ILLINOIS

Life-Cycle based Pavement Friction Management and Treatment Selection for IDOT and Local Roadways

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  - John Senger (chair)
  - Katherine Beckett
  - Doug Keirn
  - Michael Short
  - Dylan Specht
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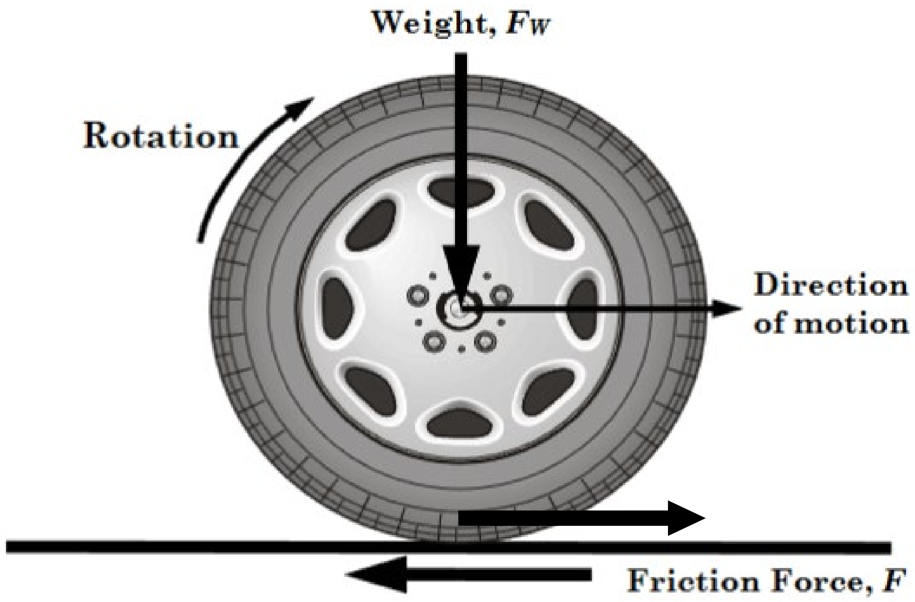
  - William Warfel

- **References**

- Hu et al. (2025). *Systematic Approach to Illinois' Pavement Friction Management*.
  - Accepted for presentation at the Transportation Research Board Annual Meeting (TRBAM 2026);
  - Presented at the AASHTO Safety Summit 2025.
- Hu et al. (2024). *Network-Level Pavement Management Based on Safety Evaluation and Friction Demand Analysis: An Illinois Case Study*.
  - Presented at the Transportation Research Board Annual Meeting (TRBAM 2025);
  - Presented at the 9th Road Safety and Simulation (RSS25); and
  - Presented at the AASHTO Safety Summit 2024.

INTRODUCTION

- Pavement friction force resists the relative motion between a vehicle tire and a pavement surface.
  - Allows drivers to control their vehicles in a safe manner both longitudinally and laterally.
  - A key input in highway geometric design, influencing stopping sight distance, curve design, and speed selections.
- The amount of friction needed on roadways varies greatly across the network: site geometrics; traffic condition; vehicle characteristics…



Adequate friction is critical for safe vehicle maneuvering, particularly on curves, ramps, intersections, and during emergency braking.

November 29, 2025

CBS News
3 days ago

Saturday was snowiest November day on record in Chicago: 8.4 inches at O'Hare - CBS Chicago

Facebook
5 days ago

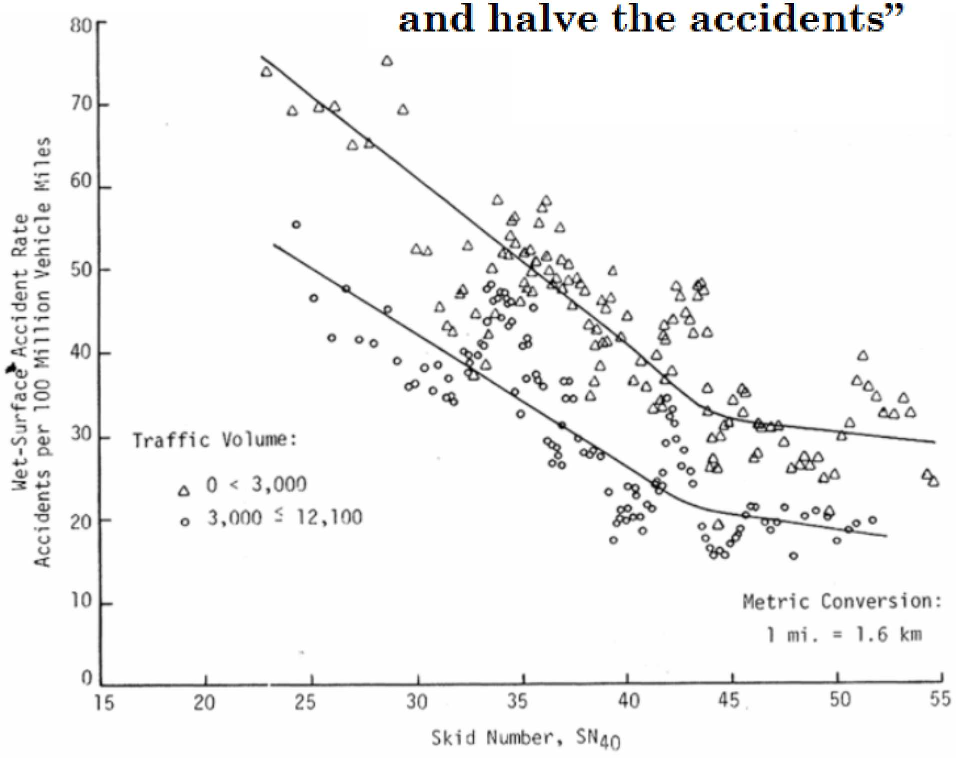
On November 29, 2025, a massive 45-vehicle pileup occurred on I-70 near Terre Haute, Indiana, caused by a sudden heavy snow squall that slashed...

INTRODUCTION

- Many factors influence crashes, but empirical research consistently shows that wet-weather crashes increase sharply as pavement friction decreases (Schulze et al., 1976; Viner et al., 2004).
- Crash risk rises significantly when friction falls below critical intervention levels (Kuttesch, 2004).
- Friction directly affects hydroplaning speed — a key factor in preventing wet-weather skidding.

Maintaining adequate friction is essential for reducing wet-weather and curve-related crash frequency and severity.

“Double the skid resistance and halve the accidents”



Source: Rizenbergs et al., 1973

INTRODUCTION

- FHWA recommends Pavement Friction Management (PFM) to obtain systemwide insights into friction-related safety and pavement management.
- It is important to link pavement friction to traffic safety and help prioritize treatment decisions.
- However, friction–safety relationships vary greatly across region, climate and operational conditions.

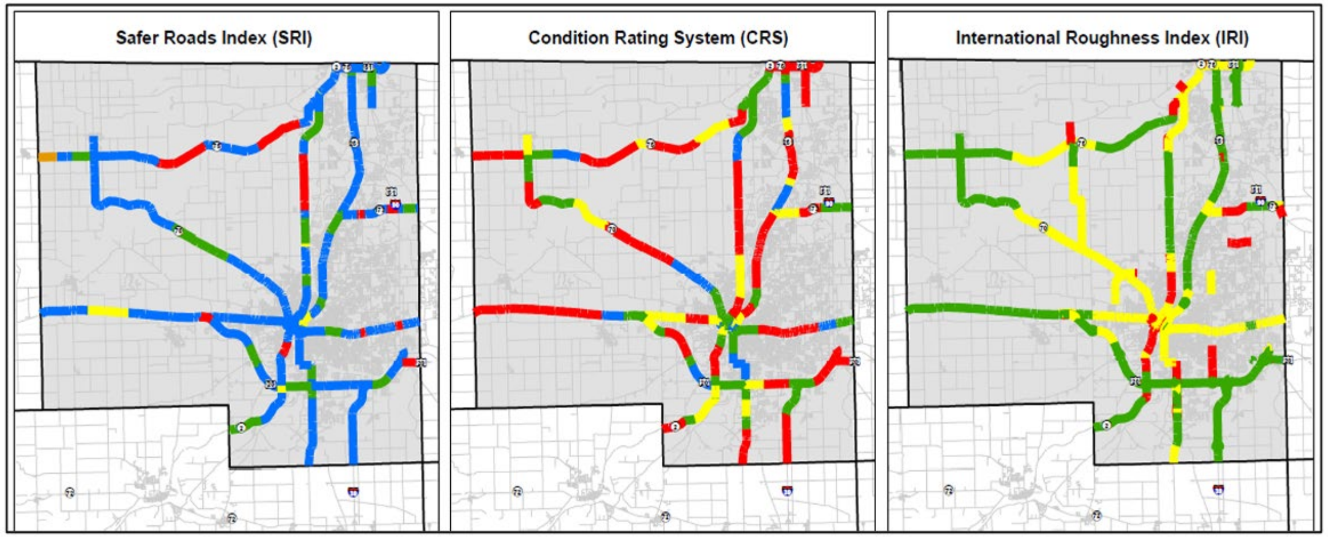
Many states currently lack a systemic PFM program tailored to its own safety conditions and asset management needs.

U.S. Department of Transportation Federal Highway Administration

Pavement Friction Management

INTRODUCTION

- IDOT and many agencies have made progressive efforts on driving traffic-related fatalities and severe injuries towards zero:
  - Illinois statewide SPFs and CMFs
  - Safety Tiers and Safer Roads Index (SRI)
  - IDOT HSM tools
  - Economic analysis programs.
- Traditionally, friction treatments are selected based on pavement conditions, material availability etc., without considering safety benefits.
- Opportunity to develop a systemic program for pavement friction measurement, analysis, and treatment selection, that is well-integrated into pavement asset management.



IDOT, Illinois Improves Transportation Decision Making Through Safer Roads Index (SRI) Ratings and Safety Tiers

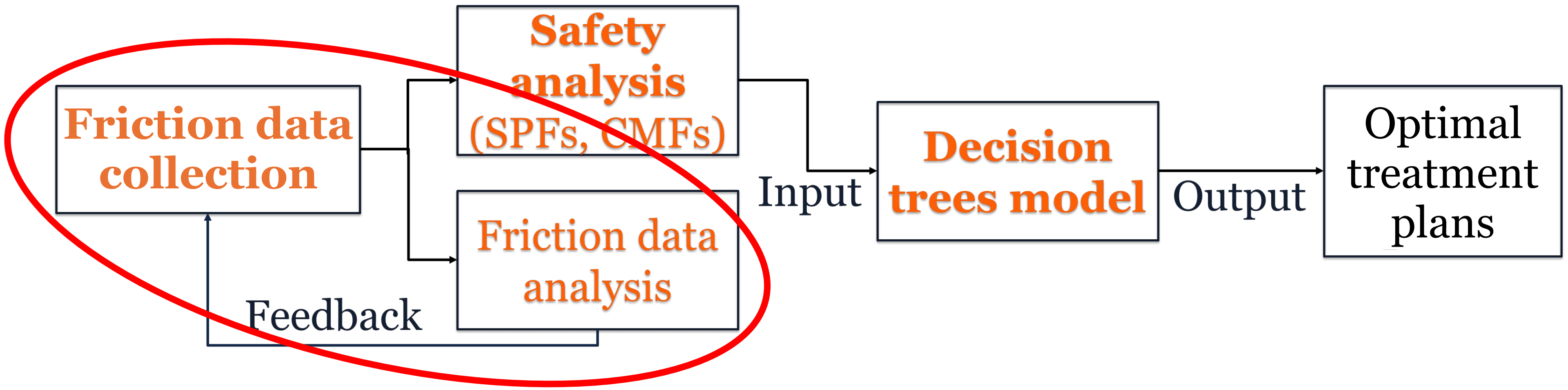
2015 FIVE PERCENT Report: Segment Safety Tiers

Peer Group	Tier	Max. PSI	K+A	Σ K+A	Σ K+A %	Tier Mileage	Tier Mileage %	Σ Mileage	Σ Mileage %
1: Rural 2-Lane	5%	70.0	748	748	25.9%	422	5.1%	422	5.1%
	High	40.5	128	876	30.3%	431	5.2%	853	10.2%
	Medium	14.0	348	1,224	42.3%	1,281	15.3%	2,134	25.5%
4: Rural Freeway 4 Lanes	5%	54.0	457	457	15.8%	76	5.1%	76	5.1%
	High	24.0	221	678	23.4%	73	4.9%	149	10.1%
	Medium	16.0	111	789	27.3%	224	15.2%	373	25.2%

FHWA, Highway Safety Improvement Program (HSIP) National Scan Tour

OBJECTIVES

- To develop a comprehensive, systemic, network-level pavement friction management program that supports safer and smoother travel in Illinois, which systematically:
  i. Evaluates current IDOT friction data collection methods, policies and status;
  ii. Performs friction-related data and safety analysis;
  iii. Develops decision tree models for network-level site screening and life-cycle cost analysis, recommending site-specific investigatory thresholds and treatments.
  iv. Guides treatment decisions that enhance both safety and state-of-good-repair.



Challenge 1 - Measurement

- Skid number (SN) is the typical measurement of pavement friction.
  - SN is currently measured Illinois using a lock-wheeled skid trailer (LWST)
  - The Sideway-force Coefficient Routine Investigation Machine (SCRIM) is used to conduct network-level CPFM in several leading states, e.g., VA, KY, FL, IL
  - 3D laser texture scanning is also common in measuring mean profile depth (MPD) for pavement friction
  - ICT Project R27-247 develops a new friction device for IDOT to collect continuous texture data based on computer vision
  - A recent USDOT-UTC project develops a crowdsourced friction data collection framework using instrumented sensors in connected and autonomous vehicles
- Safety models should be calibrated to be consistent with measurement method.


IDOT's locked wheel skid trailer

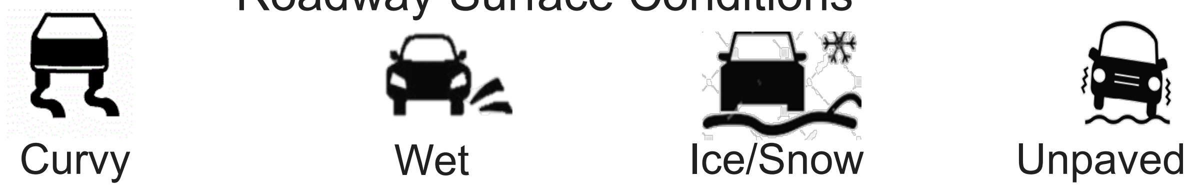
SCRIM truck

ILLINOIS CENTER FOR TRANSPORTATION
CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION
(Joint work ICT + UW Madison)

Challenge 1 - Measurement

- Crowd-sourced measurement

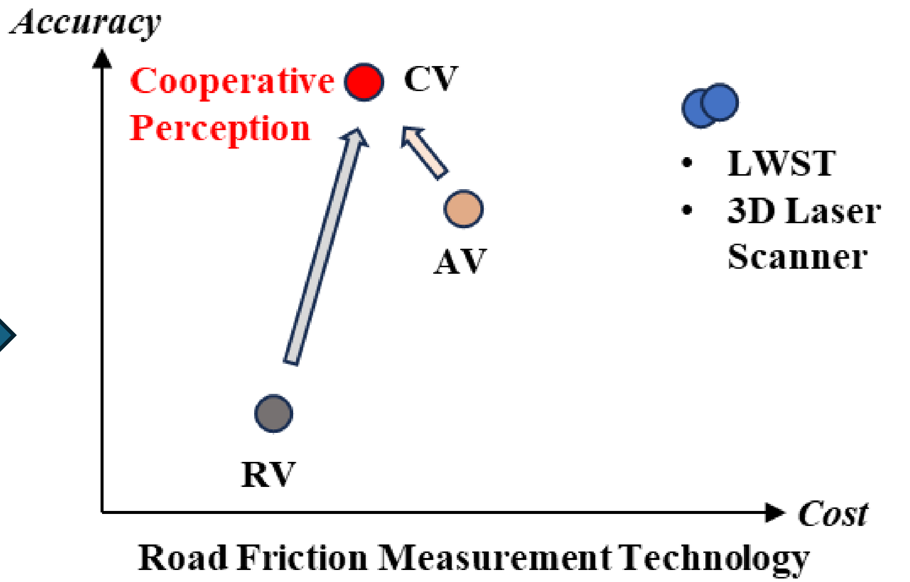
Roadway Surface Conditions

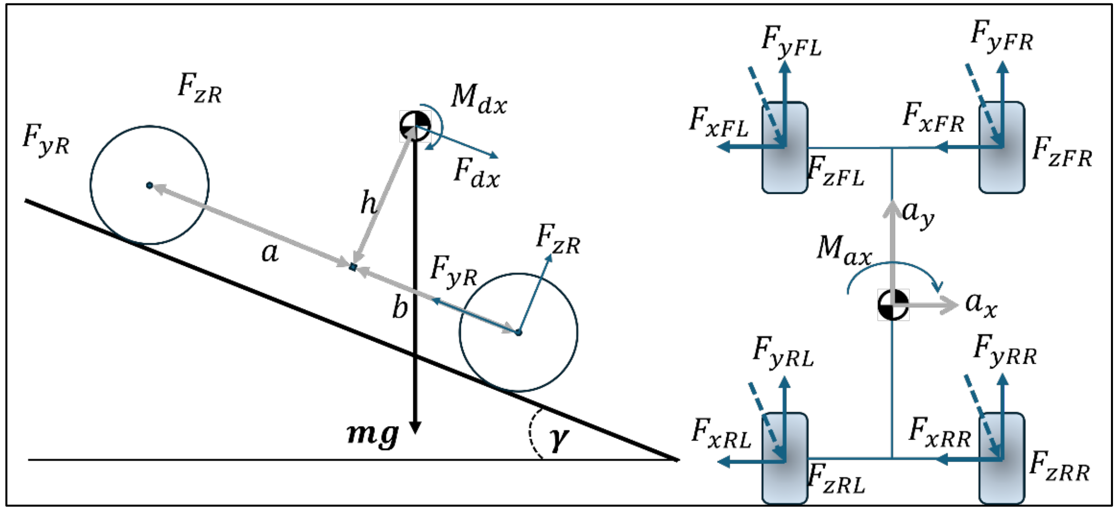


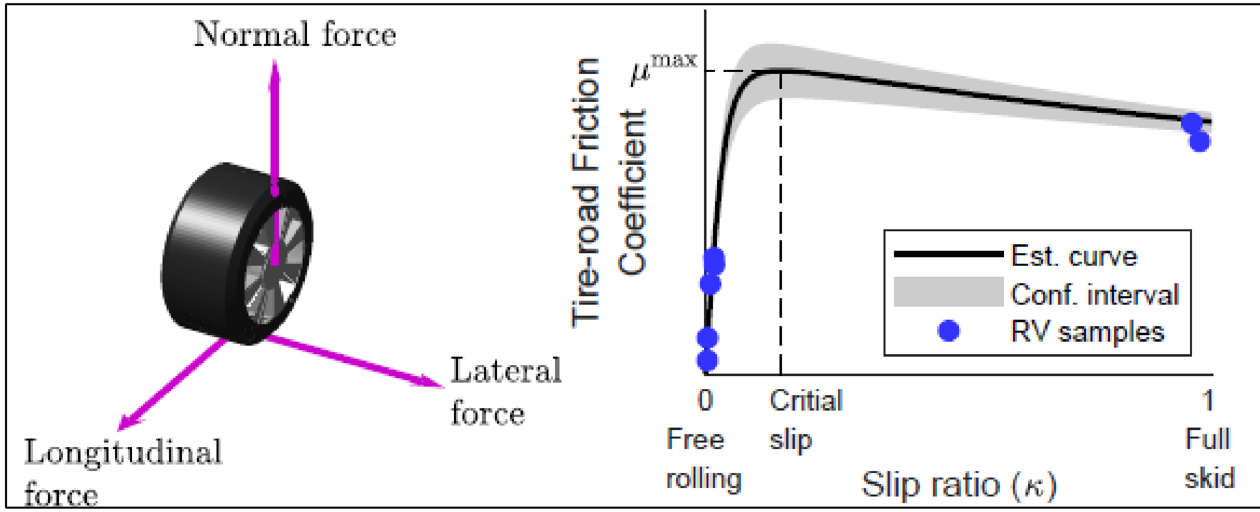
Data Collection Instrument

Regular Vehicle Telematics

Autonomous Vehicle On-Board Data







Challenge 1 - Measurement

- Illinois friction data are collected with LWST in the past
  - The correlation between LWST vs. SCRIM data is not well established.
  - Cannot consistently relate friction to crash and compare them with those of peer states without a reliable mapping.
- Use Illinois data to calibrate and validate FHWA conversion formulas
  - SCRIM standard at 30 mph (SR30) vs. LWST standard at 40 mph with ribbed (FN40R) or smooth (FN40S) tires.

$$FN40S = SR30 \cdot e^{\frac{s_{\text{SCRIM}} - s_{\text{LWST}}}{s_p}}$$

$$FN40R = 0.87 \cdot SR30 - 1.5$$

$s_p = a + b \cdot MPD,$ where

ASTM constants a = 14.2 and b = 89.7;

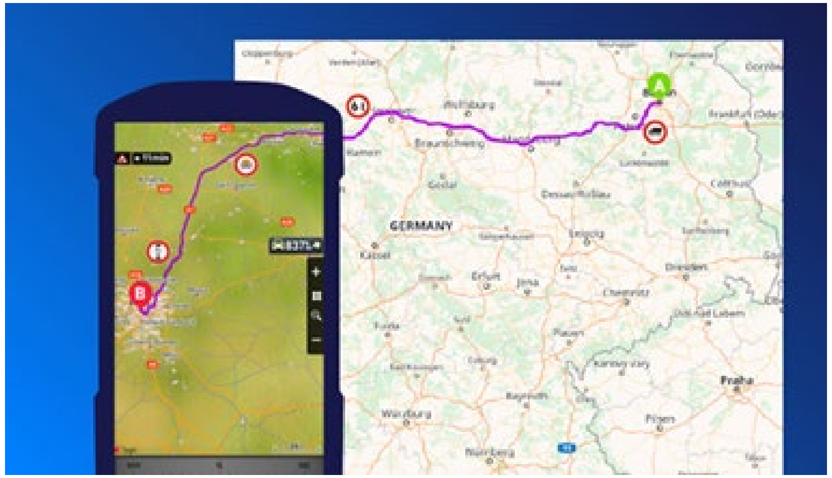
MPD = macrotexture mean profile depth (mm)

$s_{\text{SCRIM}} = 0.34 \times$SCRIM testing speed (km/h)

$s_{\text{LWST}} =$ LWST testing speed (km/h)

Sources: FHWA (2019). Locked-Wheel and Sideway-Force CFME Friction Testing Equipment Comparison and Evaluation Report. Federal Highway Administration.

Challenge 1 - Measurement



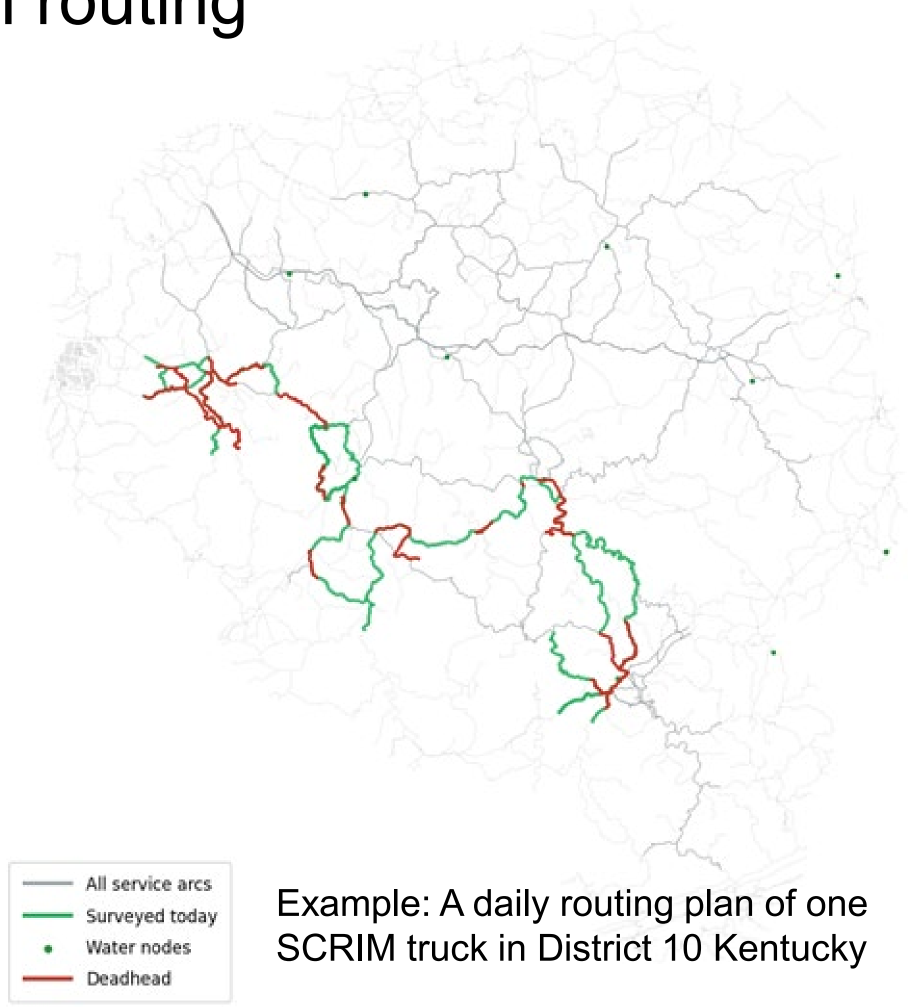
- Current network-level CPFM is costly, time-consuming, and usually not very efficient.
  - High purchase cost of SCRIM trucks
  - High operating cost for driver salary, wear-and-tear, and vehicle depreciation
  - Extensive wasted distance/time for network deadheading and water refills
  - Periodic stops for data processing and storage
  - Driver work hour limits, possible traffic delay

How to design a strategic plan to route the SCRIM trucks to survey all the planned routes with minimum deadheading time and distance.

<table>
<tr><td rowspan="2"></td><td colspan="2">District 1</td></tr>
<tr><td>Truck 1</td><td>Truck 2</td></tr>
<tr><td rowspan="3">Day 1 Morning</td><td rowspan="2">Route 1</td><td>Route 4</td></tr>
<tr><td>Route 5</td></tr>
<tr><td>Refill</td><td>Route 6</td></tr>
<tr><td rowspan="4">Day 1 Afternoon</td><td>Route 2</td><td rowspan="2">Route 7</td></tr>
<tr><td>Break</td></tr>
<tr><td rowspan="2">Route 3</td><td>Refill</td></tr>
<tr><td>Overnight</td></tr>
</table>

Challenge 1 - Measurement

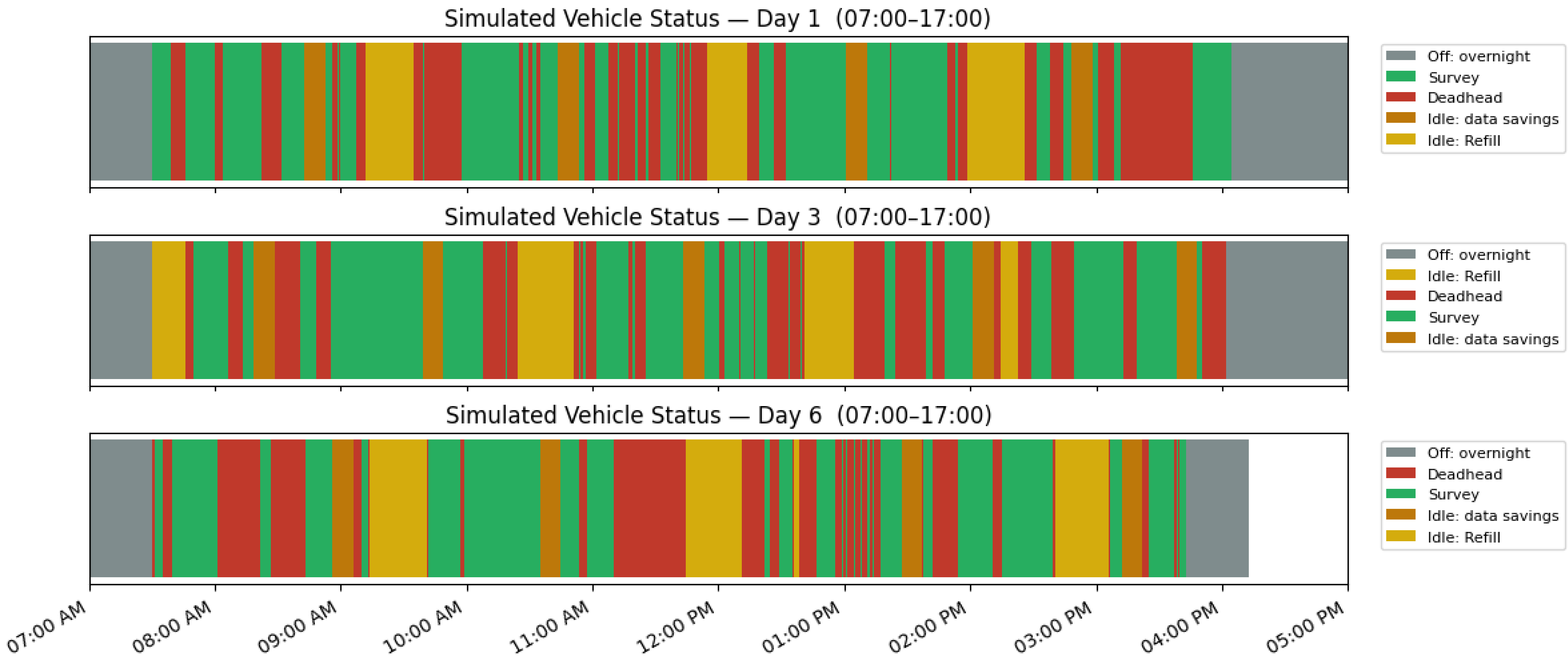
- Customized algorithm to network-level SCRIM routing
  - ❑ **Greedy Algorithm to generate an initial solution** by mimicking human thinking process
  - ❑ **Destroy and Repair (DR) meta-heuristic to solve routing problem with water refill constraints**
    - Find how trucks should survey the network in sequence to minimize the deadheading travels
    - Determine water tank levels, when and which water station to go
  - ❑ **Dynamic Program (DP) to recover time-related constraints**
    - Satisfy all the other operational & labor requirements: data saving break, overnight parking etc.
    - Minimize the total time needed including travels and breaks



Example: A daily routing plan of one SCRIM truck in District 10 Kentucky

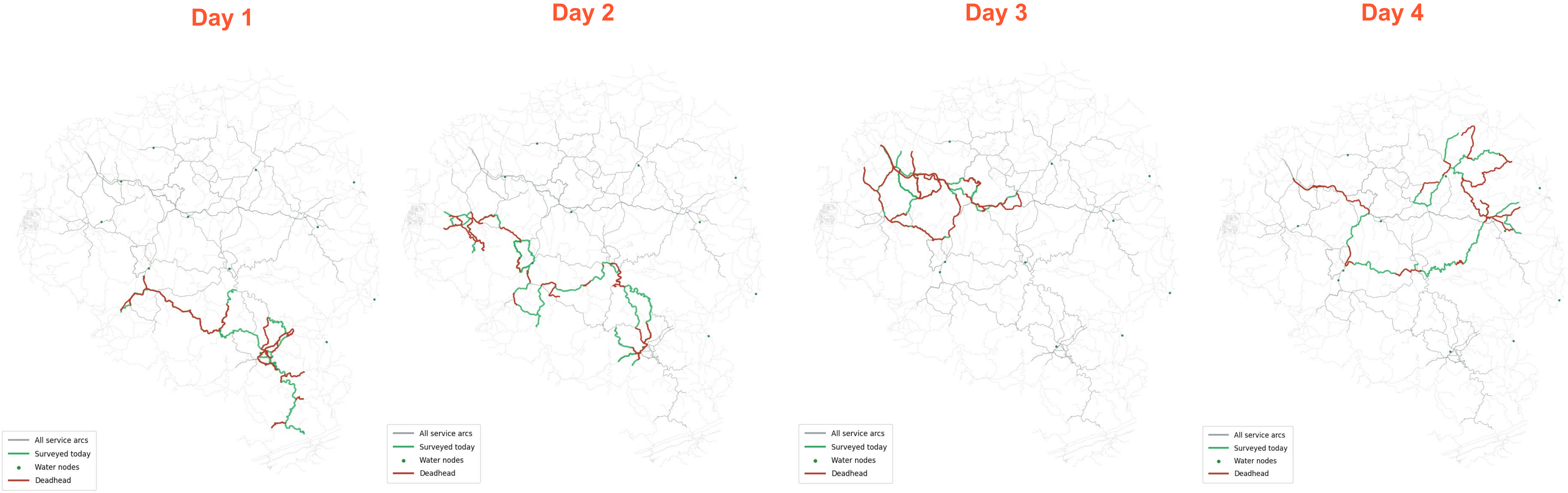
Results

Example of optimized daily trajectory – one small truck for District 10 Kentucky



Results

Example of optimized daily trajectory – one small truck for District 10 Kentucky



Results

Solution comparison

District 10 Results	A leading company's 2024 solution	Small truck		Large truck	
		Greedy solution	DR + DP	Greedy solution	DR + DP
Deadhead (mile | h)	1439.4 | 36.1	1598.4 | 39.9	768.0 | 19.2	1144.0 | 28.6	676 | 16.9
Pure survey (mile | h)	971.8 | 26.0	1116.8 | 23.9	1116.8 | 23.9	1116.8 | 23.9	1116.8 | 23.9
Other: refill, data etc. (h)	21.5	12.9	12.8	12.1	12.6
Total working (mile | h)	2411.1 | 83.7	2715.2 | 76.8	1,884.8 | 55.9	2,260.8 | 64.7	1,792.8 | 53.4
Total # of veh-day	8.8	8.1	5.8	6.8	5.6
% deadhead time saving	-	-	46.80%	-	53.00%
% total time saving	-	-	33.20%	-	36.20%
Est' mileage saving	-	-	671	-	763
Computation time	-	1 sec	1h9min	1 sec	3h34min

Note: Our results are based on the entire planned network with 1116.8 mile, and we enforce 1 hr deadhead to/from hotels everyday, which adds 40 miles of deadhead distance daily.

- Our greedy solution has similar performance as the company's benchmark solution.
- Our optimized solution can reduce 670+ miles of deadheading distance, equivalently, save **about half** of the time spent on deadheading travels for District 10.

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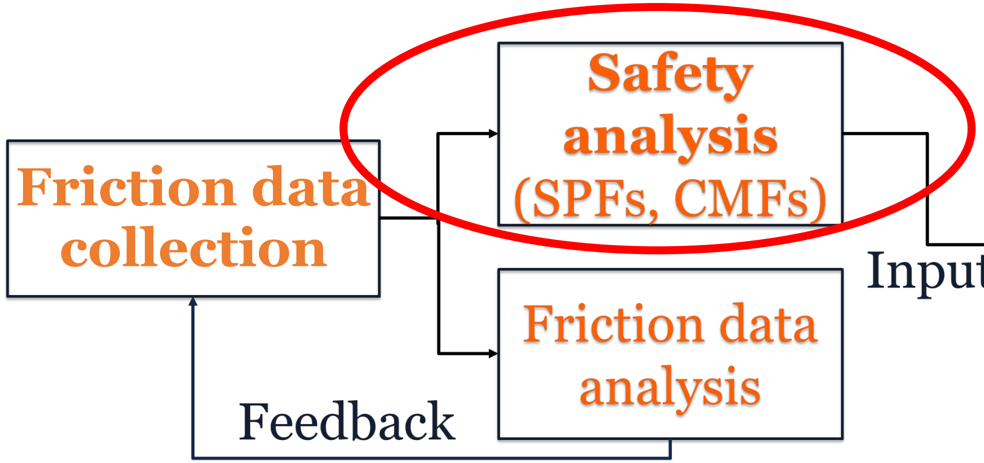


Challenge 2 - Safety Analysis

- Develop statistical models to quantify the impacts of pavements friction on safety

Roadways segment SPFs

$$\text{(expected crashes per year)} = \text{(segment length)} \cdot \alpha_0 \cdot (AADT)^{\alpha_1} \cdot CMF_R(v,R,e) \cdot CMF_{LW}(LW) \cdot CMF_{SW}(SW) \cdot CMF_{SN}(SN)$$

where α_0, α_1 are parameters, and $CMF_R(v,R,e), CMF_{LW}(LW), CMF_{SW}(SW), CMF_{SN}(SN)$ capture the impacts of curvature, lane width, shoulder width, and skid number, such as the following:

$$CMF_R(v,R,e) = 1 + \alpha_2 v^6 / R^2, CMF_{LW}(LW) = \alpha_3 e^{LW-12}, \; CMF_{SW}(SW) = \alpha_4 e^{SW-8}, CMF_{SN}(SN) = \alpha_5 e^{SN-40}.$$

Intersection SPFs

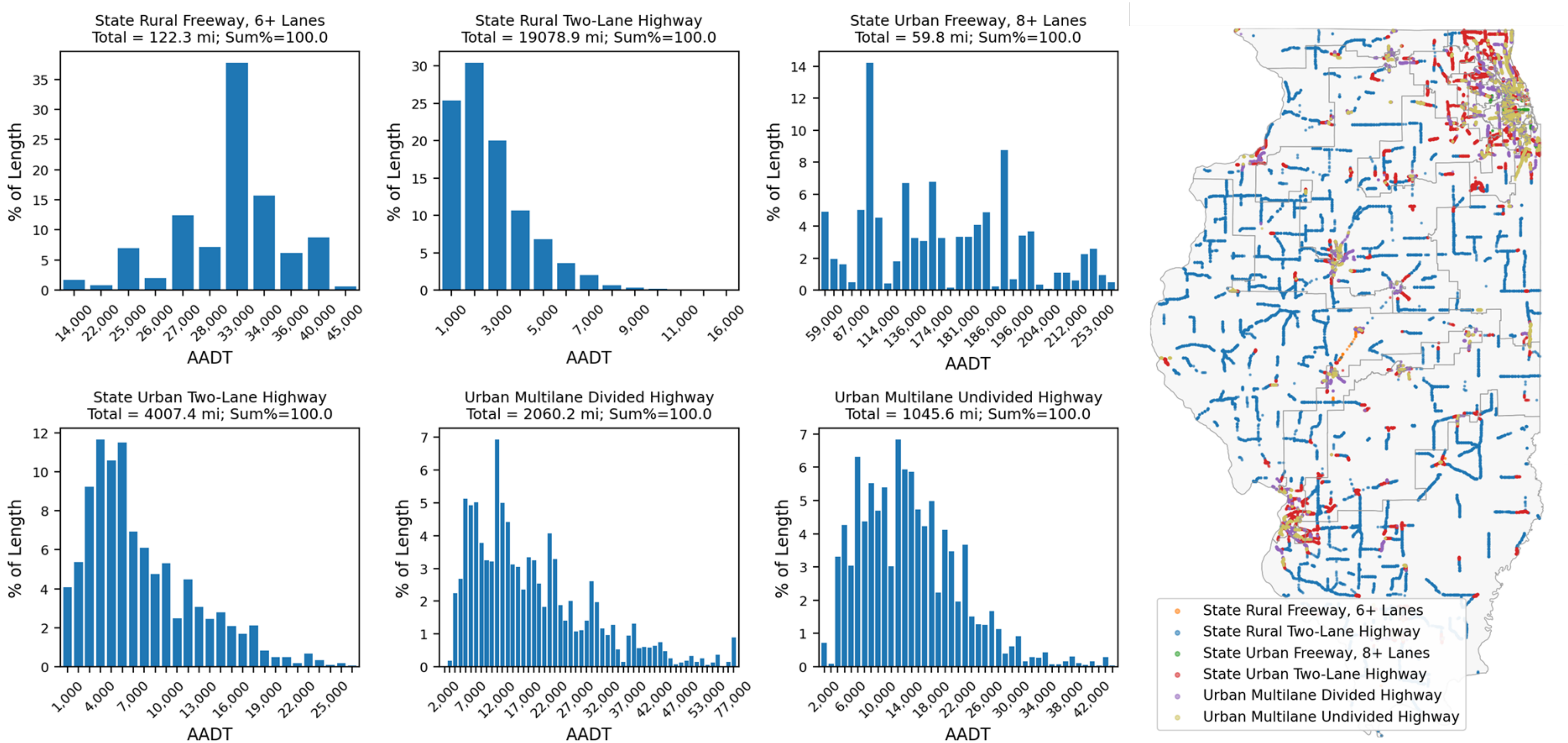
$$\text{(expected crashes per year)} = \alpha_0 \text{ (Major Road AADT)}^{\alpha_1} \text{ (Minor Road AADT)}^{\alpha_2} \cdot CMF_{\text{Control}} \cdot CMF_{LW}(LW_{\text{major}}, LW_{\text{minor}}) \cdot CMF_{SW}(SW_{\text{major}}, SW_{\text{minor}}) \cdot CMF_{SN}(SN)$$

where $\alpha_0, \alpha_1, \alpha_2$ are parameters, and CMF_{Control} captures the impacts of control types.

- A generalized linear model (GLM) assuming a negative binomial error distribution is used in the regression, together with empirical Bayesian (EB) analysis.

Illinois Peer groups

- 12 roadway peer groups and 7 intersection peer groups
  - Urban/Rural Two-Lane Highways
  - Urban/Rural Freeways
  - Urban Multilane Divided/Undivided Highways
  - …
  - Urban/Rural Signalized Intersection
  - Urban/Rural All-Way Stop Control
  - Urban Multilane Minor Leg Stop Control
  - …



Six IL roadway peer groups with friction measurement: Mileage distribution by traffic and spatial representation

Challenge 2 - Safety Analysis

Example: Urban Multilane Minor Stop Control: SPFs & CMFs

```
                     NegativeBinomial Regression Results
==============================================================================
Dep. Variable:            total_crash   No. Observations:                 4232
Model:               NegativeBinomial   Df Residuals:                     4222
Method:                           MLE   Df Model:                            9
Date:                Wed, 05 Feb 2025   Pseudo R-squ.:                 0.03679
Time:                        10:35:41   Log-Likelihood:                -4000.2
converged:                       True   LL-Null:                       -4153.0
Covariance Type:            nonrobust   LLR p-value:                 1.679e-60
================================================================================
                  coef    std err          z      P>|z|      [0.025      0.975]
--------------------------------------------------------------------------------
Intercept     -11.0654      0.790    -14.003      0.000     -12.614      -9.517
lnAADT_major    0.6877      0.061     11.205      0.000       0.567       0.808
lnAADT_minor    0.6710      0.062     10.837      0.000       0.550       0.792
ma_MED_WTH      0.0004      0.005      0.088      0.930      -0.008       0.009
ma_LN_WTH      -0.0298      0.020     -1.523      0.128      -0.068       0.009
ma_O_SHD_1     -0.0227      0.012     -1.896      0.058      -0.046       0.001
mi_MED_WTH      0.0109      0.009      1.253      0.210      -0.006       0.028
mi_LN_WTH       0.0288      0.006      4.556      0.000       0.016       0.041
mi_O_SHD_1     -0.0371      0.019     -1.999      0.046      -0.073      -0.001
Q25_Avg_FN     -0.0122      0.004     -3.395      0.001      -0.019      -0.005
alpha           1.3021      0.092     14.095      0.000       1.121       1.483
================================================================================

===== Additional Info =====
AIC: 8022.360
Alpha: 1.3021
Alpha 95% CI: [1.1211, 1.4832]
Alpha is significant? Yes
```

```
===== CMF CALCULATIONS =====
- Q25_Avg_FN (+10 friction units)
  CMF = exp(-0.0122 ⊠ 10.00) = 0.885
  => Decreases crashes by 11.48%
- lnAADT_major (+1000 AADT (baseline=10000))
  CMF = (1.10)^(0.6877) = 1.068
(From 10000 to 11000 AADT)
  => Increases crashes by 6.77%
- lnAADT_minor (+1000 AADT (baseline=10000))
  CMF = (1.10)^(0.6710) = 1.066
(From 10000 to 11000 AADT)
  => Increases crashes by 6.60%
- ma_MED_WTH (+1 foot)
  CMF = exp(0.0004 ⊠ 1.00) = 1.000
  => Increases crashes by 0.04%
- ma_LN_WTH (+1 foot)
  CMF = exp(-0.0298 ⊠ 1.00) = 0.971
  => Decreases crashes by 2.94%
- ma_O_SHD_1 (+1 foot)
  CMF = exp(-0.0227 ⊠ 1.00) = 0.978
  => Decreases crashes by 2.25%
- mi_MED_WTH (+1 foot)
  CMF = exp(0.0109 ⊠ 1.00) = 1.011
  => Increases crashes by 1.09%
- mi_LN_WTH (+1 foot)
  CMF = exp(0.0288 ⊠ 1.00) = 1.029
  => Increases crashes by 2.92%
- mi_O_SHD_1 (+1 foot)
  CMF = exp(-0.0371 ⊠ 1.00) = 0.964
  => Decreases crashes by 3.64%
```

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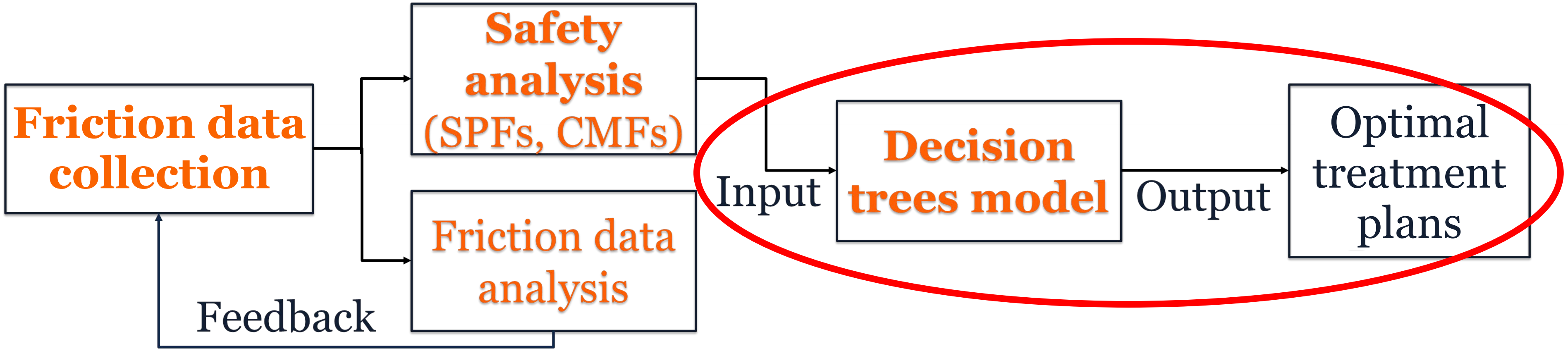
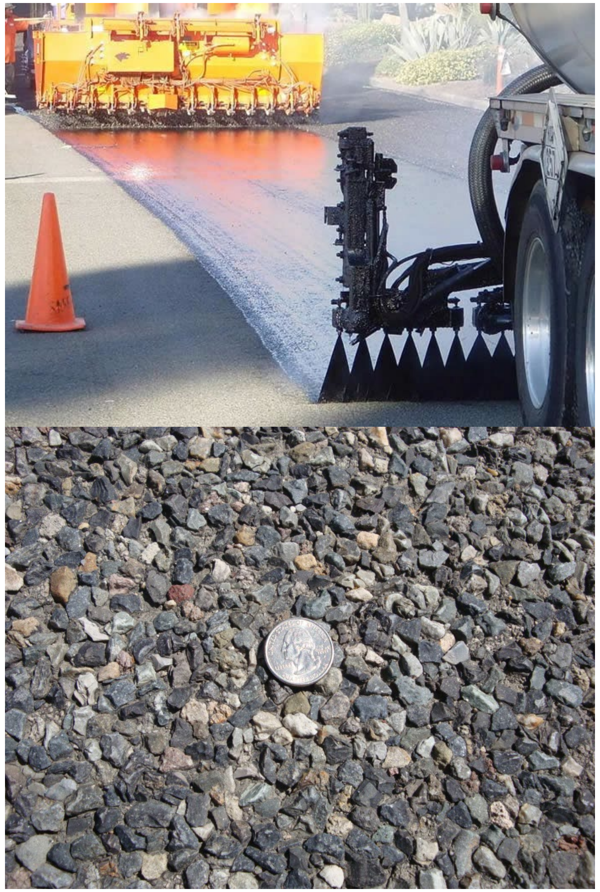


Challenge 3 – Treatment Selection

- Pavement treatments help restore both pavement friction and serviceability performance, and their effectiveness depends on materials, thickness, surface texture, and placement methods.
  - ➢ High-performance treatment (e.g., HMA overlay, UTBWC)
    - Improve ride quality (reduce roughness)
    - Restore adequate friction value
    - Seal and protect underlying pavement structure
    - High construction cost
  - ➢ Friction-oriented treatment (e.g., chip seal, micro-surfacing)
    - Non-structural layers
    - Provide durable wearing surface
    - Only seal minor surface defects
    - Low construction cost

Sources: The Transtec Group, Inc.

HMA overlay

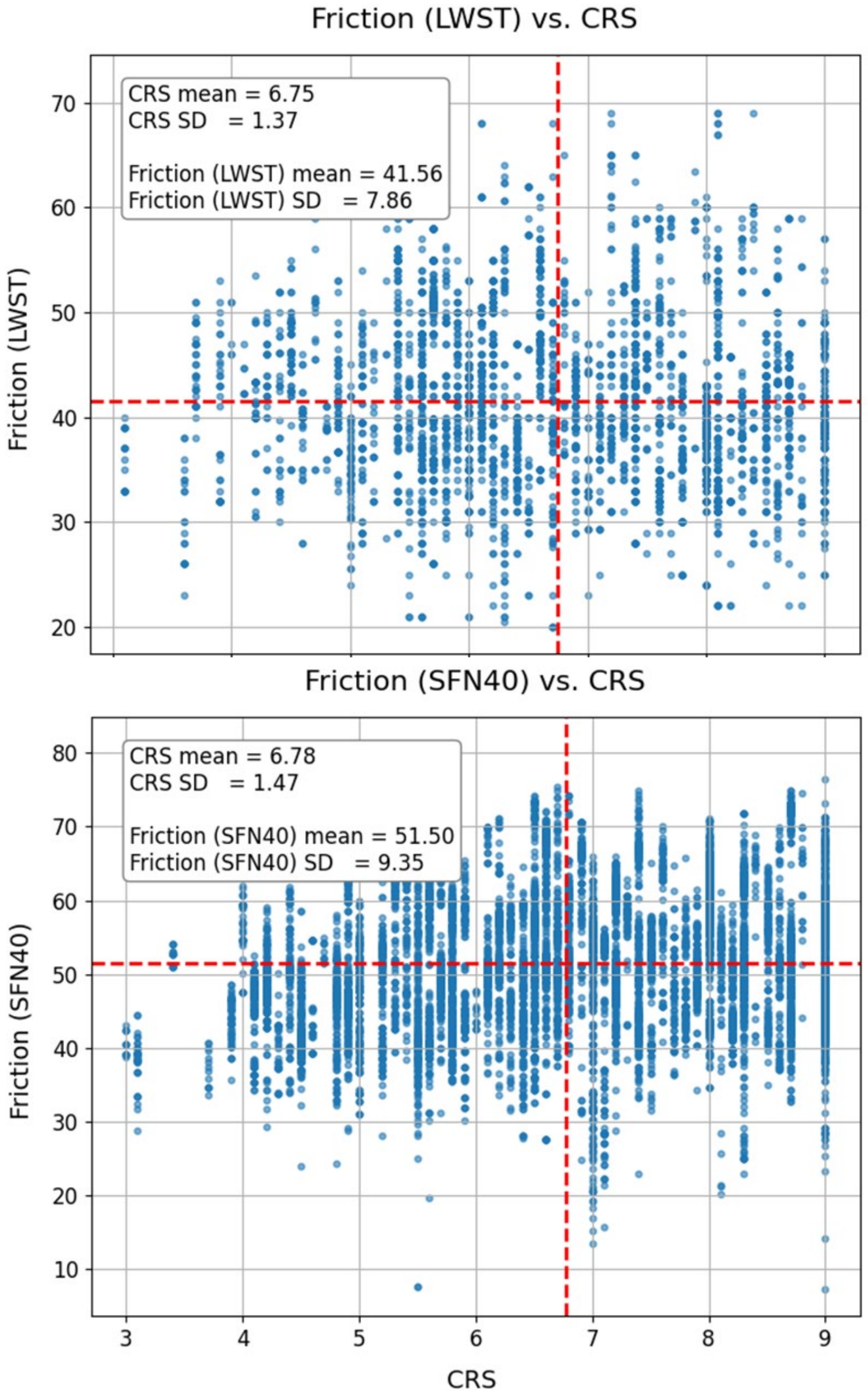


Sources: top: California Chip Seal Association; bottom: The Transtec Group, Inc.

Chip seal

Challenge 3 – Treatment Selection

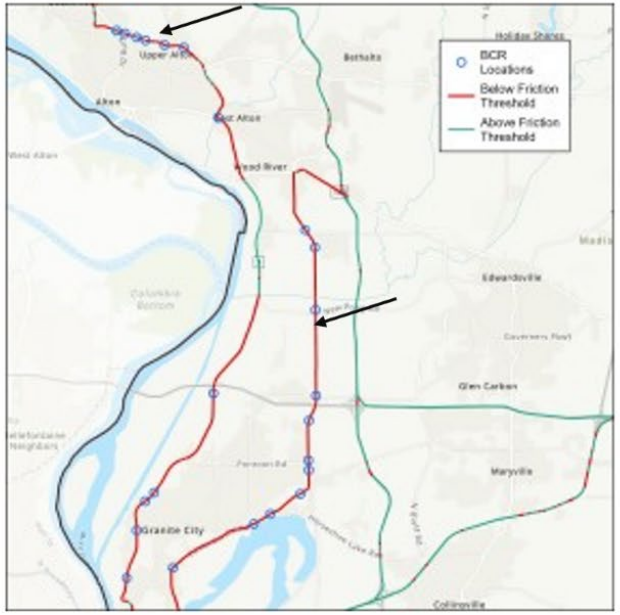
- Friction vs. Serviceability
  - Friction has not been explicitly considered in the current pavement asset management program
  - Many pavement surface treatments are used in Illinois (HMA overlay, UTBWC, micro-surfacing etc.) improve both friction and CRS
    - ❑ 2015 FHWA report "*Evaluation of Pavement Safety Performance*"
  - Pavement friction and CRS values are **<u>not</u>** always positively correlated: low friction + good CRS, low CRS + low friction.



Challenge 3 – Treatment Selection

- How to make treatment decisions under multiple performance metrics?

Asset Management
Interaction of CFME, Safety Tier (PSI), and CRS



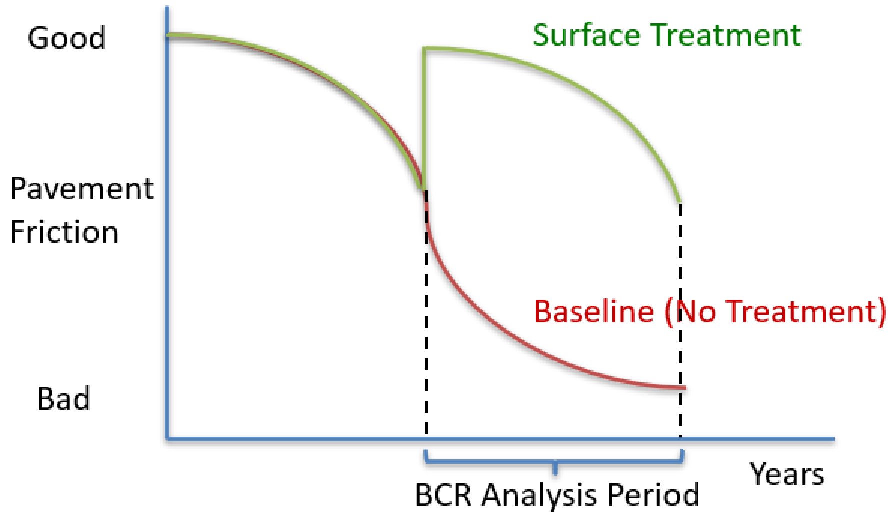
CFME

Safety Tiers (SRI/PSI)

Condition Rating System (CRS)

Benefit Cost Ratio (BCR) Method

1. Identify treatment options
   - Determine expected friction improvement, construction cost, etc.
2. Determine comprehensive crash costs
3. Predict potential crash reduction
   - Based on estimated SPFs and EB method
   - Determine # of expected crashes that can be reduced if friction treatment is applied
4. Compute Benefit-cost (B/C) ratio in an analysis period (e.g., 3-7 years)
5. Treatment prioritization
   - Rank the pavement segments by B/C ratio and prioritize treatments accordingly



Crash Severity	Crash Count (2012-2014)	NHTSA Cost/Crash (Police-Reported)	Comprehensive Costs
Fatality (K)	430	$9,962,008	$4,283,663,520
Injury (A, B, C)	26,921	$223,510	$6,017,123,864
PDO (O)	65,094	$10,644	$692,883,652
Total	92,445	-	$10,993,671,036

Source: FHWA-RC-20-0009

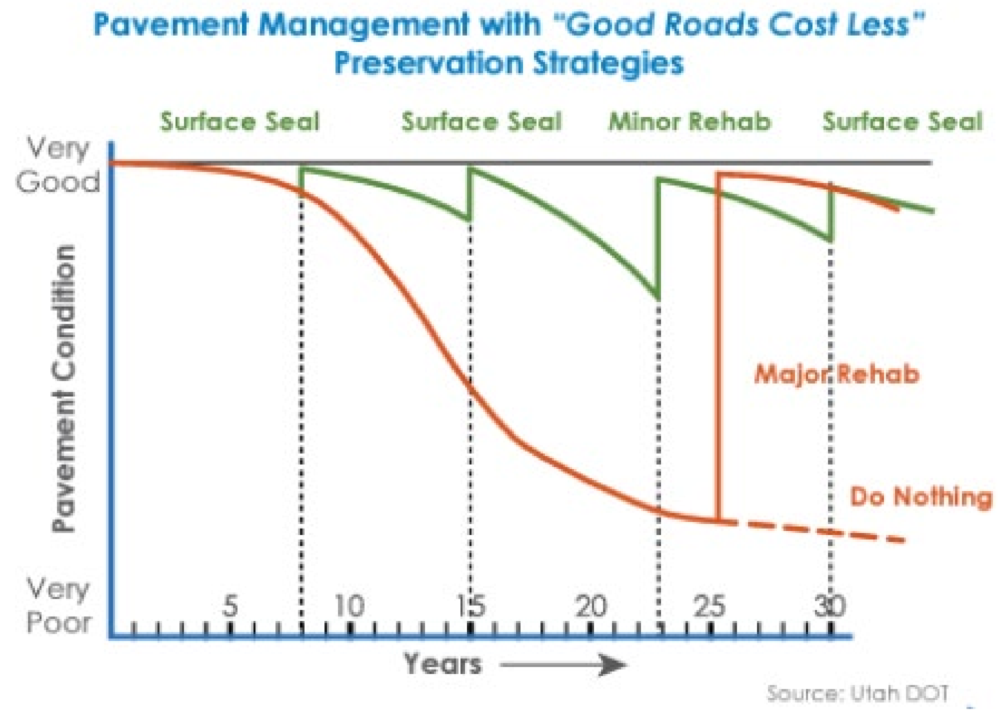
$$B / C = \frac{\text{Monetary Crash savings}}{\text{Treatment Construction cost}}$$

Challenge 3 – Treatment Selection

- Limitations of traditional BCR method
  - Some focuses on safety cost only, or pavement serviceability (CRS/IRI) only
  - Some considers short-term costs/benefits only, ignoring life-cycle impacts
    - Biased towards low-cost treatments (which usually have high BCRs)
    - Prioritizes treatments on worse pavements (likely with high BCRs), ignores the potentials of preventative maintenance strategies.
  - Some uses an arbitrary planning horizon (e.g., 3-7 years for safety, or 10-30 years for pavement serviceability)

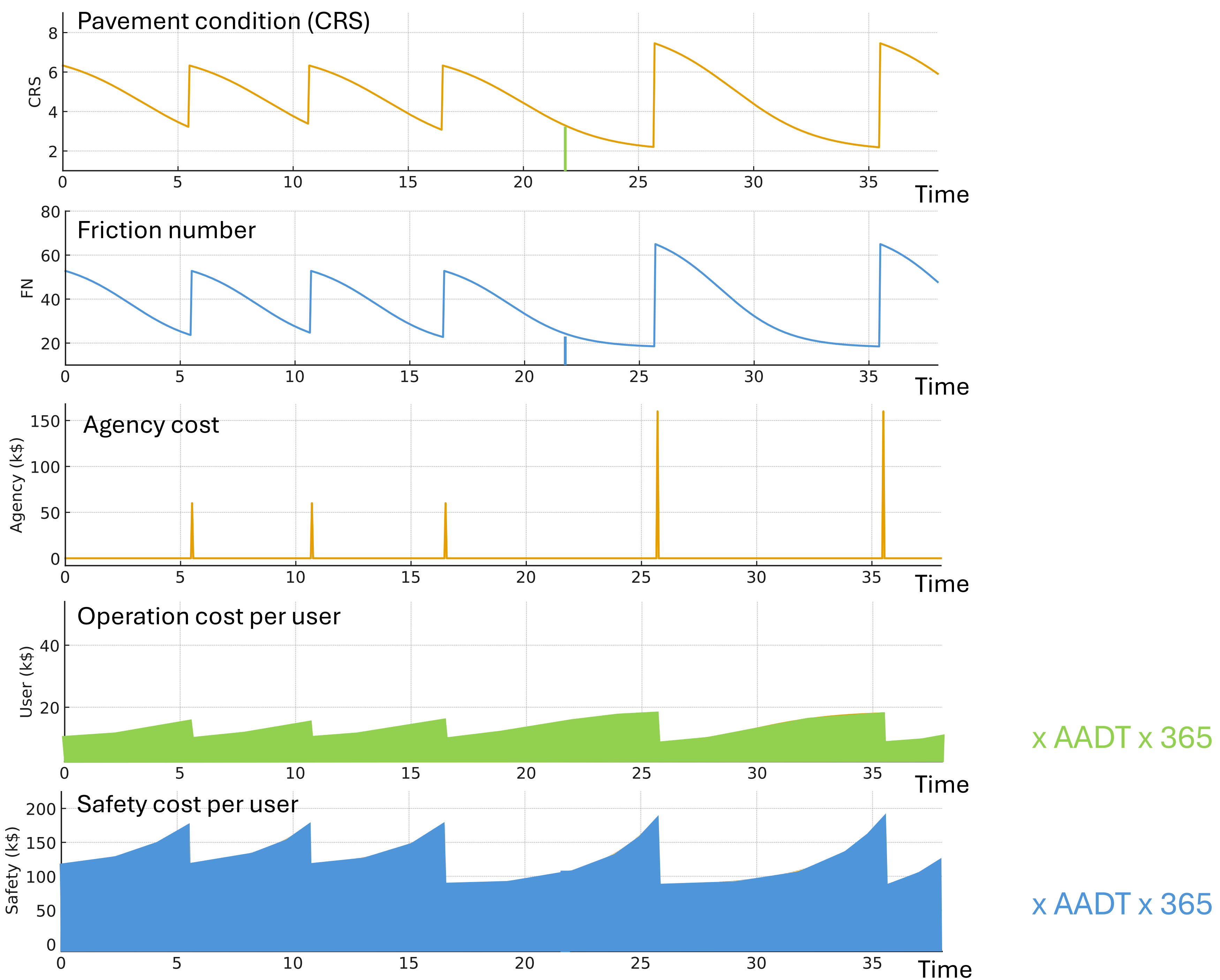
Life-Cycle Cost Approach

- In an infinite horizon
  - Model the deterioration process of friction and CRS over time
  - Quantify long-term life-cycle (safety) benefit & cost of treatments on improving both friction and CRS
  - Considers interactions of multiple treatments over time
  - Develop site-specific treatment decision trees
- Minimize the overall discounted cost in the infinite horizon.




Pavement condition (CRS)
CRS
8
6
4
2
0
5
10
15
20
25
30
35
Time
Agency cost
Agency (k$)
150
100
50
0
0
5
10
15
20
25
30
35
Time
Operation cost per user
User (k$)
40
20
0
5
10
15
20
25
30
35
Time

x AADT x 365



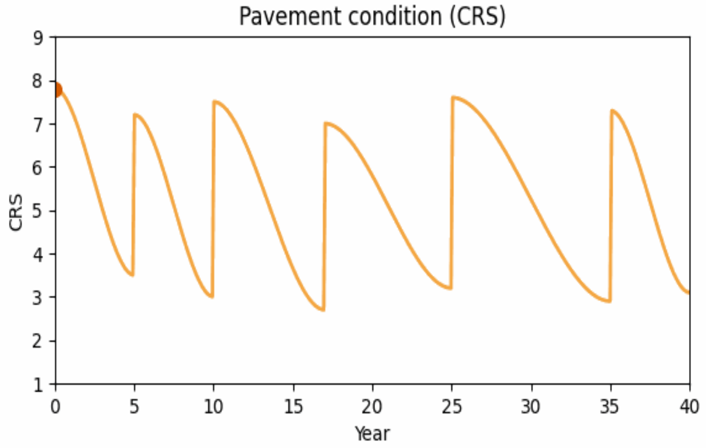
Pavement condition (CRS)
CRS
8
6
4
2
0
5
10
15
20
25
30
35
Time
Friction number
FN
80
60
40
20
0
5
10
15
20
25
30
35
Time
Agency cost
Agency (k$)
150
100
50
0
0
5
10
15
20
25
30
35
Time
Operation cost per user
User (k$)
40
20
0
5
10
15
20
25
30
35
Time
x AADT x 365
Safety cost per user
Safety (k$)
200
150
100
50
0
0
5
10
15
20
25
30
35
Time
x AADT x 365

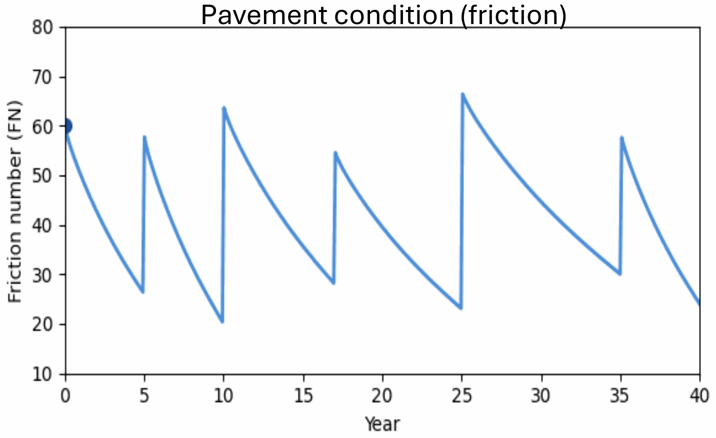
Life-Cycle Cost Approach

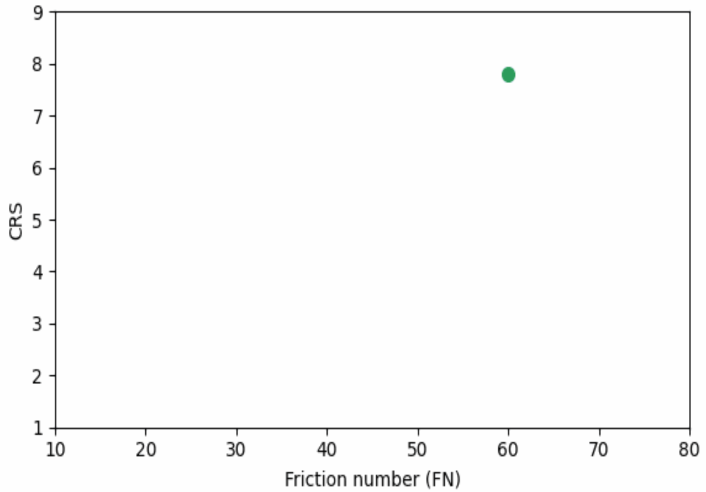
- Integrated framework that translate both friction (safety) and CRS (serviceability) into universal “cost $” representations
  - Categorize highway network segments by facility type (peer group, traffic, etc.)
  - Pavement state (CRS, friction) evolution
  - User cost: safety cost, pavement user serviceability cost
  - Treatment: Minor vs major; friction-oriented vs roughness-oriented
    - Cost vs. effectiveness

– **Objective:** To find an optimal rule (i.e., policy) that tells IDOT what treatment should be done based on pavement type, traffic, and current friction/CRS values

Example: For an urban 2-lane highway segment with traffic = 3500 AADT/lane, if the current CRS is 4.0, and the current friction number is 30 → Apply micro-surfacing







Life-Cycle Cost Approach

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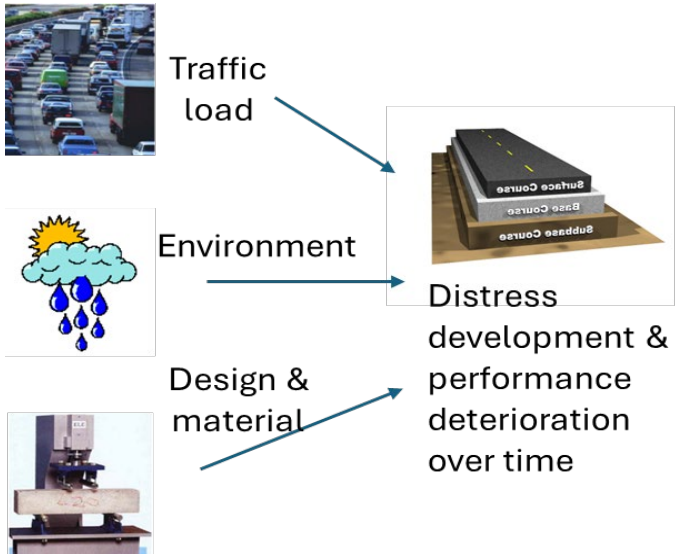
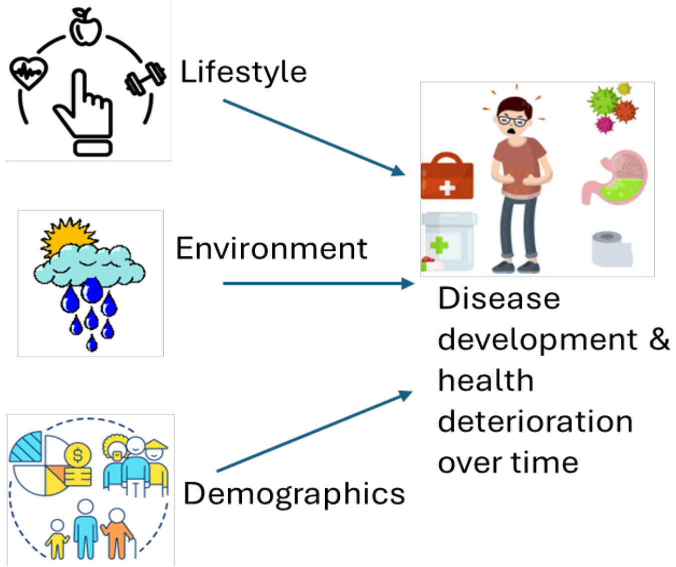


- Analogy to hospital emergency room practice
  - Categorize patients by demographics (age, gender, lifestyle, etc.)
  - Health state (vitals, pain) evolution
  - User cost: risk of complications, patient suffering
  - Treatment: Minor vs major; medicine vs surgery



LCCA Framework

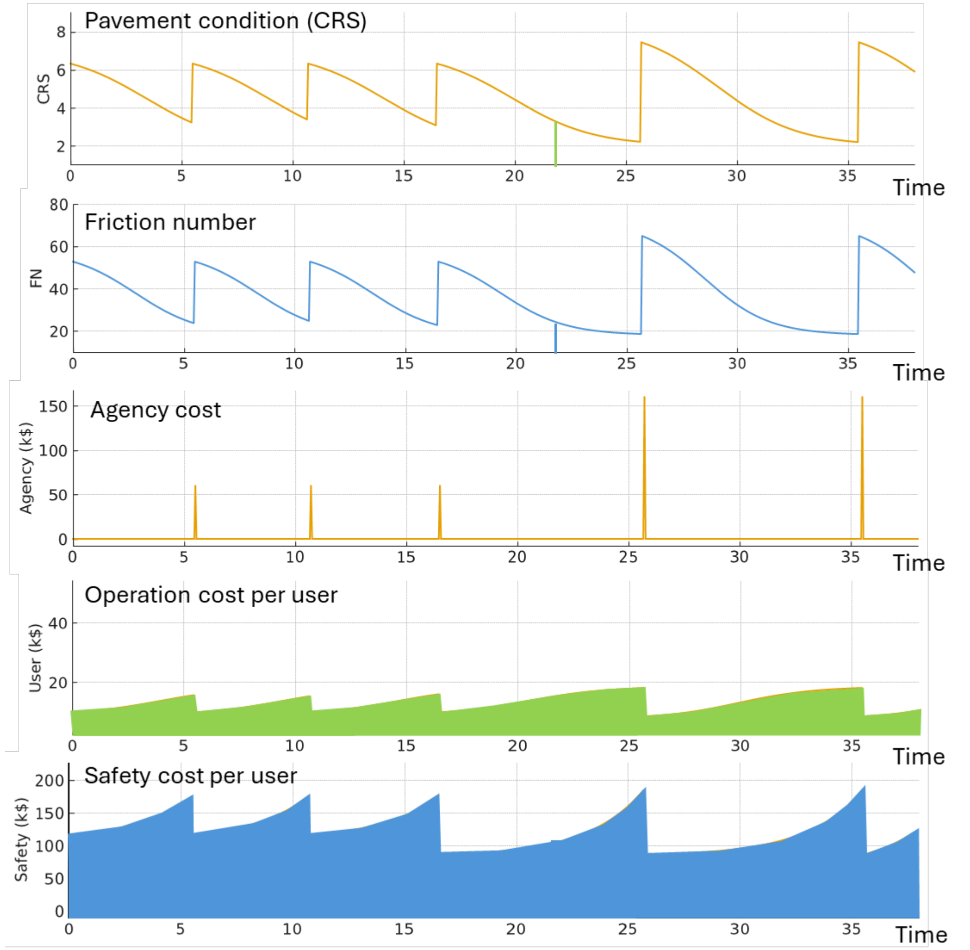
- Per unit-length pavement segment
  - Peer group i, traffic load q, CRS s, friction f

$$\text{state } \phi_t = (s(t^-), f(t^-))$$

  - Three possible cost components: (i) safety, friction-related, (ii) serviceability, CRS-related, (iii) treatment M_{ri} (\$/lane-mile)

$$C_i(q, s, f) = c_0 + c_1 s + b_i(f, q) \text{ (\$/veh-mile)}, \quad \forall i, q.$$

  - We can select any treatment (including do-nothing) at each year τ, each with certain cost and restoration effectiveness; denoted a_τ
  - The pavement state after treatment at year τ will be transitioned to year $\tau + 1$ via deterioration
  - Solve for the optimal policy (by dynamic programming) that minimizes the discounted sum of all costs (discount rate v) over an infinite horizon



$$\min_{\{\phi_\tau, a_\tau\}} \sum_{\tau=0}^{\infty} z_\tau[\phi_\tau, a_\tau]$$

where one-year cost is

$$z_\tau[\phi_\tau, a_\tau] = q \int_\tau^{\tau+1} C(q, \phi_t) e^{-vt} \mathrm{d}t + M_{a_\tau} \cdot e^{-v\tau}$$

Illinois Case Study

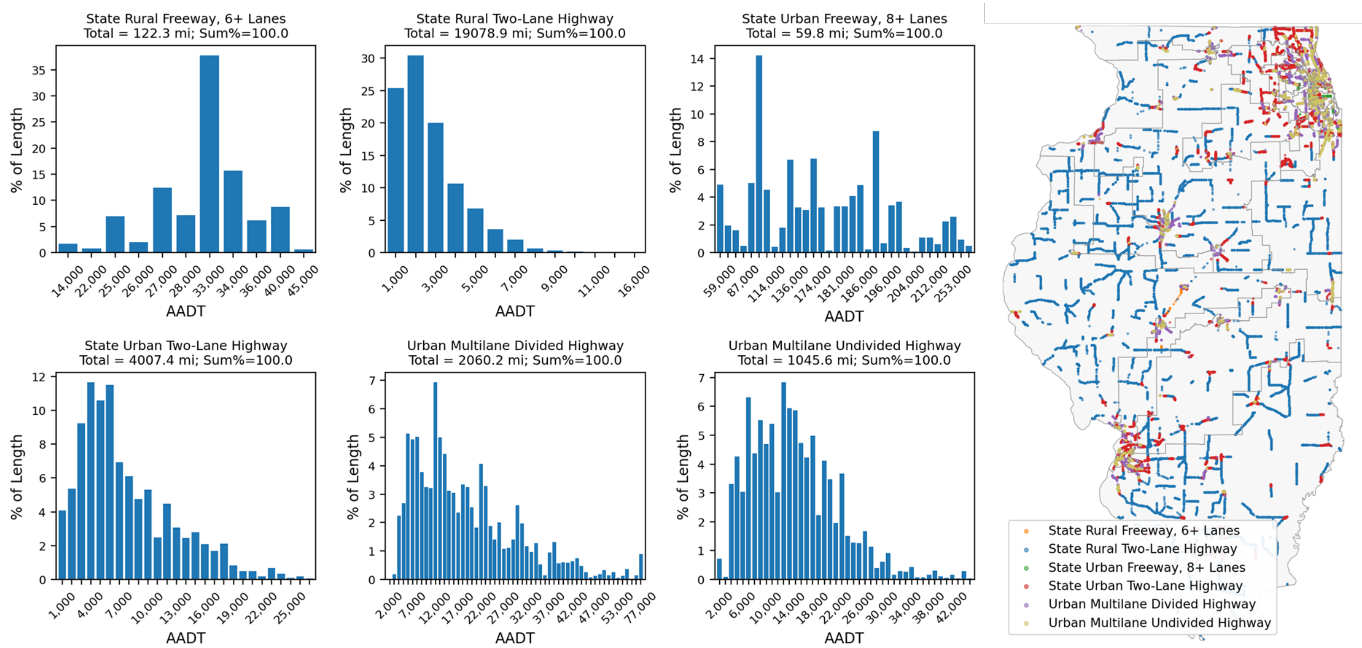
- Model Input

  – **Peer groups**: SPFs, traffic load distributions.

Pavement Facility type i	β_0	β_1	β_2
Urban Multi-Lane Undivided Highway	1.194e-4	1.196	4.907e-3
Urban Two-Lane Highway	8.251e-4	0.957	2.313e-3
Urban Multi-Lane Divided Highway	1.394e-4	1.165	1.630e-2
Urban Freeways 6+ Lanes	5.978e-4	1.001	5.322e-2
Rural Freeways 8+ Lanes	4.900e-2	0.432	7.221e-3
Rural Two-Lane Highway	1.299e-2	0.611	1.315e-2

Safety Performance Function Coefficients

Note: expected crash rate = $\beta_0 q^{\beta_1} e^{-\beta_2 f}$ *for each type, where* q *is traffic (AADT),* f *if friction number*



(a) (b)

  – **Cost parameters**:
    – Safety cost: 169 k$/crash,
    – CRS (User) cost: 4e-6 k$/veh-mi/CRS

Example: One lane-mile Urban Two-Lane Highway segment under 3500 AADT/lane with f=55 and CRS=5 has an expected annual safety cost of 293.8 k$ (1.74 crashes/yr) and a user cost of 19.8 k$.

If friction reduces to 30, safety cost increases by 17.5 k$; if CRS reduces to 3, user cost increases by 9.8 k$

Illinois Case Study

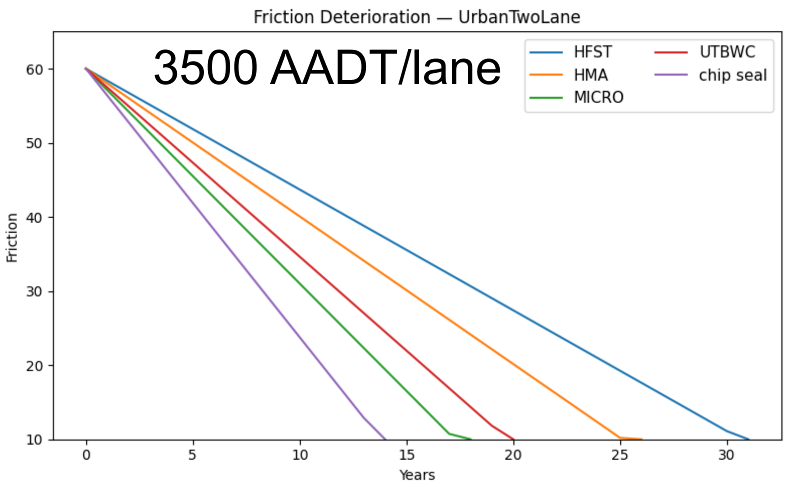
- Model Input
  - **Deterioration model**: how friction deteriorates over time
    - Linear deterioration with traffic load, based on both pavement types, traffic load, and the treatment applied previously $\hat{r}$

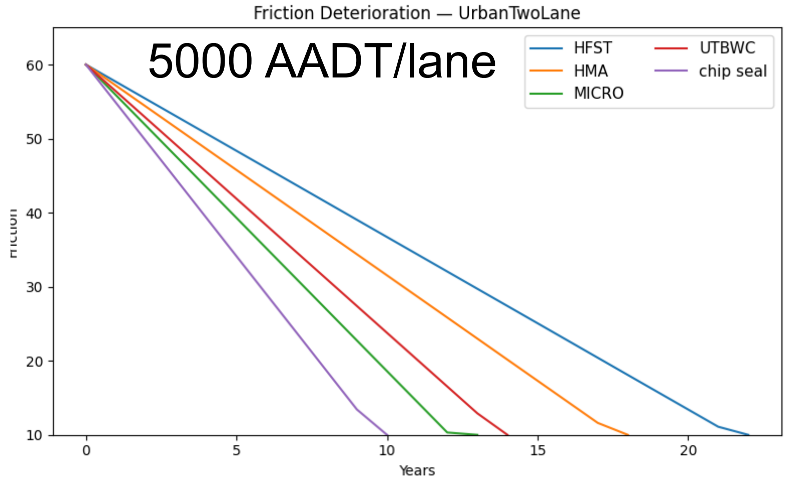
$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} = F(q,\hat{r}) = \begin{cases} -(a_2 + a_{3\hat{r}}q), & f(t) > f_{\min}, \\ 0, & f(t) = f_{\min}, \end{cases} \quad \forall q, t \in (\tau, \tau+1).$$

Table 1. Friction deteriorate rate by facility type and previous treatment

Pavement Facility type i	1.2-in HMA overlay	20mm UTBWC	0.5-in chip seal	9.5mm micro-surfacing	HFST
Urban Multi-Lane Undivided Hwy	5.940e−04	7.560e−04	1.080e−03	8.640e−04	3.240e−04
Urban Two-Lane Highway	5.692e−04	7.245e−04	1.035e−03	8.280e−04	3.105e−04
Urban Multi-Lane Divided Hwy	5.445e−04	6.930e−04	9.900e−04	7.920e−04	2.970e−04
Urban Freeways 6+ Lanes	5.198e−04	6.615e−04	9.450e−04	7.560e−04	2.835e−04
Rural Freeways 8+ Lanes	4.702e−04	5.985e−04	8.550e−04	6.840e−04	2.565e−04
Rural Two-Lane Highway	4.455e−04	5.670e−04	8.100e−04	6.480e−04	2.430e−04

Note: All values are derived and adjusted based on Wang and Wang (2013), Susanna et al. (2017).





Example: Urban Two-Lane Highway

Illinois Case Study

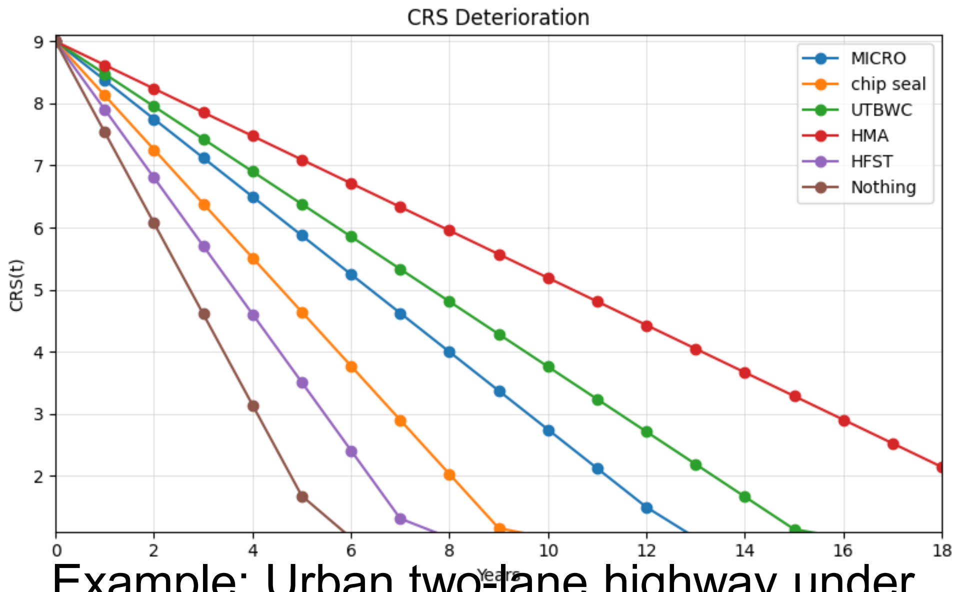
- Model Input
  - **Deterioration model**: how CRS deteriorates over time
    - Linear deterioration with traffic load, the truck percentage Tr, and the CRS value right after treatment CRS' (ICT Project R27-150: Ozer et al. 2018)

$$\text{CRS} = 9.0 - m \times (\alpha_{AADT} \ln(AADT) - \alpha_{\text{CRS}'}\text{CRS}' + \alpha_{Tr} Tr + \beta) \times t$$

Table 2: CRS deterioration coefficients by treatment

Treatment	m	α_{AADT}	$\alpha_{CRS'}$	α_{Tr}	β
"9.5mm micro-surfacing"	0.90	0.028	0.064	0.17	0.889
"0.5-in chip seal"	1.13	0.046	0.088	0.32	0.920
"20mm UTBWC"	0.60	0.082	0.253	1.02	1.873
"1.2-in HMA overlay"	0.38	0.042	0.118	0.74	1.493
'HFST"	1.01	0.138	0.257	1.31	1.05

Note: All values from Table 3.9. in R27-150 report except for HFST..



Example: Urban two-lane highway under 3500 AADT/lane

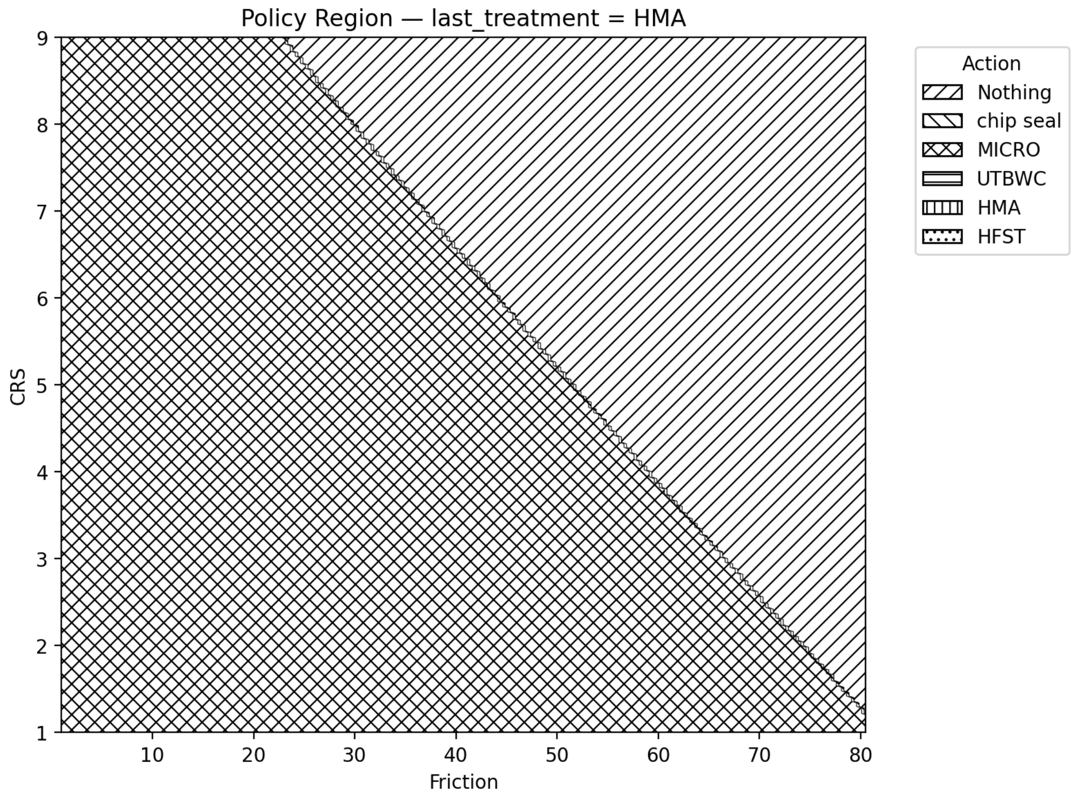
Illinois Case Study

- Model Input
  - **Treatment toolbox**: construction cost M_r, and CRS and friction value h_r right after treatment

Treatment r	M_r (10^3\$/lane-mi)	CRS'_r	h_r
1.2-in HMA overlay	120.0	8.0	60
20mm UTBWC	48.0	7.2	60
0.5-in chip seal	15.0	6.5	52
9.5mm micro-surfacing	25.0	7.0	58
HFST	220.0	5.0	80

Illinois Case Study

- Model output
  - Mapping from any (friction, CRS) state to an optimal treatment
  - Each region corresponds to an optimal treatment, and the “boundaries” give thresholds



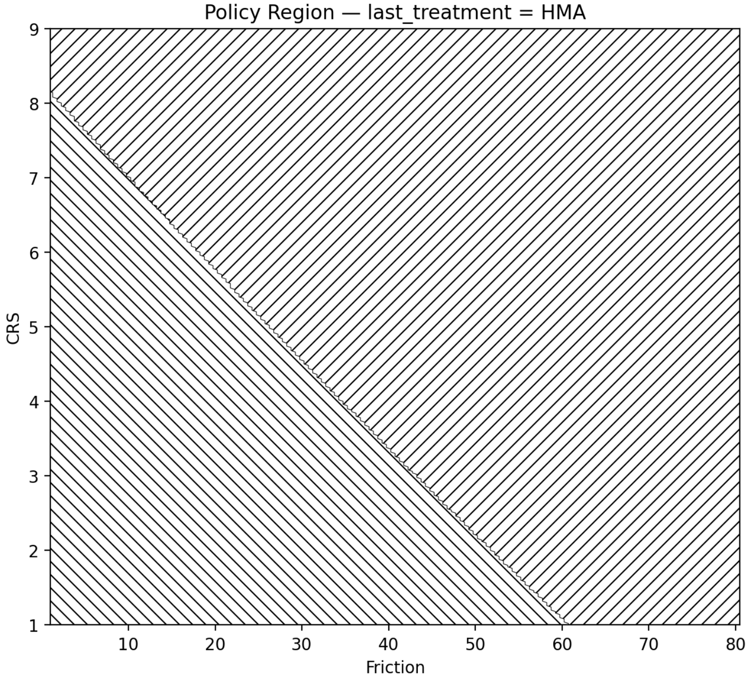
Optimal Policies for Urban Two-Lane Highway Segment under 3500 AADT/lane

Insights: Such a simple mapping can be used to simultaneously screen the problematic sites and determine the most cost-effective treatment.

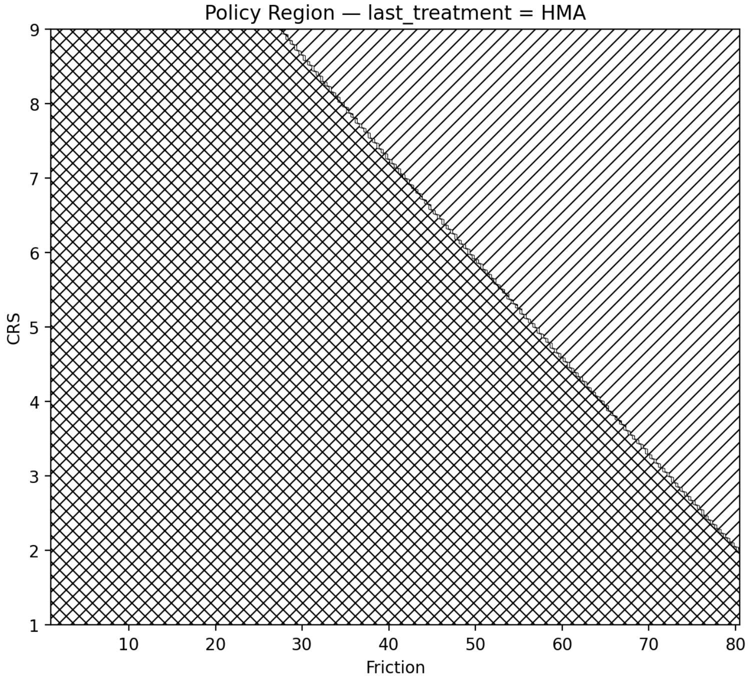
- Threshold boundaries are indication of friction & CRS investigatory levels
- One unique mapping for each pavement type & traffic load range

Illinois Case Study

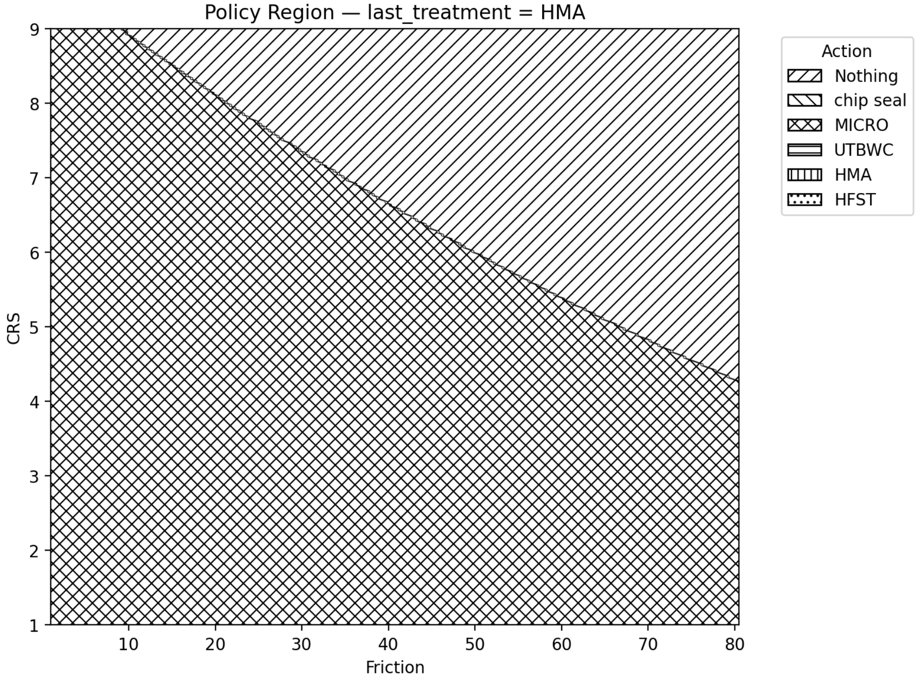
- Model output



Urban Two-Lane Highway Segment under 1000 AADT/lane



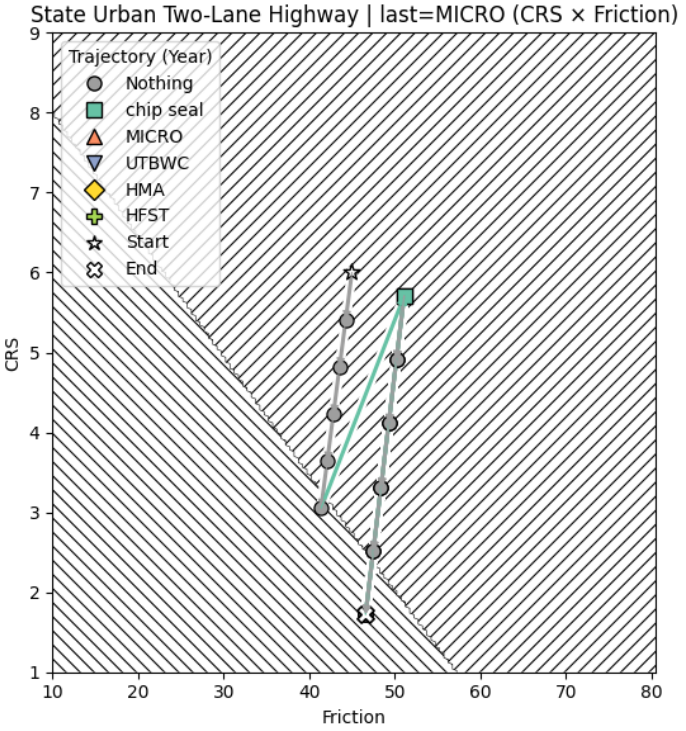
Urban Two-Lane Highway Segment under 5000 AADT/lane



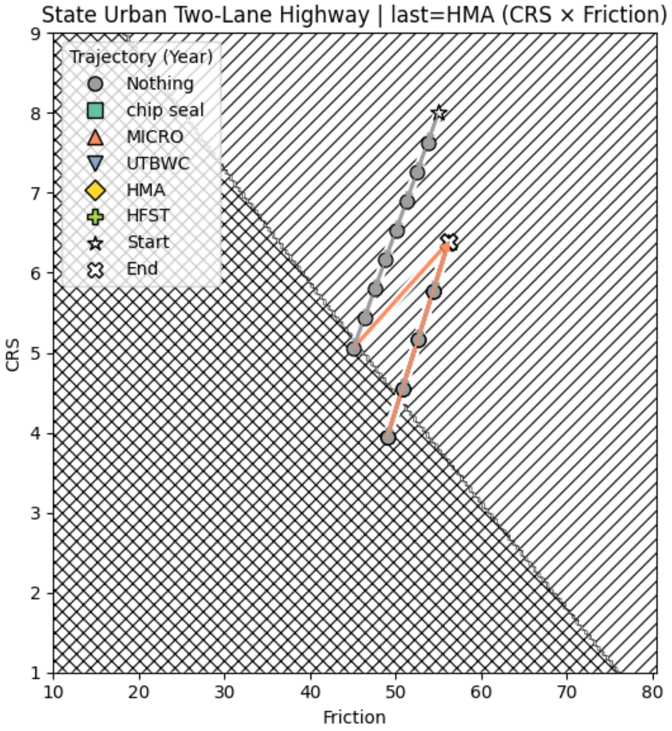
Rural Freeways, 6+ Lanes under 5500 AADT/lane

Decision Trees for Site Screening

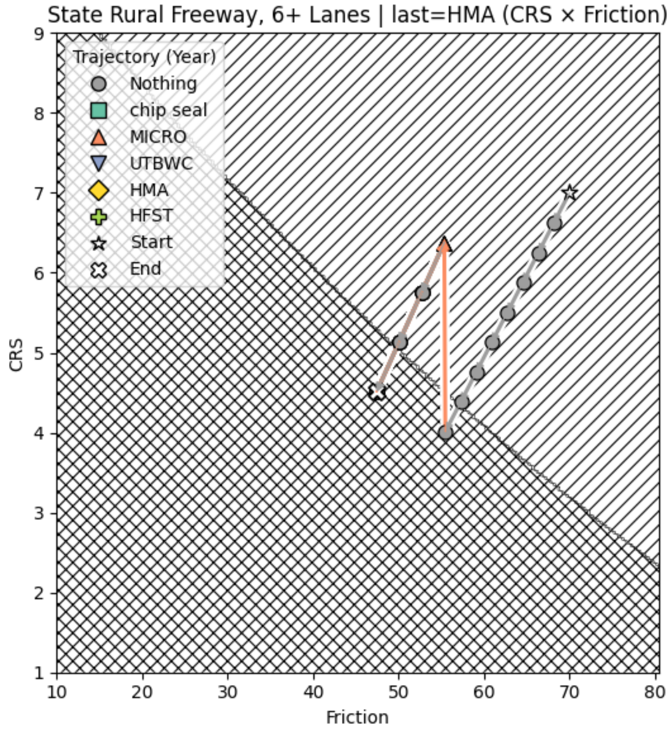
- Sample evolution



Urban Two-Lane Highway Segment under 1000 AADT/lane



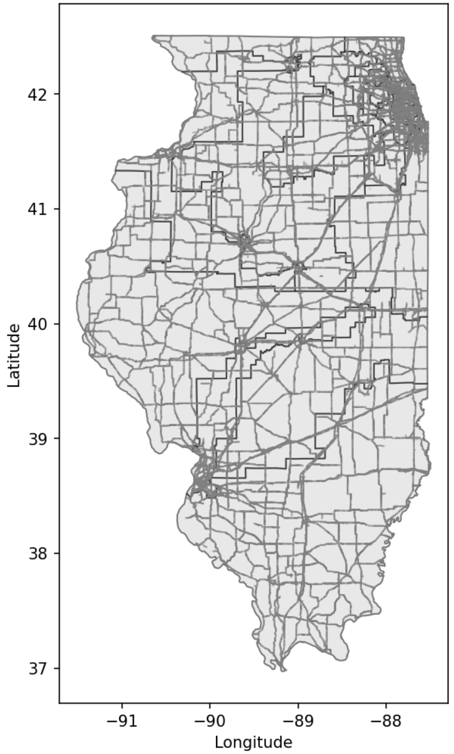
Urban Two-Lane Highway Segment under 2500 AADT/lane



Rural Freeways 6+ Lanes Segment under 3667 AADT/lane

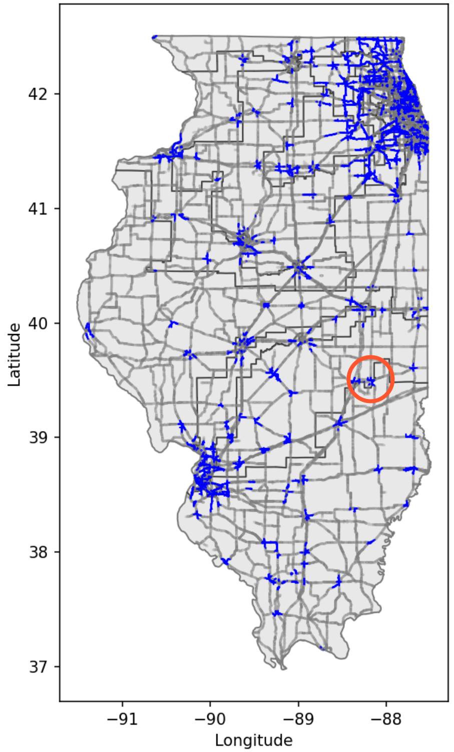
Decision Trees for Site Screening

- Site screening and treatment selection



Highway network

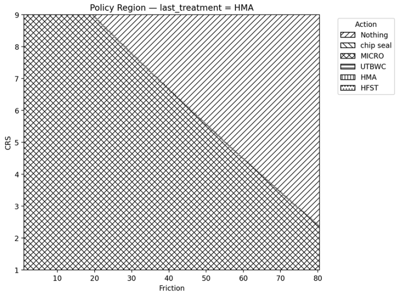
Determine the peer group



Urban Two-Lane Highway

Find the traffic load, current friction value, current CRS value

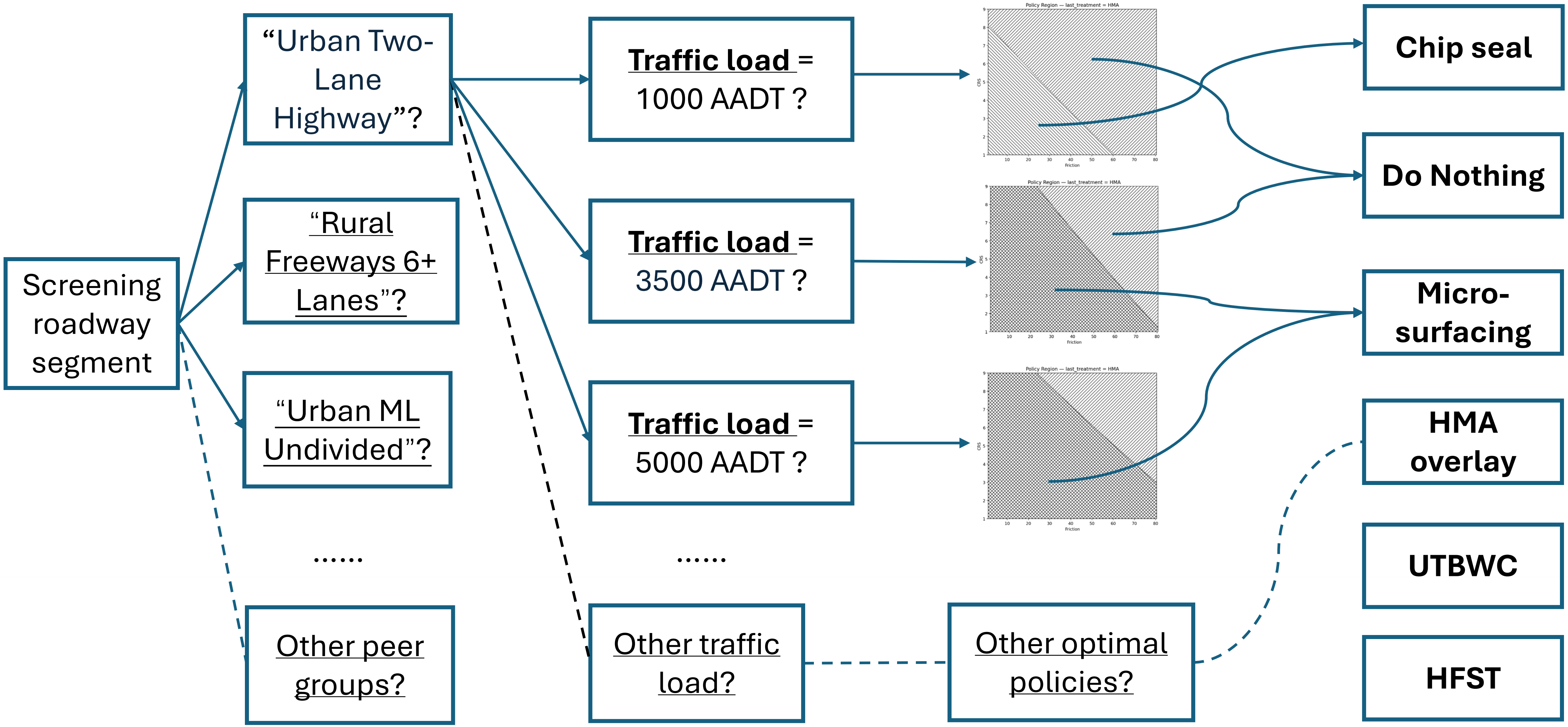
Optimal policy structure from LCCA framework



Output: Does it need treatment? Which treatment is optimal?

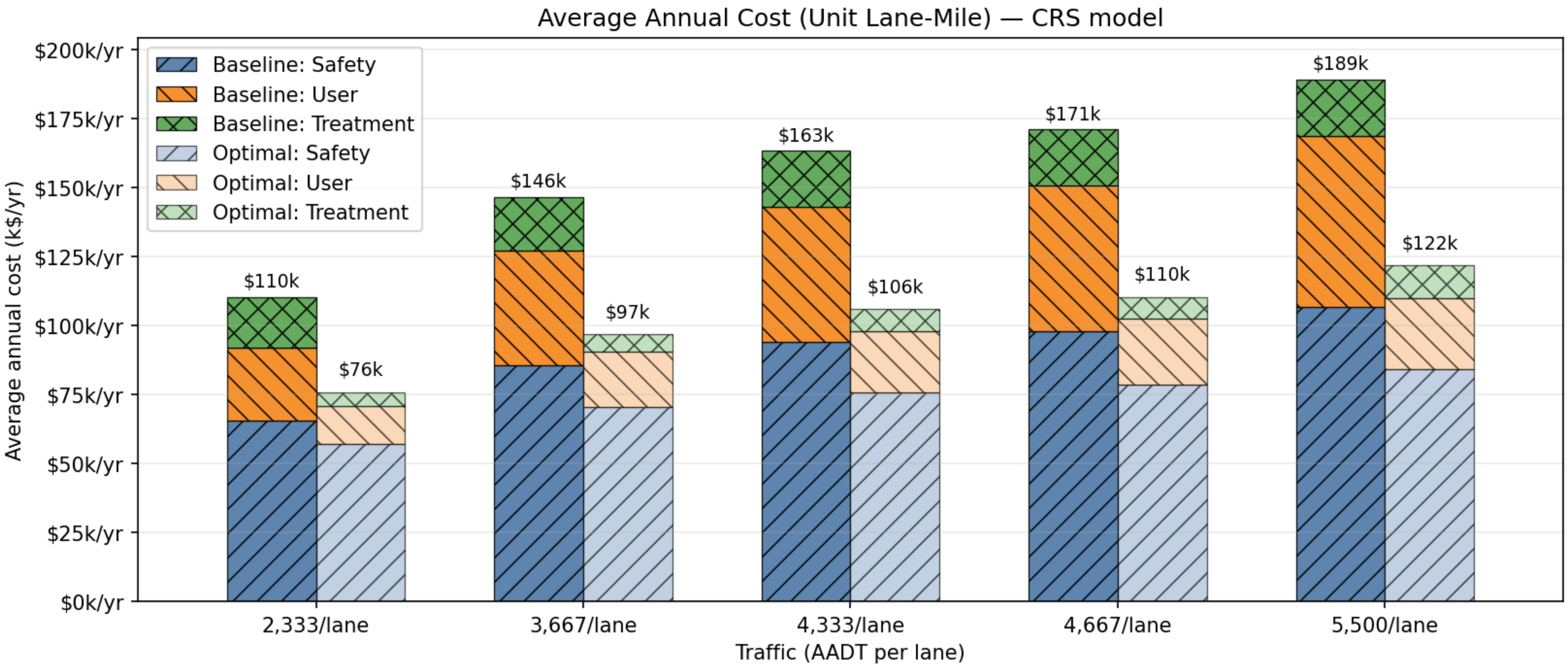
Decision Trees for Site Screening

- Example of decision tree flow chart



Decision Trees for Site Screening

- Cost comparison with baseline threshold-based policy
  - Example: Rural Freeways 6+ Lanes 30-year horizon; if f < 40, do micro-surfacing, if CRS < 4, do UTBWC



Final Remarks

- Systematic strategies for friction measurements and data collection
  - Unifying data from various technologies (e.g., LWST, SCRIM, 3D laser scanning, computer vision, CAV on-board sensor)
  - Efficient schedule/route plan for network level data collection
- Integrated framework for safety analysis and asset management
  - Customized data-driven SPFs and CMFs for Illinois
  - Network screening + treatment selection
  - A variety of treatment options (e.g., HMA overlay, UTBWC, chip seal, micro-surfacing, HFST)
  - There is no reason why “treatment” options cannot include initial pavement design and/or binder/aggregate choices…

Thank You!

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Model Parameters & Assumptions

Basic parameter settings

- **Trucks (large vs. small)**
- Large truck capacity: 2200 gal; Small truck capacity: 945 gal
- Service arc length: extracted from the GIS file
- Survey speed: 25 mph, 40 mph, 50 mph based on speed limit
- Water consumption: 24 lpm, 36 lpm, 48 lpm
- Deadhead distance: OpenStreetMap
- Deadhead speed: 50 mph
- Refill rate at water facilities: ranged from 2000 gph to 6600 gph
- Break: 30 minutes break every 8 hr, max 12 hr work daily 1.5 days before cumulative 70 hr in 8 days.

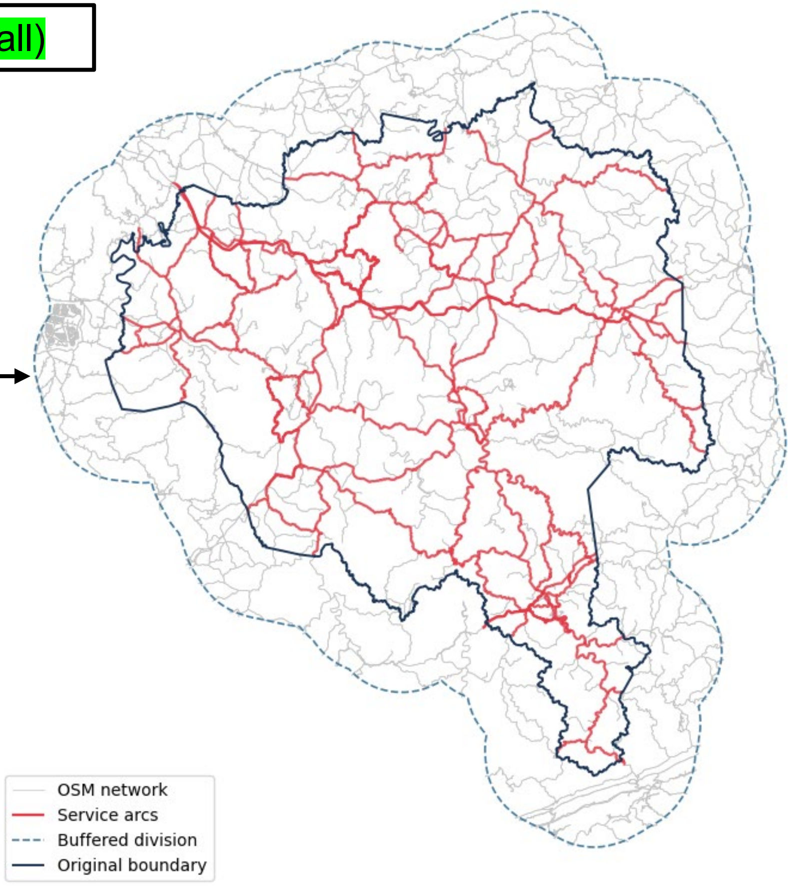
One truck for D10 (large/small)

8 miles of boundary buffer

Calibrated deadhead speed: 40mph

Max 9.5 hr work daily including 1 hr for hotel

D10 Service Arcs over OpenStreetMap Network
Total mileage = 1116.9 mi



Additional assumptions

- Deadhead time to nearest hotel: 0.25 hr for all nodes.
- No delay from traffic light, congestion, data activities.
- No crew substitution during a trip
- Any other rules that we should consider?

0.5 hr morning or evening deadheading

10 min buffer for data saving every 35 miles of surveying

Improved greedy initial solution (still greedy but smarter)

BCR Method

- General principles from the 2025 FHWA guide "*Benefit-Cost Analysis Guidance for Discretionary Grant Programs*"
  - Well-defined <u>baseline case</u> vs <u>alternatives</u>
  - Demand modeling and forecasting
  - Recommended $ discounting: 7%
  - Appropriate analysis period: 3-7 years

KABCO Level	Monetized Value (2023 $)
O – No Injury	$5,300
C – Possible Injury	$118,000
B – Non-incapacitating	$246,900
A – Incapacitating	$1,254,700
K – Killed	$13,200,000
U – Injured (Severity Unknown)	$229,800