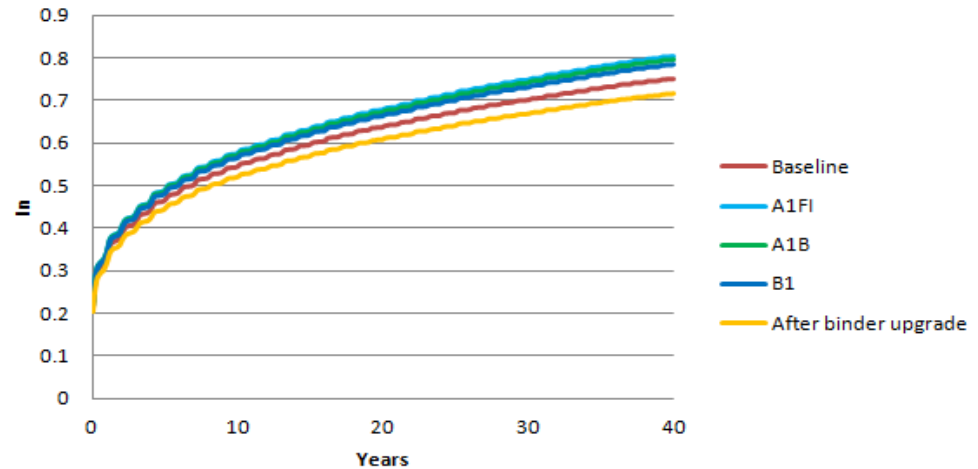
Example of Possible Adaptation Option

Richmond, VA

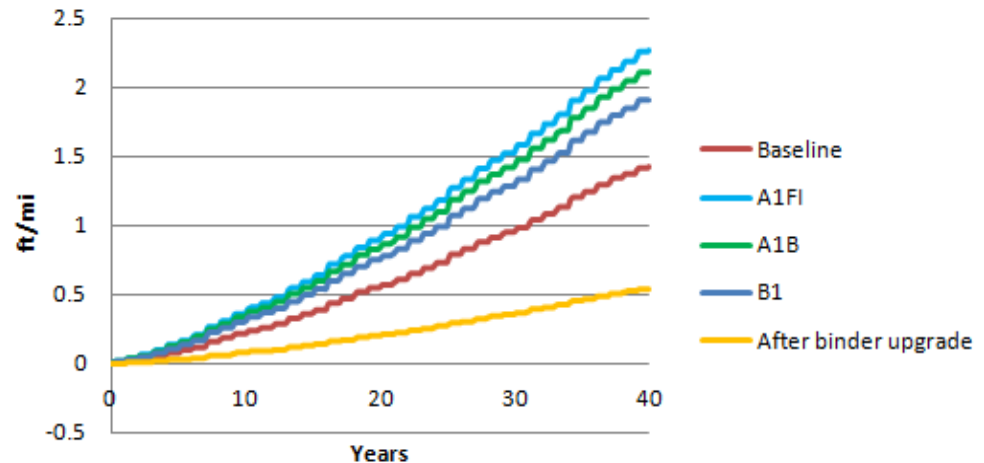
Layers	Material	Design B Grade
Surface course	SM-12.5D	PG 70-22
AC	BM-25.0D	PG 64-22
AC	BM-25.0D	PG 64-22
Granular Base	A-1-a	-
Subbase	A-7-6	-
Subgrade	A-7-6	-



Rutting



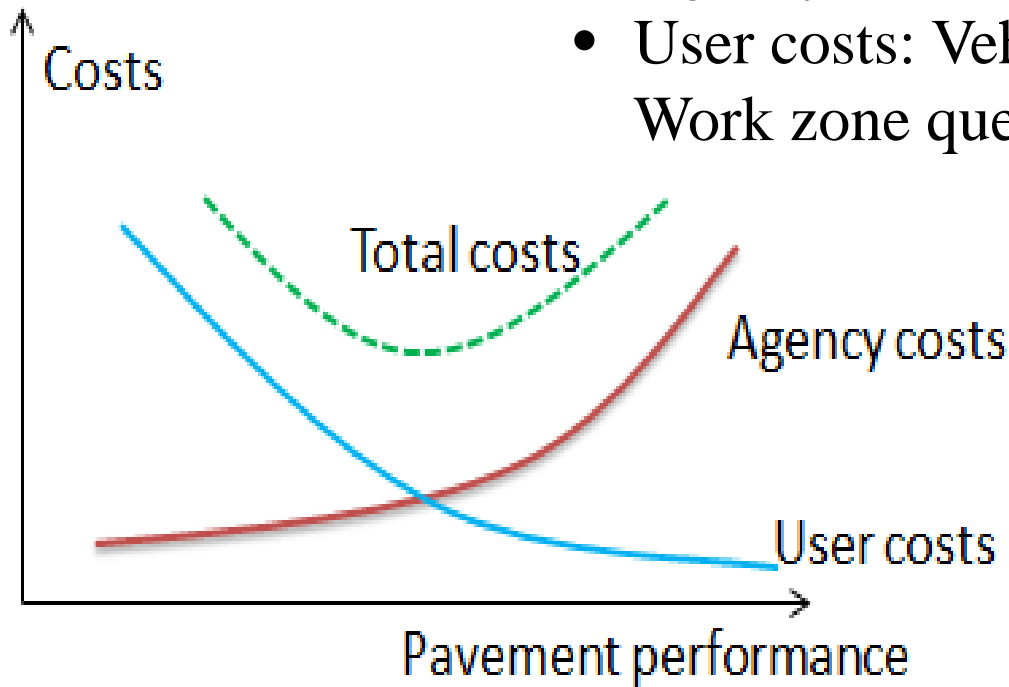
Longitudinal cracking



Life-cycle Cost Analysis and Maintenance Optimization

LCC (in net present value) components:

- Agency costs: maintenance costs
- User costs: Vehicle operating costs (VOC), Work zone queueing delay & moving delay



To minimise the total life-cycle costs:

$$LCC = \sum_{t=1}^t \sum_{n=1}^n \left[B_{t,n} \times \left[AC_{t,n} \times f + WZVOC_{t,n} + WZdelay_{t,n} \right] + VOC_t \right]$$

by optimising $(B_{t,n}; n = 3)$:

$X = X_1, X_2, X_3, \dots, X_n$ ($X_n = 0$ or 1)

$Y = Y_1, Y_2, Y_3, \dots, Y_n$ ($Y_n = 0$ or 1)

$Z = Z_1, Z_2, Z_3, \dots, Z_n$ ($Z_n = 0$ or 1)

Limited by:

$$Rut_{min} \leq Rut(t, X, Y, Z, \dots) \leq Rut_{max}$$

$$IRI_{min} \leq IRI(t, X, Y, Z, \dots) \leq IRI_{max}$$

Where,

t = analysis year

n = intervention type

X, Y, Z, \dots = different intervention types

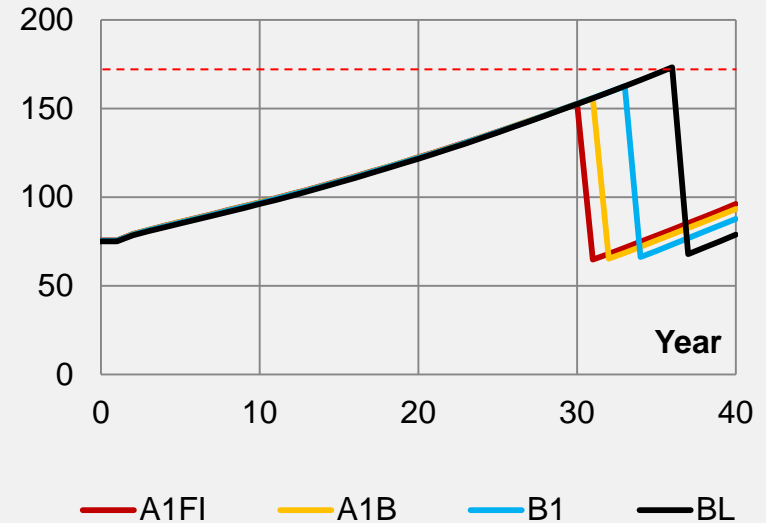
Alternatives

Alt. 0: Do nothing

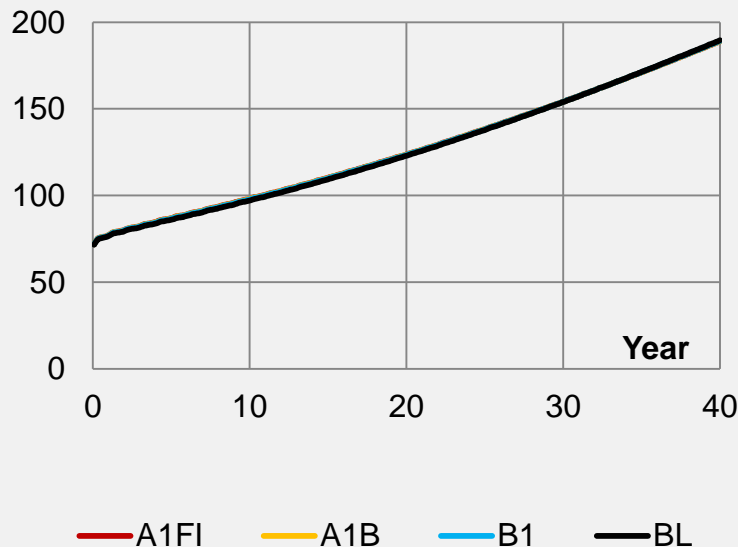
Alt. 1: Responsive maintenance
(minimize agency costs)

Alt. 2: Maintenance optimization
(minimize total costs)

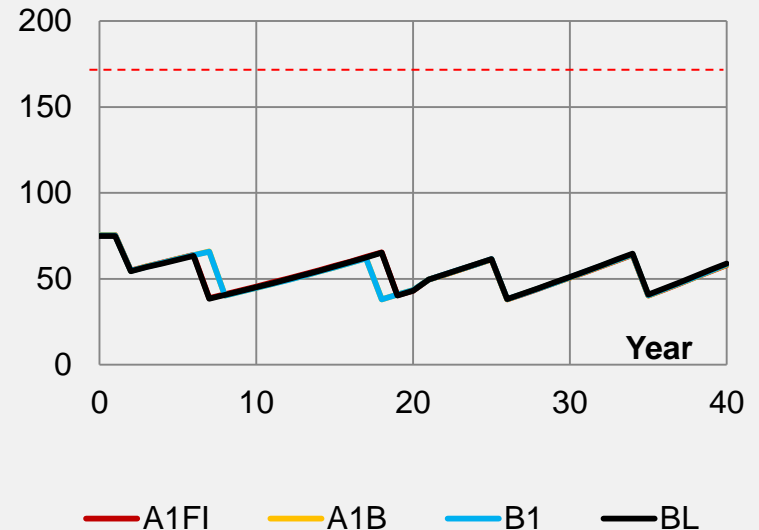
Alternative 1; IRI (in/mi)



Alternative 0, IRI (in/mi)

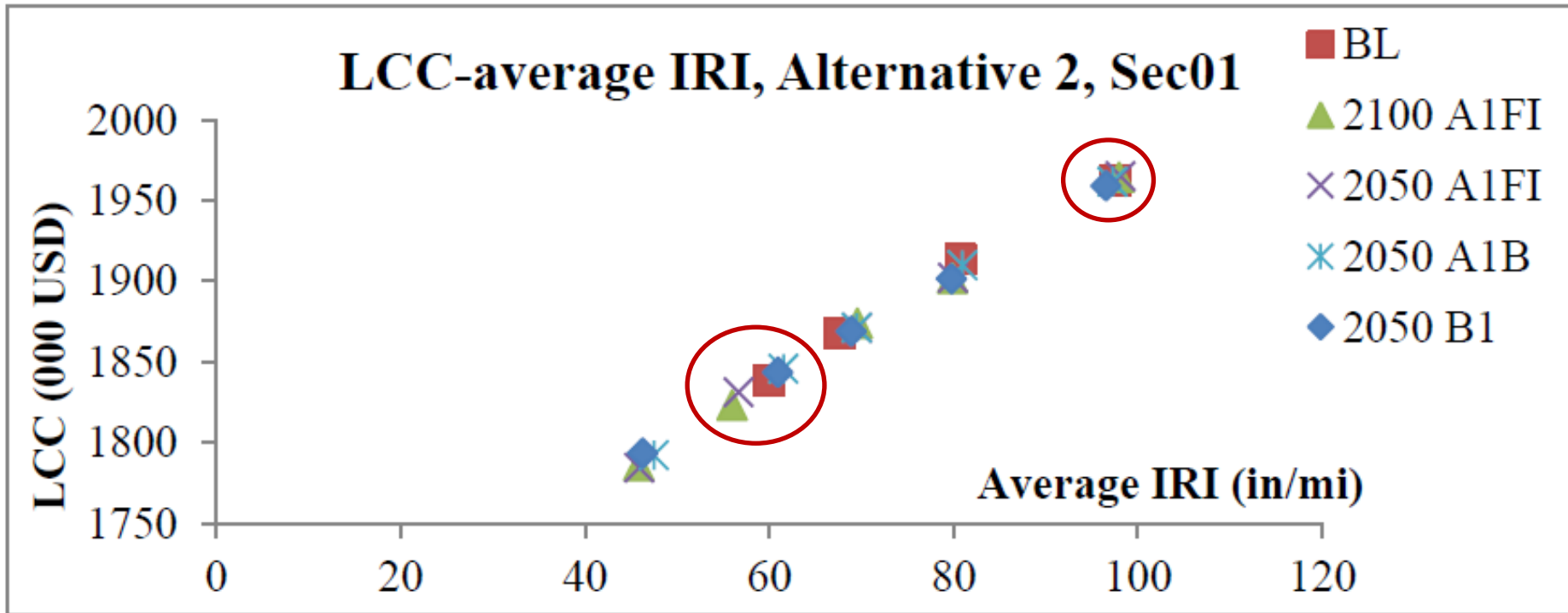


Alternative 2; IRI (in/mi)



Results

Minimized total life-cycle costs (LCC) under climate change scenarios



A1FI = high emission scenario

A1B = medium emission scenario

B1 = low emission scenario

BL = baseline

Conclusions

- **Climate change may:**
 - ✓ **Accelerate deterioration:**
 - ✓ Rutting (high influence)
 - ✓ IRI (low influence)
 - ✓ Cracking (site-specific influence)
 - ✓ **Reduce flexible pavements' service lives**

Conclusions (cont.)

■ Mixed LCC Impact

- ✓ Road users may need to pay more (without maintenance)
- ✓ With optimized maintenance, LCC impact can be mitigated
- ✓ Agency costs may increase (maintenance with strict threshold) but result in savings for the road users (if no additional treatments are triggered)
 - 0.006-0.007 \$/vehicle/mile
 - + 0.002-0.006 \$/vehicle/mile

Benefits of International Collaboration

- Different approaches
 - ✓ Focus on Climate Change
- Complementary Strengths
 - ✓ Pavement Modeling
 - ✓ Optimization approaches
 - ✓ Real-life data
- Broader perspective
 - **More innovative solutions**

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Questions?

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