Consequential Life Cycle Assessment-based Pavement Maintenance and Rehabilitation Framework

High Performance Asphalt Materials Symposium

Waterloo

October 2nd, 2019

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Outline

- Introduction
  - Motivation for study
- Background
  - Life Cycle Assessment (LCA)
- Methodology (very briefly)
  - Future climate data
  - Realistic traffic conditions
  - Maintenance and rehabilitation alternatives
- Selected LCA Results
- Conclusion and Summary
- Contributions

Motivation

- Traditional pavement management is based on **performance** and **economic factors**.

- Typically pavement LCA are performed using historical climate data.
  - However, flexible pavements are sensitive structures and their performance can be **influenced by climate**.

- Including both **user and agency impacts** during the operation phase of an LCA is important for resiliency in pavement management system
  - Unlike so called “Cradle to Gate” LCA

Objective

To develop LCA framework that incorporates use of **realistic traffic data** (RTD), **future climate projections** and **varying maintenance and rehabilitation** (M&R) strategies for consequential analyses.

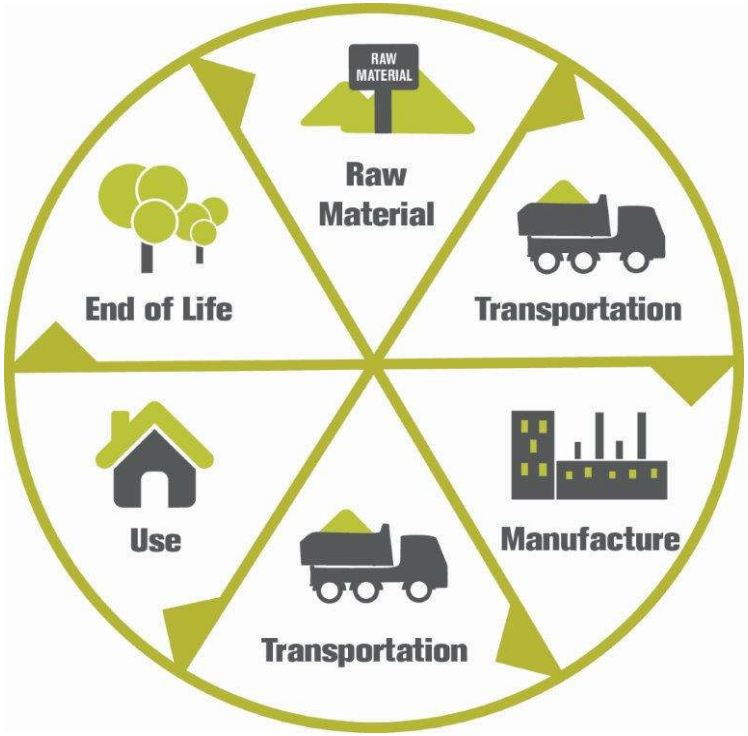
Pavement and Asphalt Materials: Quantify the **increase in fuel consumption** and resulting emissions due to decreased **ride quality (IRI)** caused by accumulated distresses and pavement degradation over the service life.

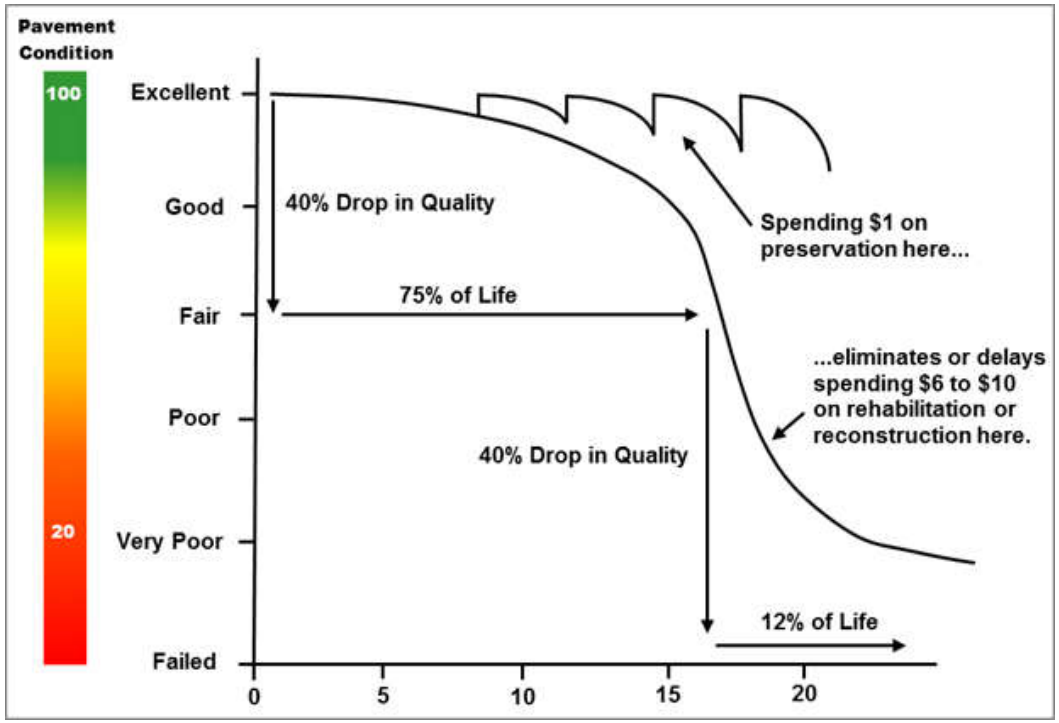
LCA Outcomes

✓ Global Warming Potential (GWP)
✓ Cumulative Energy Demand (CED)
✓ Life Cycle Costs (LCC)

Background

- LCA is a technique used to assess cost and environmental impacts associated with various stages of a product's design life.
- Pavement Management and Pavement Performance → Optimization





General Methodology

1. Select Project Domain and Identify Baseline Conditions

- Length: 26 km / 16 miles
- Location: I-495, MA
- Baseline: No maintenance treatment (also for comparison, constant traffic speed)

2. Inventory

- Material properties, traffic volumes, climatic information, pavement structures

3. Realistic Traffic Data

- Data mining from Google maps for trip delay times
- Varying acceleration and deceleration scenarios inferred from traffic delay (green, orange, red, dark red)
- Utilize EPA MOVES software to calculate emissions

4. Pavement ME Simulations

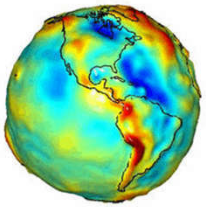
- Simulate alternative pavement cross sections with varying material characteristics as well as maintenance and rehabilitation options
- Pavement distresses, International Roughness Index (IRI)

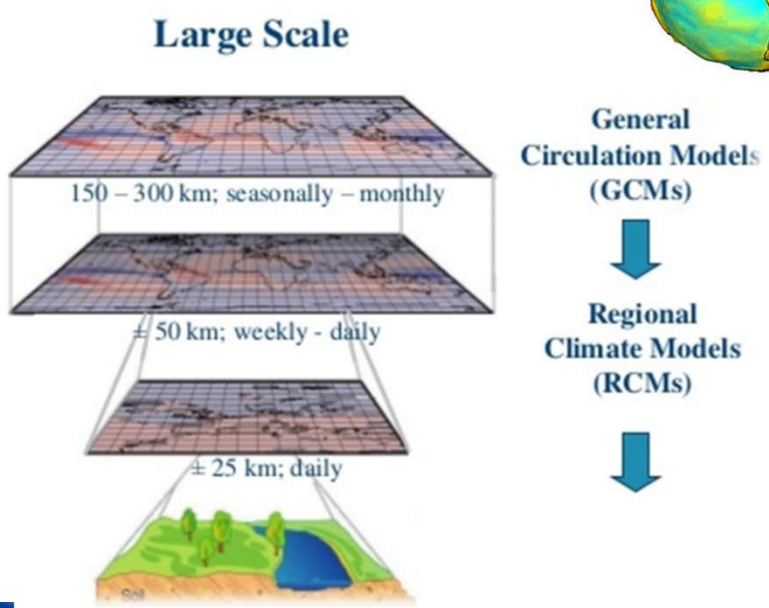
5. LCA Impact Assessment

- Quantify GWP, CED and LCC associated with each scenario

Climate Downscaling

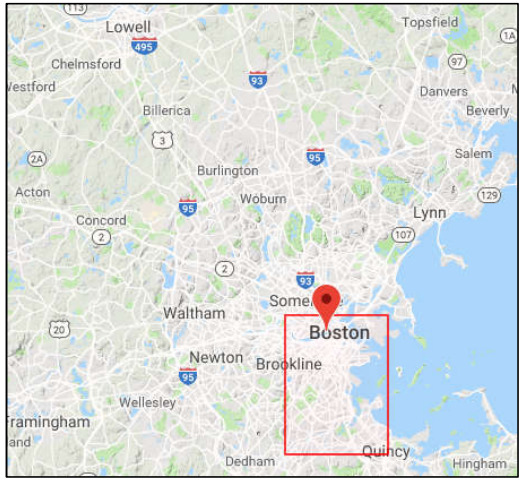
Downscaling *is the general name for a procedure to take information known at large scales to make predictions at local scales.*





Coupled Model Intercomparison Project Phase 5 (CMIP5)

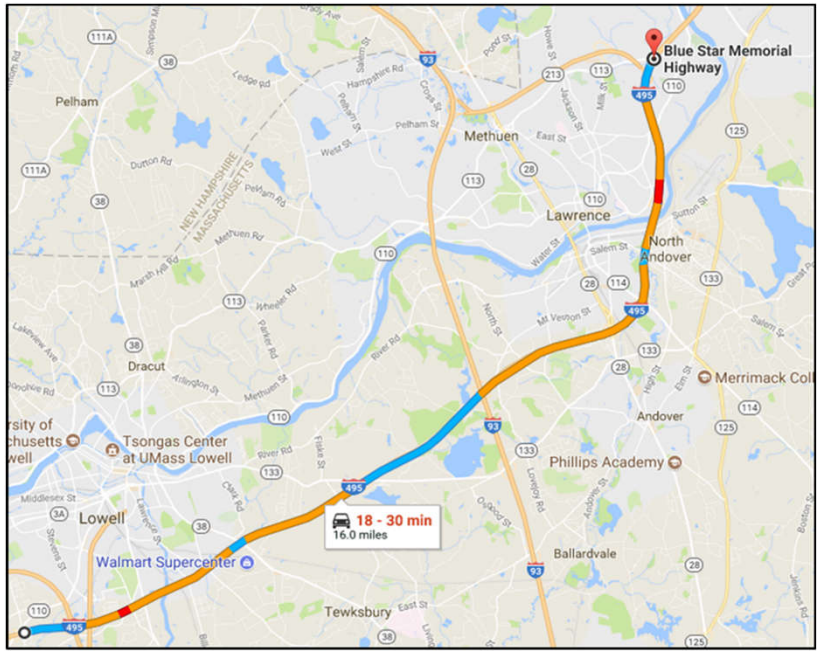
- Variables: Precipitation, Max. and Min. temperature
- Coverage: 1950-2099
- Resolution: Daily
- Resolution: 12km by 12km grid



Operations (Use) Phase of LCA

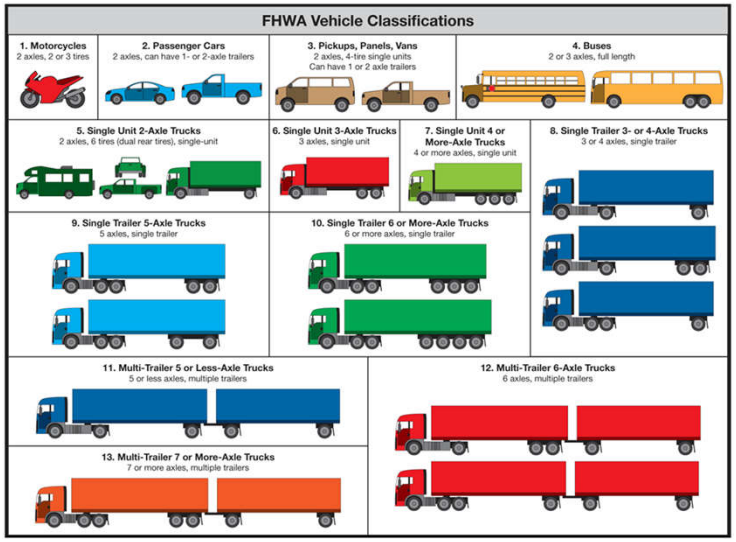
- Two major components briefly discussed here:
  - **Realistic traffic data (RTD) input**
  - Pavement performance and Maintenance & rehabilitation alternatives

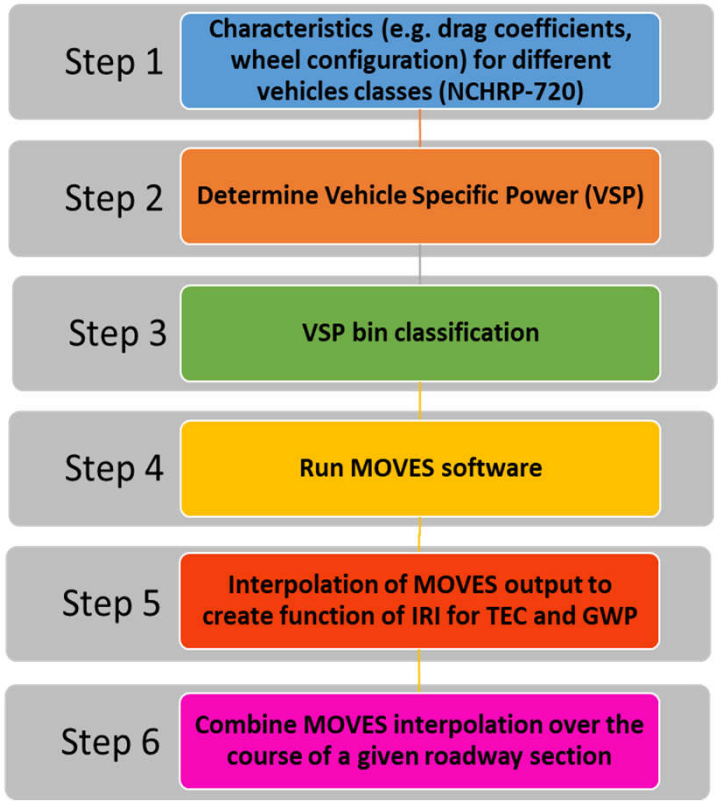
Source: Boston Globe



Realistic Traffic Data

- Google Maps → Daily hourly patterns
- Simulate realistic driving conditions (SHRP2 NDS)
- EPA Motor Emissions Vehicle Simulator
- MassDOT Transportation Data Management System → Hourly Vehicle Class Volumes





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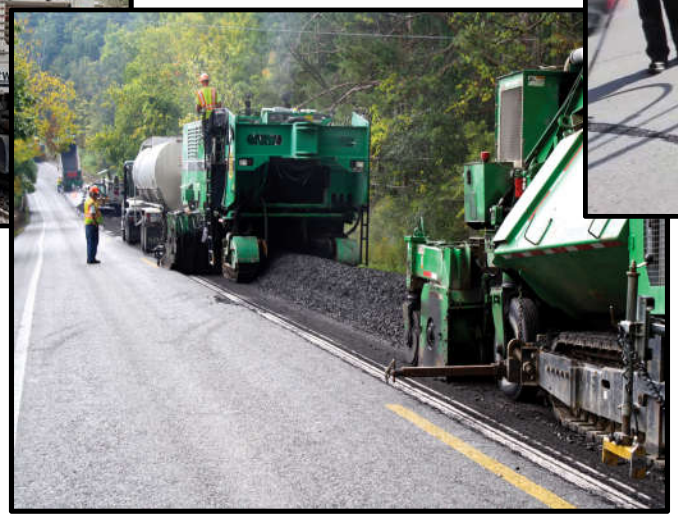
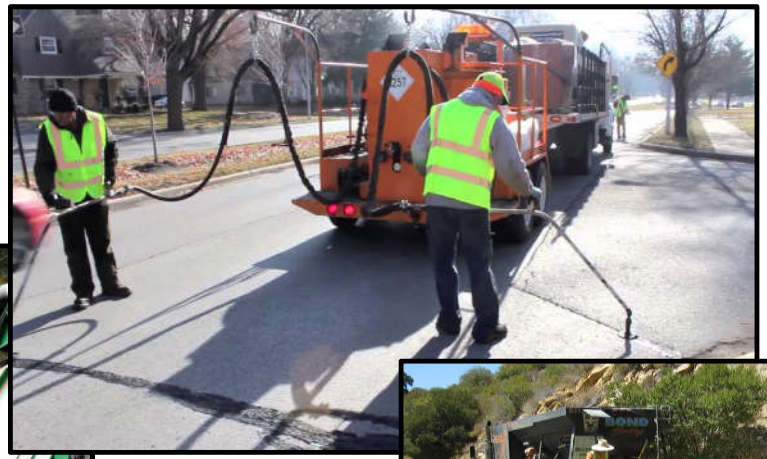
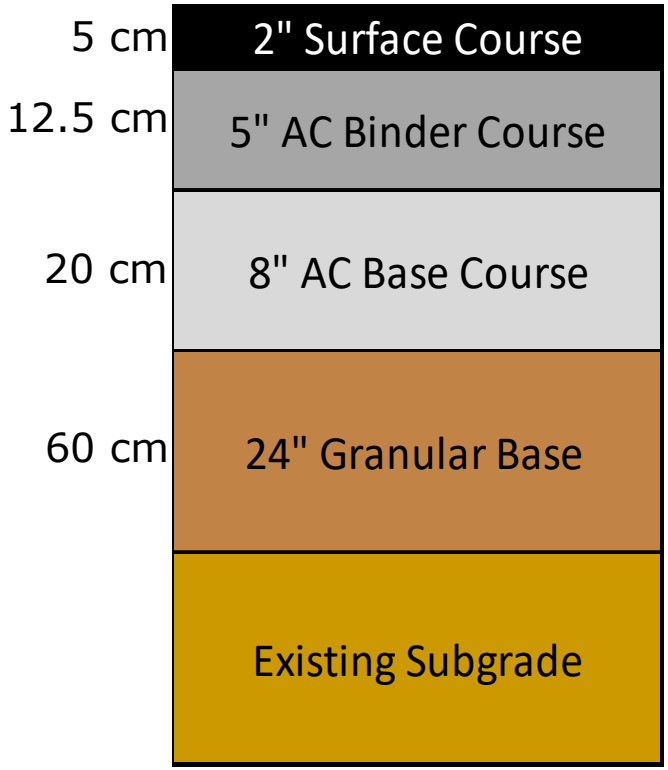




Pavement Performance and M&R Alternatives (1/2)

- Evaluate 5 different cross sections with varying material characteristics
  - Surface Courses
    - *Binder: PG58-28, PG64-28, PG70-34(PMA)*
    - *Air void (%): 3 - 6.2*
    - *AC (%): 5.4 – 7.8*
  - Base and Subgrade
    - *Granular Base: A-2-4*
    - *Subgrade: A-2-6*



Pavement Performance and M&R Alternatives (2/2)

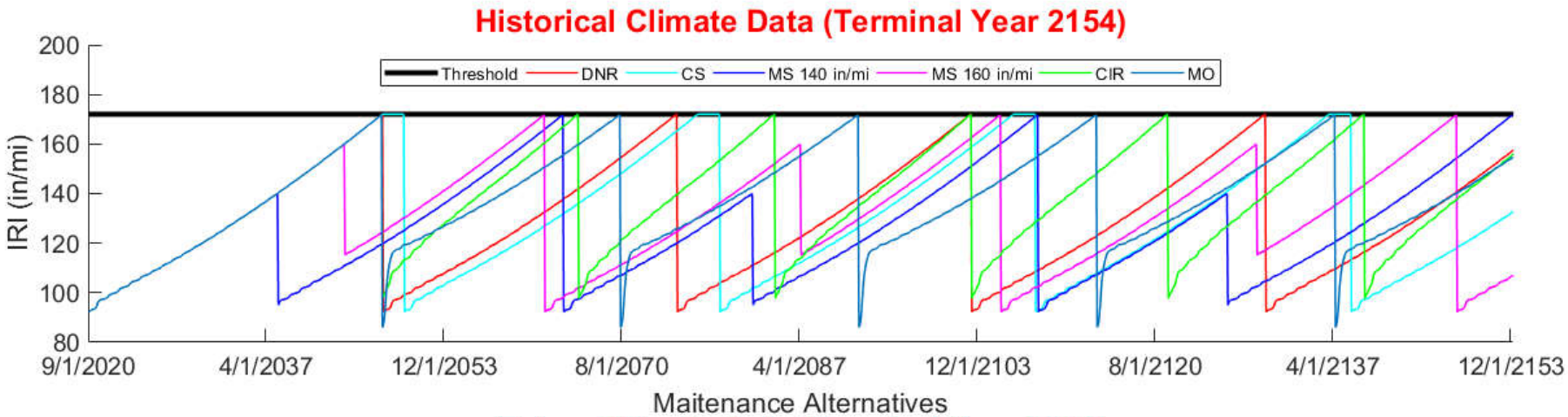
- Pavement performance simulated for 6 M&R (simplistic) scenarios:
  - Do Nothing Reconstruct (DNR)
  - Crack Sealant (CS)
  - Microsurfacing (MS 2.2 m/km or 140 in/mi)
  - Microsurfacing (MS 2.5 m/km or 160 in/mi)
  - Cold-In-Place Recycling (CIR)
  - Mill & Overlay (MO)
- Initial IRI = 1 m/km (63 in/mi)
- Terminal IRI = 2.7 m/km (172 in/mi)
- Minimum of maintenance 3 cycles

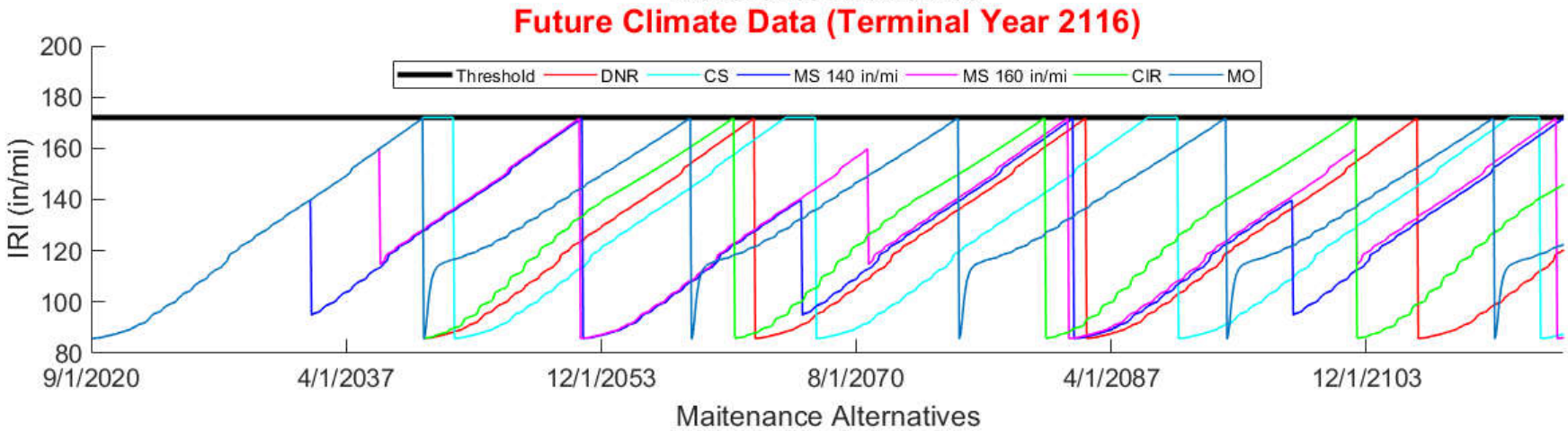
AASHTOWare Pavement ME Design

Literature Sources:

- ✓ *Cole et al., 2016*
- ✓ *Gary Fitts, 2003*
- ✓ *Harikrishnan Nair et al., 2015*
- ✓ *Lane et al., 2005*
- ✓ *Mousa et al., 2018*
- ✓ *Stephen Damp, 2008*
- ✓ *…others*

Pavement Performance: IRI vs Time





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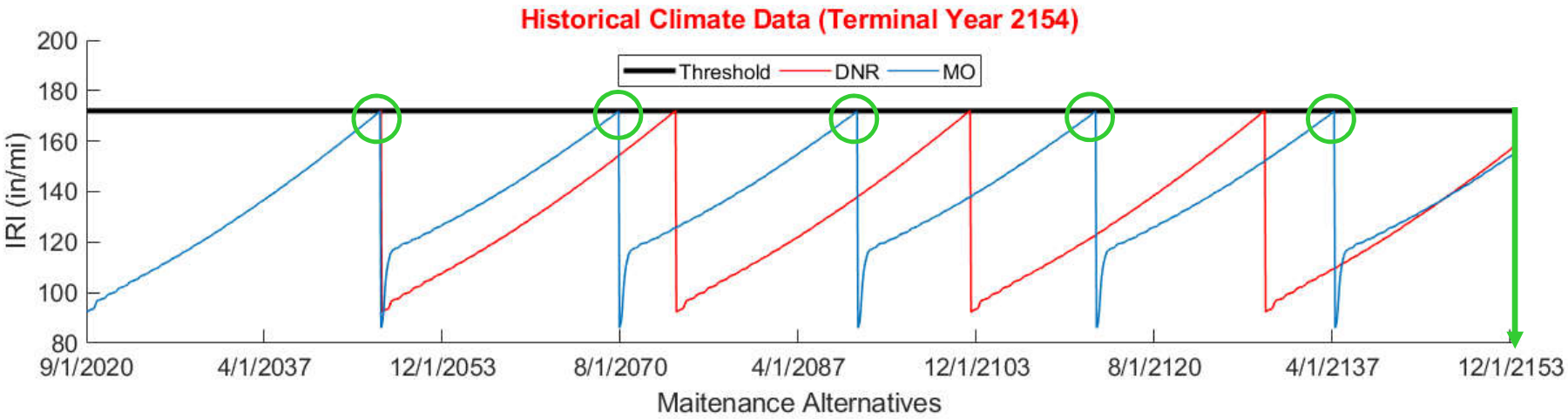
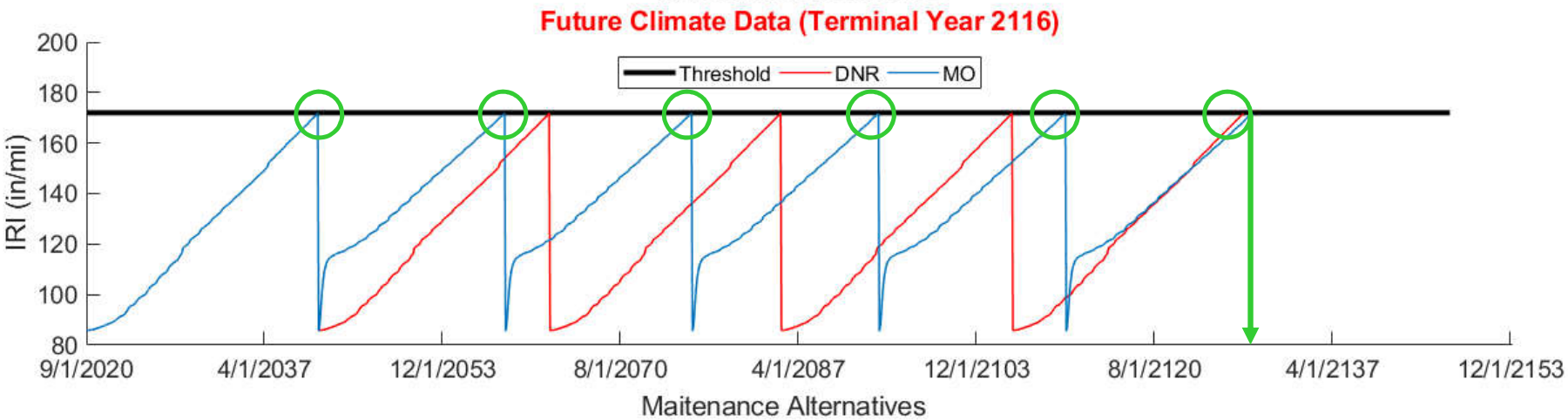
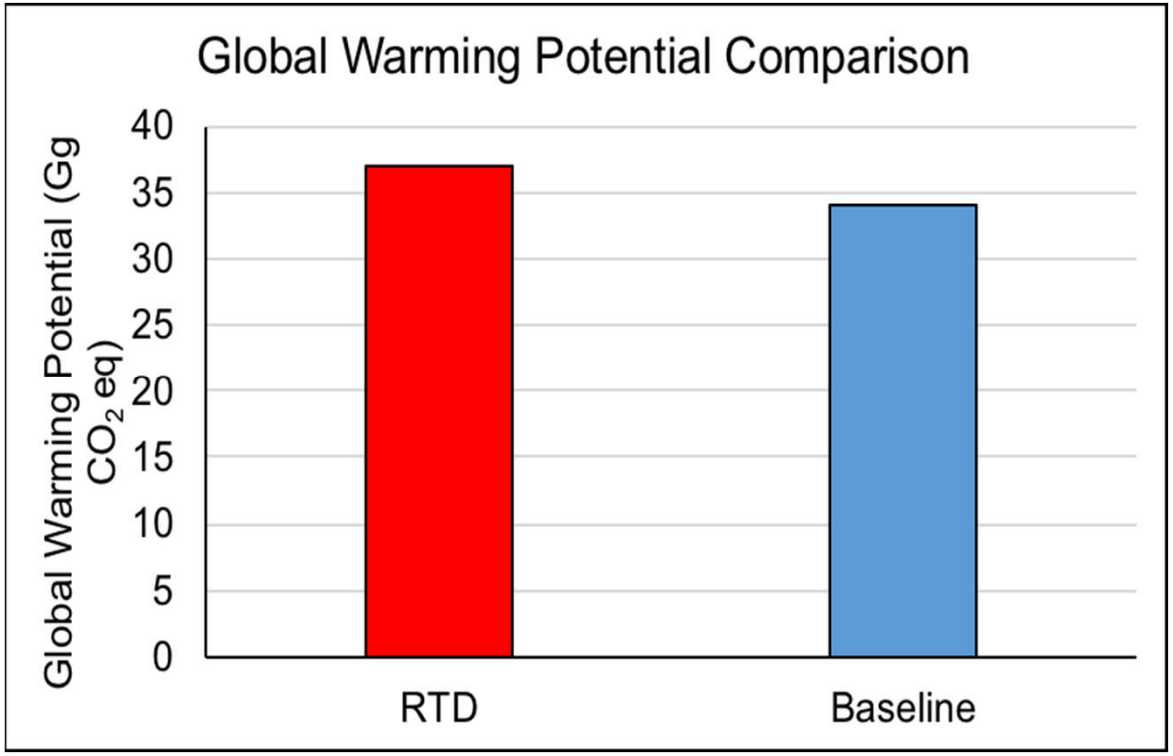




Results: Inclusion of RTD

- **6.4% increase** in GWP and CED with the inclusion of RTD



Results: M&R Cost Comparison

Net Present Value (Historical Climate Data)

Cross Section	Maintenance Alternative (in millions of $)					
	DNR	CS	MS (IRI =140)	MS (IRI =160)	CIR	MO
1	**$232**	**$219**	**$187**	**$191**	**$158**	**$157**
2	$231	$219	$187	$156	$158	$157
3	**$232**	**$224**	**$187**	**$191**	**$158**	**$157**
4	$267	$252	$219	$199	$159	
5	$299	$277	$253	$215	$160	

Most Economical **Least Economical**

Net Present Value (Future Climate Data)

Cross Section	Maintenance Alternative (in millions of $)					
	DNR	CS	MS (IRI =140)	MS (IRI =160)	CIR	MO
1	**$264**	**$252**	**$212**	**$212**	**$158**	**$157**
3	**$269**	**$256**	**$218**	**$212**	**$158**	**$157**

Average percent difference from MO alternative (most economical):

- CIR = 0.678 %
- MS 160 = 13.1 %
- MS 140 = 17.5 %
- CS = 33.7 %
- DNR = 38.3 %

With Future Climate Data

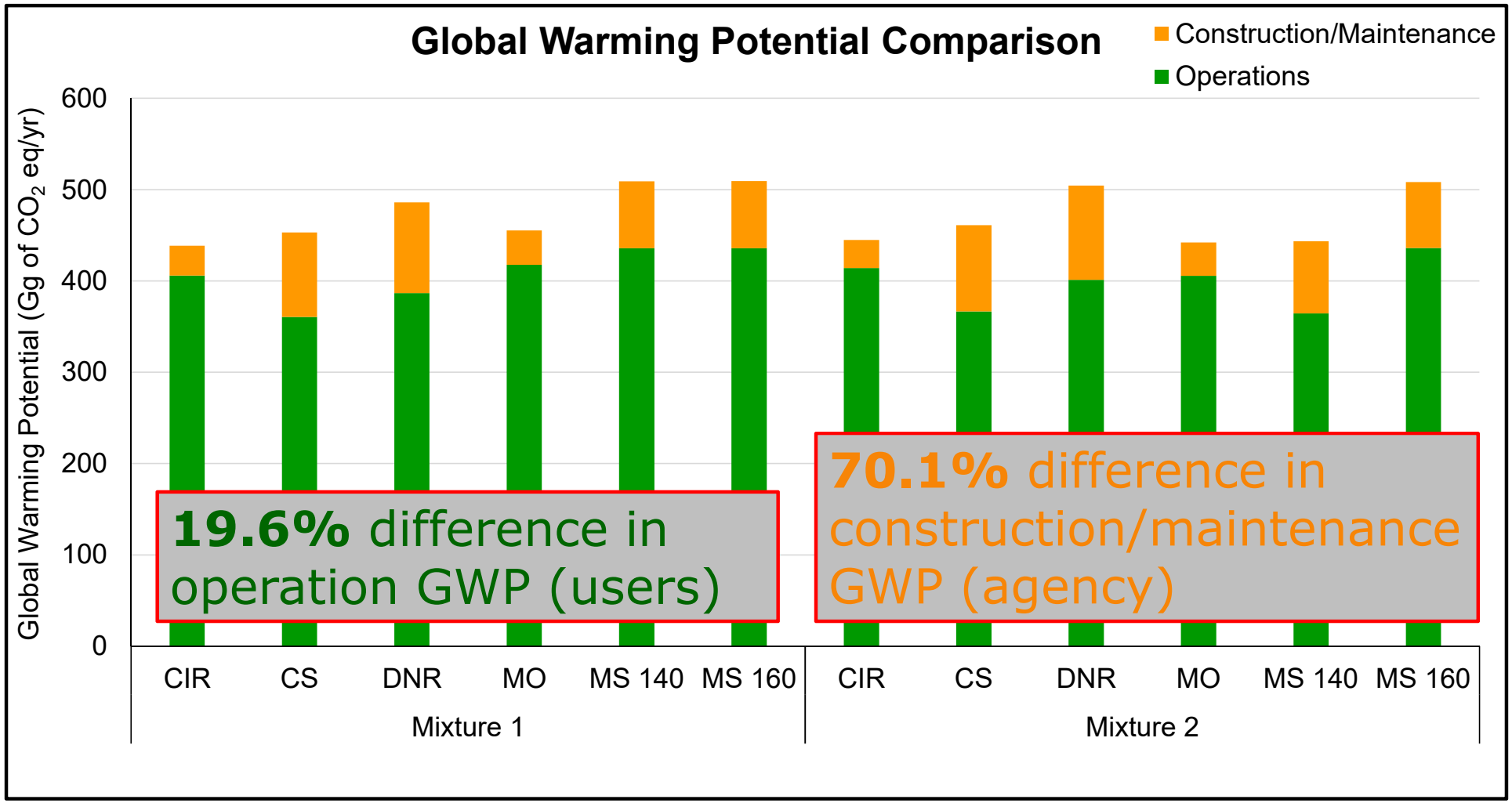
- CIR = 0.683 %
- MS 160 = 29.6 %
- MS 140 = 31.0 %
- CS = 47.0 %
- DNR = 51.7 %

M&R Cost Comparison

- The **average percent increase** in NPV **using future climate** data to historical data with respect to the most economical M&R strategy (Mill and Overlay):
  - *CIR = 0.79%*
  - *MS 160 = 77.5%*
  - *MS 140 = 55.6 %*
  - *CS = 33.0%*
  - *DNR = 29.7 %*

➢ For this highway (and assumptions made in the analysis) MO or CIR may be more economically resilient M&R strategy in terms of costs in future climate conditions.

LCA Results with Future Climate



Conclusions and Summary

- Use phase should not be ignored!
- Inclusion of RTD is critical in LCA with user impacts and costs (in this case study there was **6.4% increase GWP and CED)**
- Incorporating future climate data into methodology results in decreased service life of pavement structures in North Eastern US.
  - Results in up to **8% increase (users) and 38% increase (agency)** impacts of GWP and CED using future climate data.
- In general, the **ranking of M&R** alternatives remains **constant** but the **margin of difference in NPV costs increased** among different M&R scenarios.
- Optimization of pavement structure, M&R type and timing has different impacts for agencies and users.

Future Work

- Explore more M&R strategies and a combination of strategies over the service life the roadway.
  - Pavement LCA Symposium 2020 paper
- Investigate the effect of future climate on the effectiveness of M&R strategies on field performance (IRI)
- Perform LCA using a probabilistic approach rather than a deterministic approach, esp. for future climate projections
- Improve operational impact component of LCA (for example, recent works at University of Nevada Reno and University of Nottingham)

Publications

1. Qiao, Y., Dave, D., Parry, T., Valle, O., Mi, L., Ni, G., Yuan, Z., and Zhu, Y., 2019. Life Cycle Costs Analysis of Reclaimed Asphalt Pavement (RAP) Under Future Climate. Sustainability 2019, 11(19), 5414; https://doi.org/10.3390/su11195414.
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Thank you for your attention!

- Acknowledgements
  - Minnesota Department of Transportation
  - UNH Center for Infrastructure Resilience to Climate
  - UNH Materials Research Group