

Protocols for Concrete Bridge Deck Protections and Treatments

WHRP

Ahmed Albughdadi, Iowa State University

Basak Bektas, Minnesota State University Mankato

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Objective

Developing a **cost-effective** and **data-driven** lifecycle treatment plan for preservation of Wisconsin bridge decks

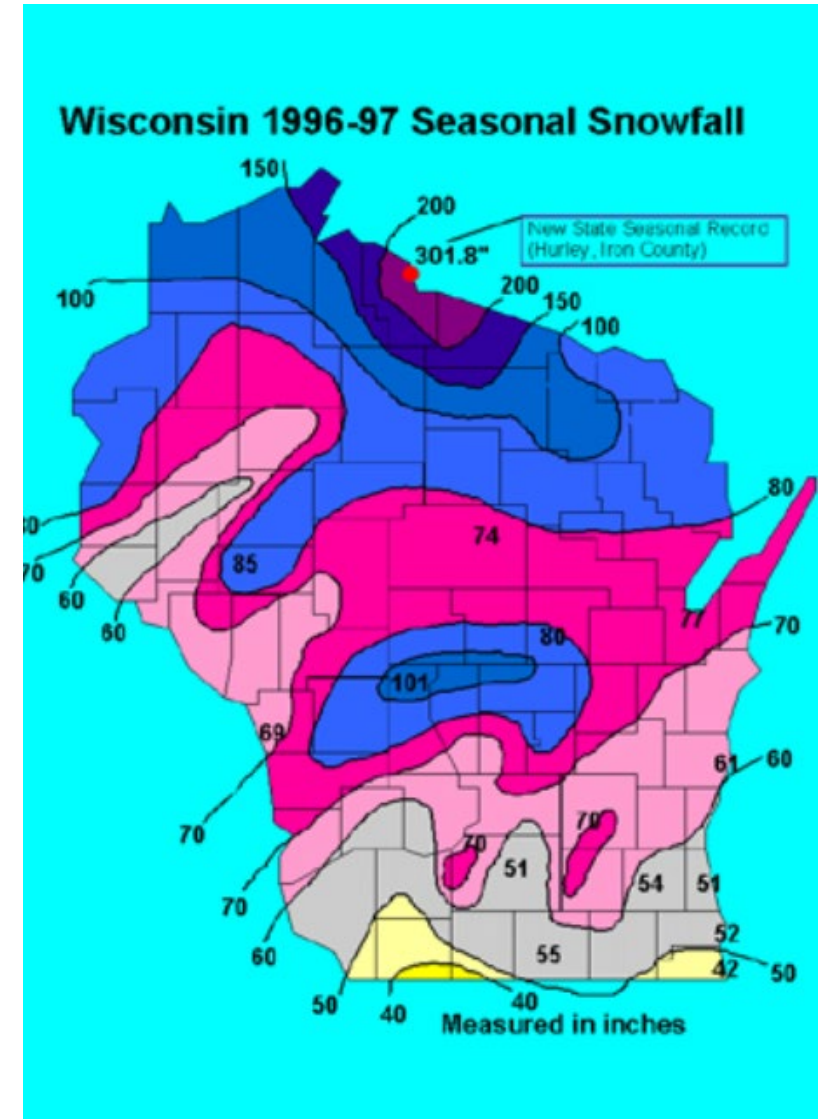
Approach

Inclusion of external factors

Selected bridge deck preservation strategies including common combinations of deck treatments

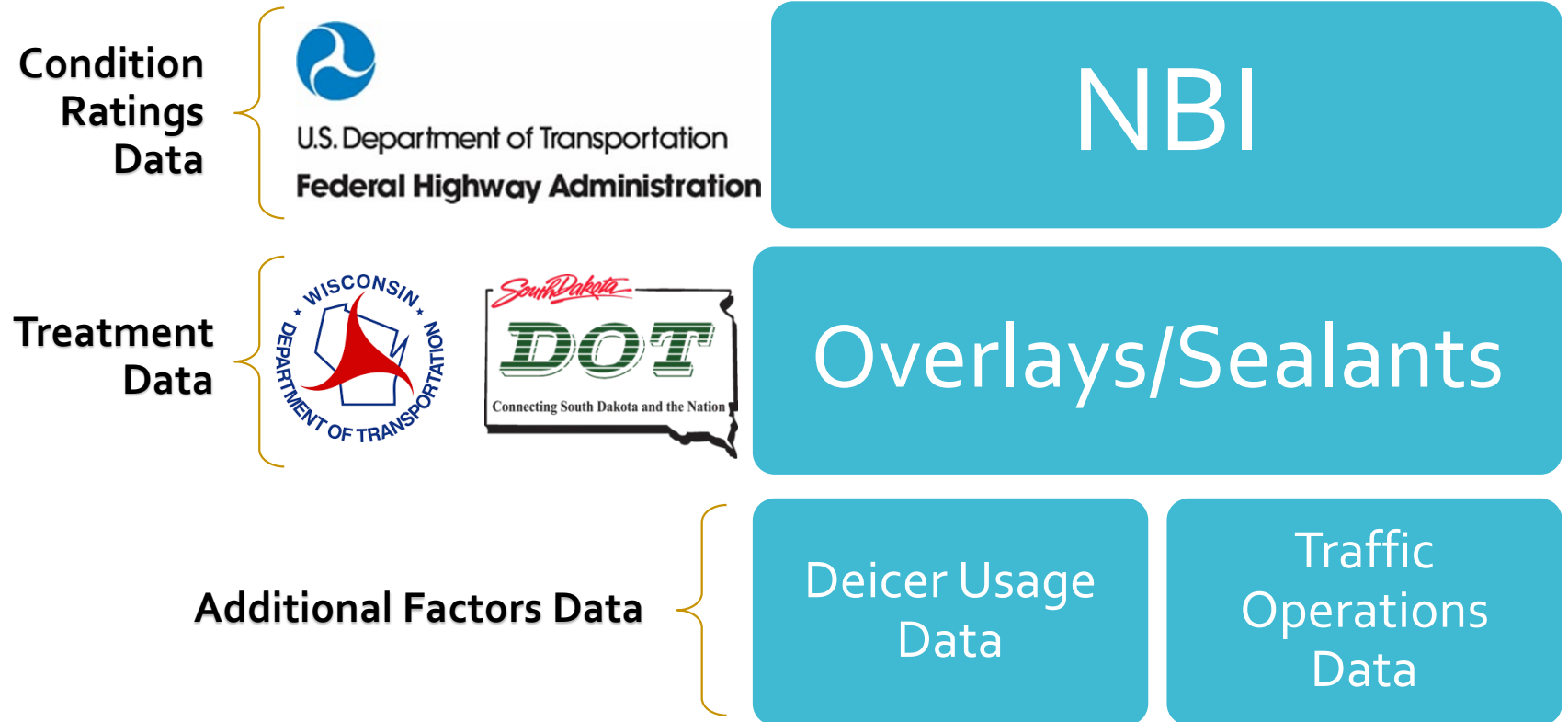
Ideal timing of each bridge deck treatment or treatment combination, with respect to bridge condition or age

Estimated effective time of treatments



Data Sources

Data Processing
Data Categorization
Results & Analysis
Additional Factors
Conclusions



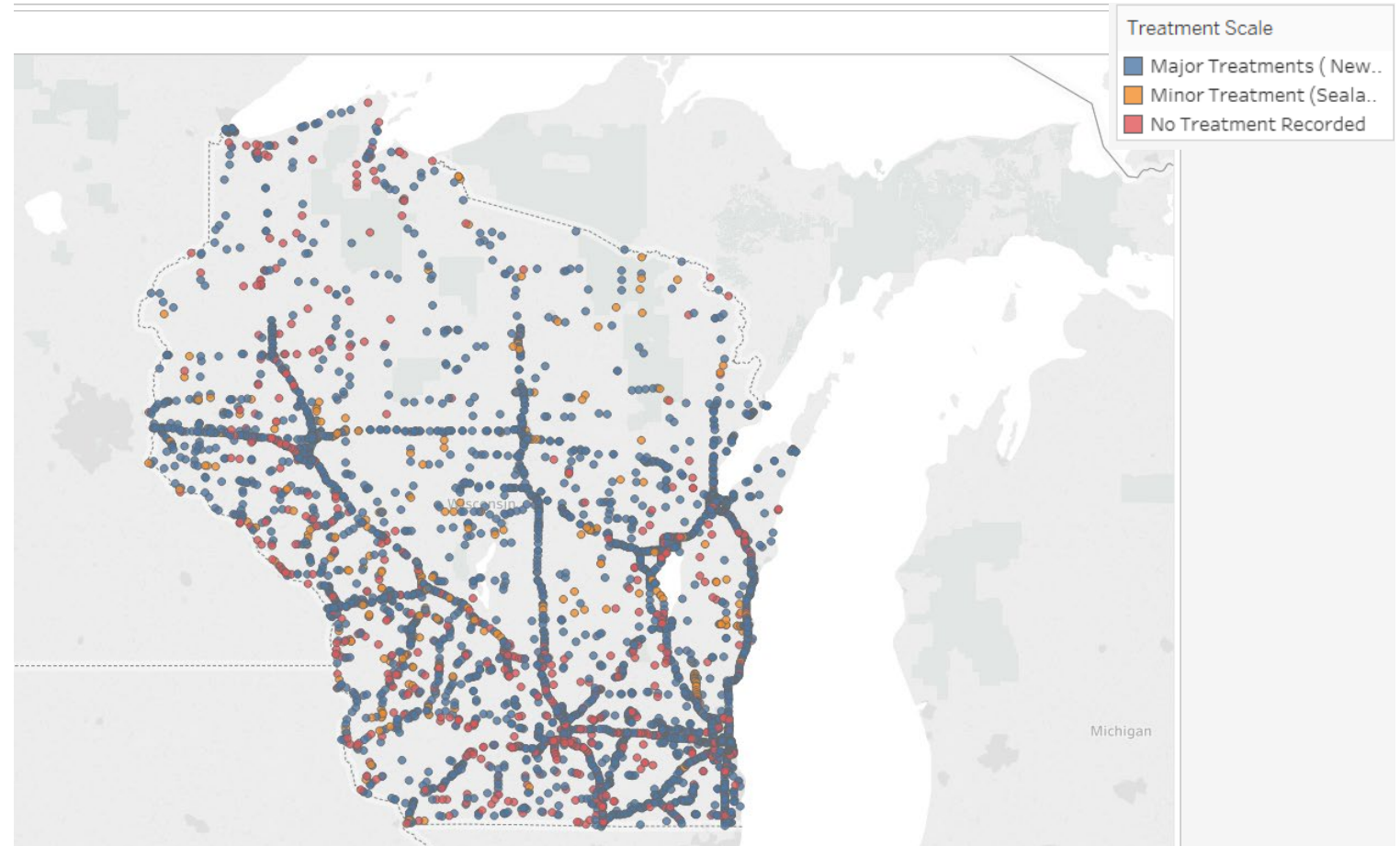
Data Processing

Additional Factors
Data Categorization
Data Analysis
Future Work

HSIS

Regional Data

TREATMENT DATA



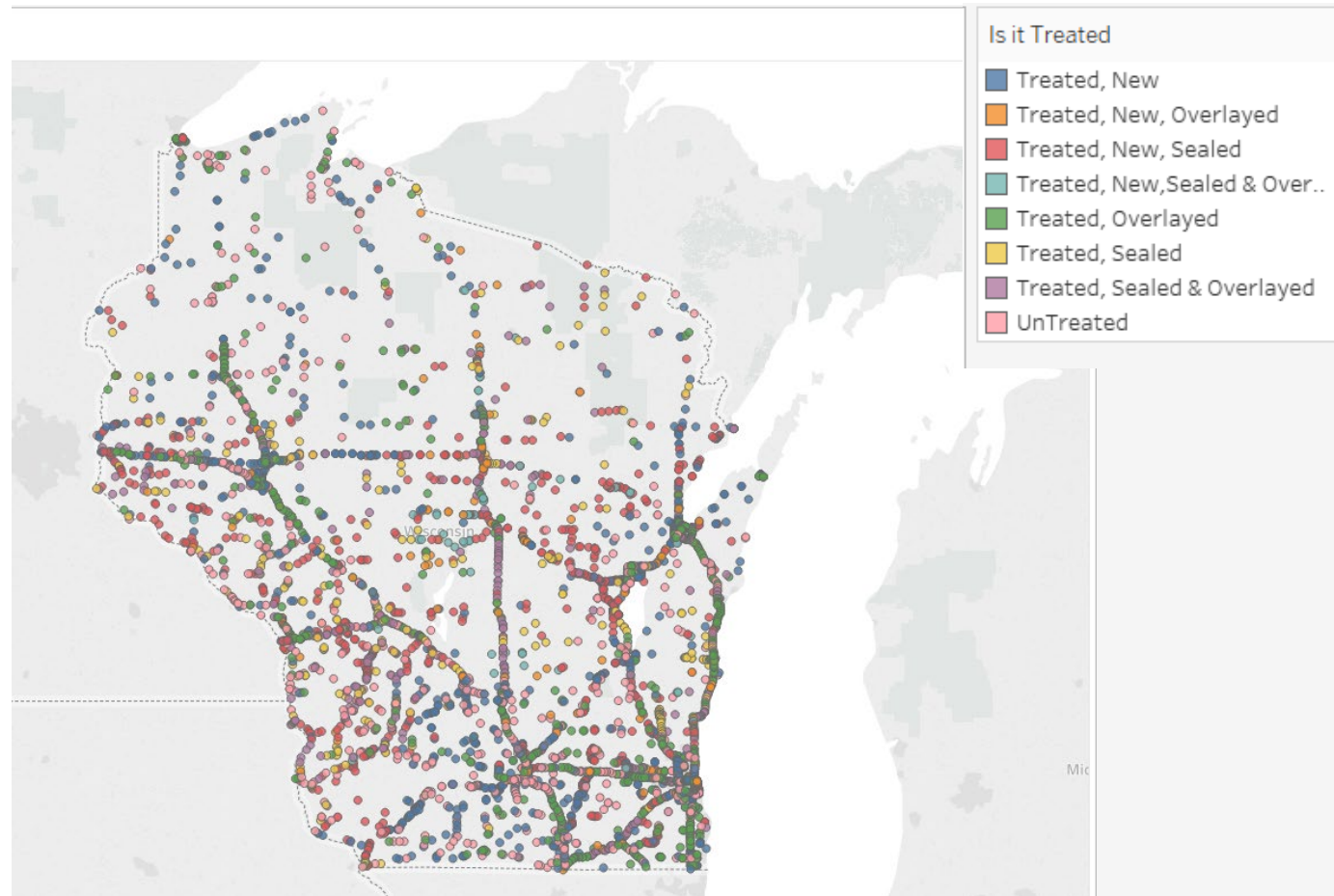
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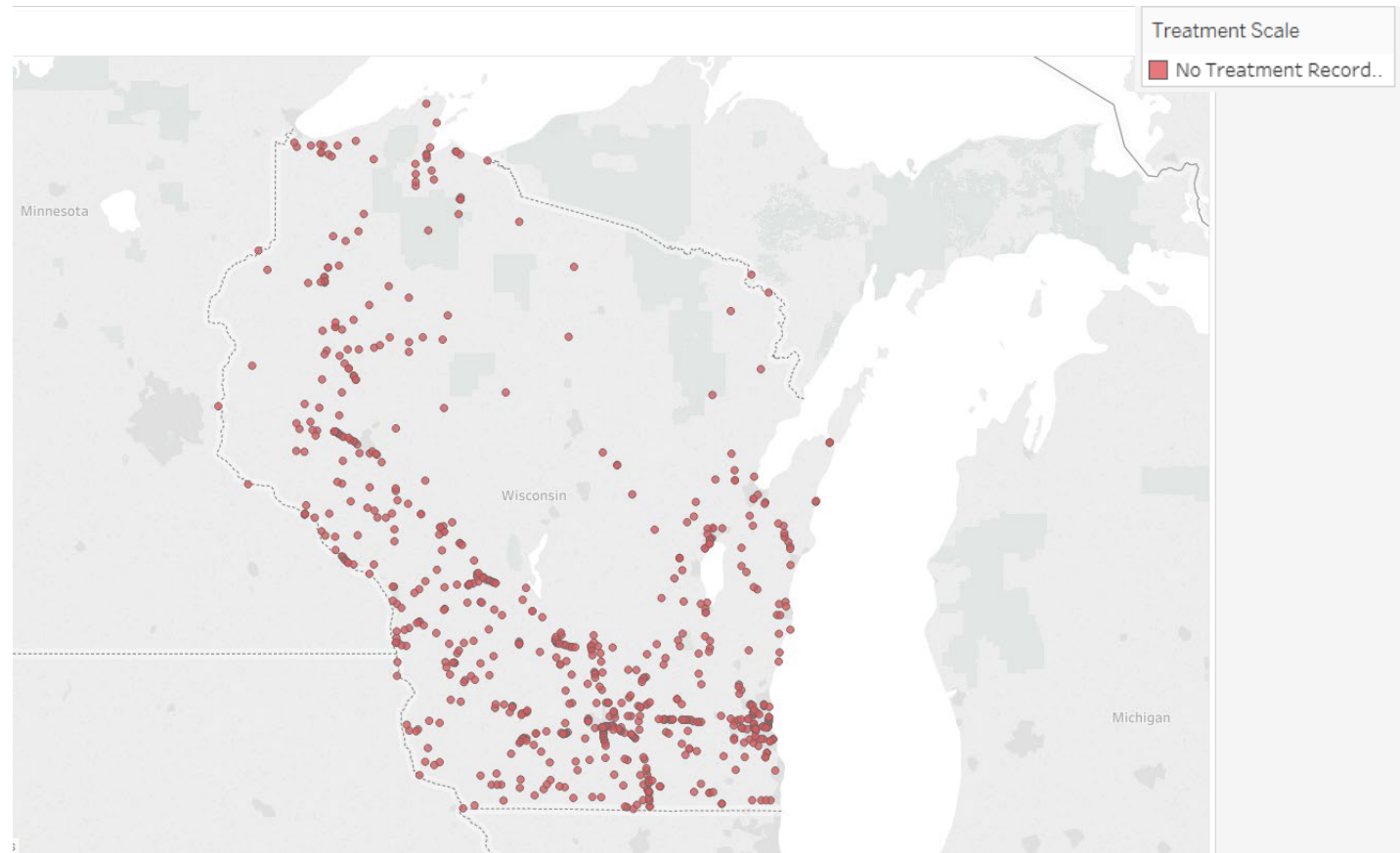
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HSIS

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TREATMENT DATA



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HSIS

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TREATMENT DATA

TIS: 1,2,3

NBI Rating	UnTreated		Next NBI Rating					
			4	5	6	7	8	9
4	1%	1%	1%	0%	0%	0%	0%	0%
5	1%	4%	2%	0%	0%	0%	0%	0%
6	1%	6%	9%	13%	2%	1%		
7	0%	0%	11%	6%	8%	0%		
8	0%	0%	2%	22%	7%	0%		
9	0%	0%	0%	0%	3%	0%		

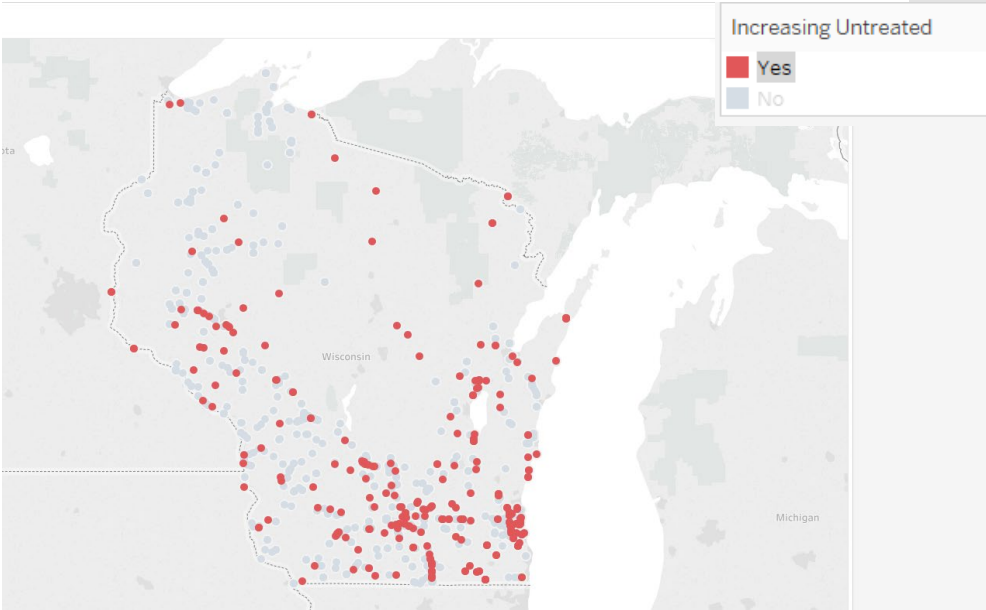
Totals	Total Decreasing	Total Increasing	Total still	Percent Increasing from Total
	319	196	196	28%

TIS: All

NBI Rating	UnTreated		Next NBI Rating					
			4	5	6	7	8	9
4	1%	0%	0%	0%	0%	0%	0%	0%
5	1%	7%	2%	0%	1%	0%		
6	0%	9%	10%	6%	1%	0%		
7	0%	1%	16%	11%	4%	0%		
8	0%	0%	1%	20%	6%	0%		
9	0%	0%	0%	0%	1%	0%		

Totals	Total Decreasing	Total Increasing	Total still	Percent Increasing from Total
	996	322	706	16%

TIS: Time-in-state
For our research, time spent in an NBI condition rating



(No treatment recorded)
Need to be flagged, excluded for analyses

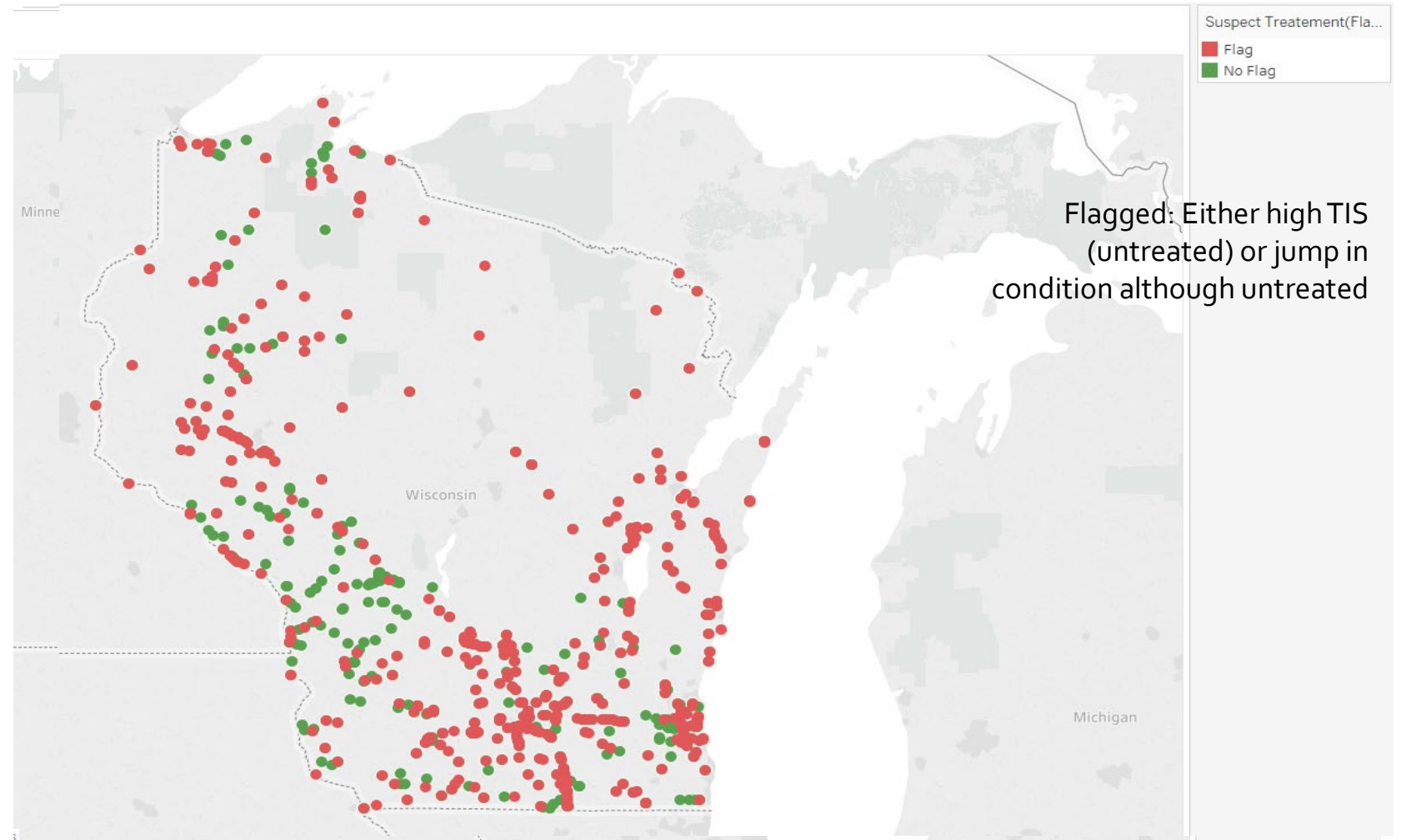
Data Processing

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TREATMENT DATA



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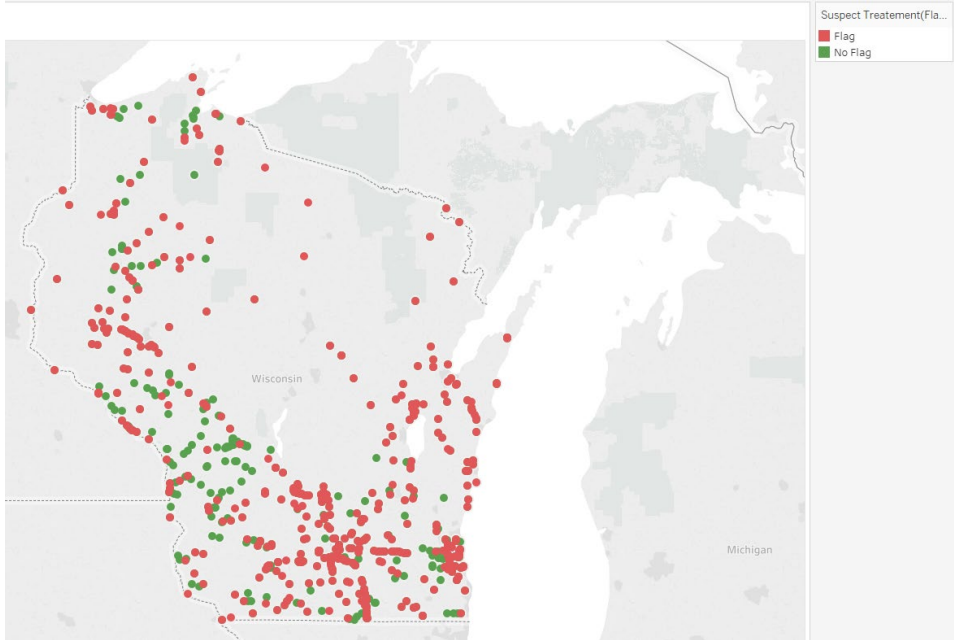
HSIS

Regional Data

TREATMENT DATA

Total Number of Increasing untreated TIS observations	322
Unique Number of High TIS above Q3	549
Total Number of records of question in Untreated	871
Total Percentage of Questionable Records in Untreated	43.0%

- Excluded



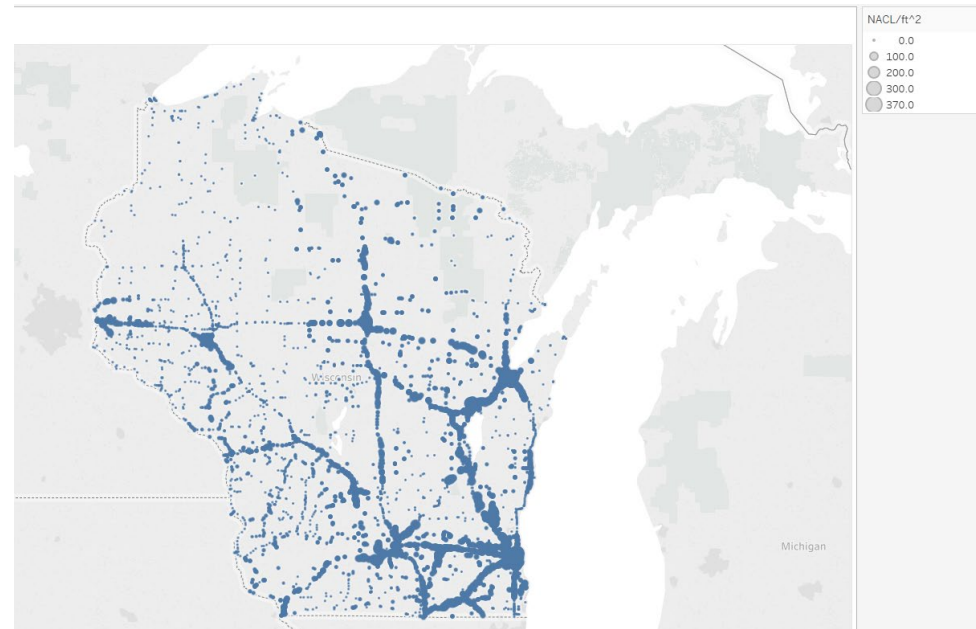
Data Processing
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AVL Data

Storm Data

Traffic
Operations
Data

- Records for **7** winter seasons were acquired from AVL database
 - 1,172 roadway segments
 - Bridges were spatially joined to roadway segments
 - Amount of salt usage per bridge was calculated
 - Amount of salt usage per sq. ft was calculated
 - Averages of the 7 winters were assigned to each bridge.



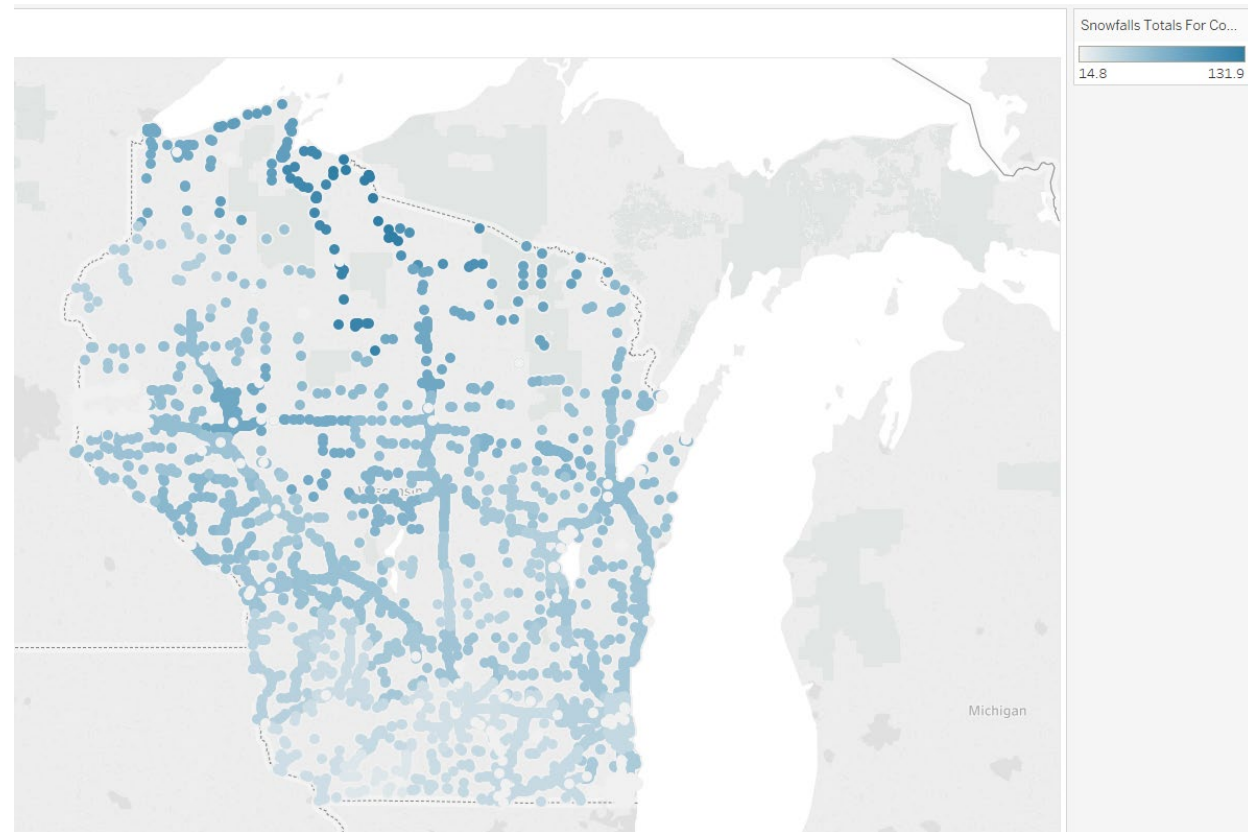
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AVL Data

Storm Data

Traffic
Operations
Data

Storm data for year 2017 and average over the years were used



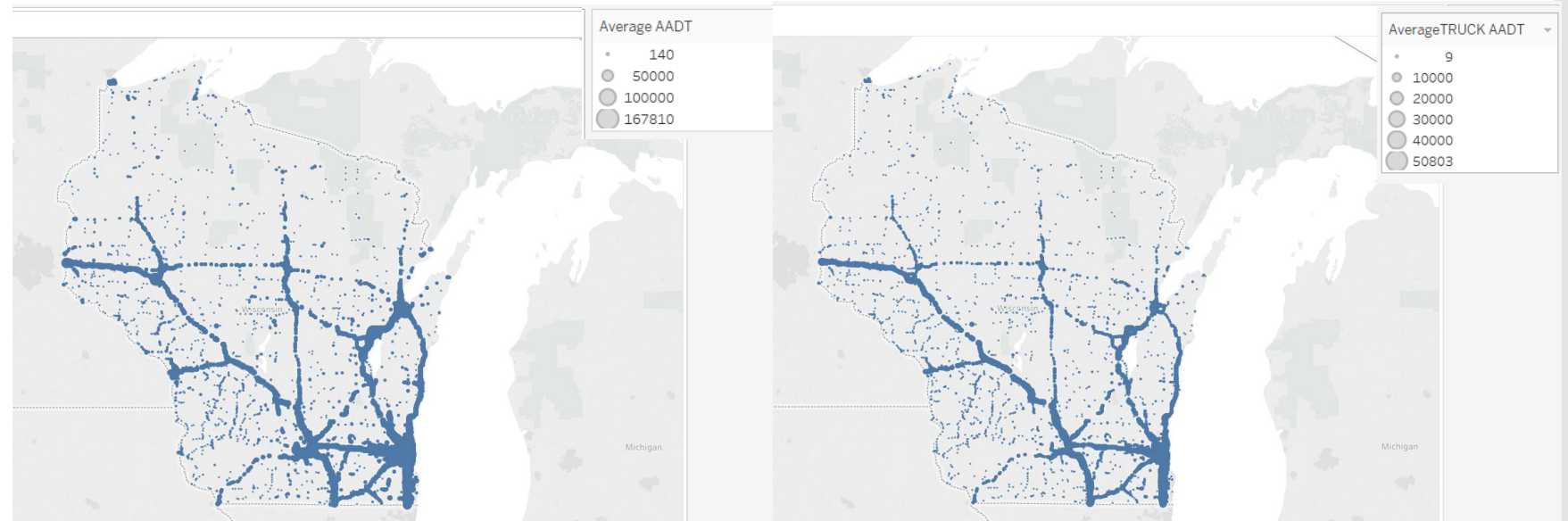
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AVL Data

Storm Data

Traffic
Operations
Data

Average AADT and truck AADT from multiple years of data were used for the analysis.



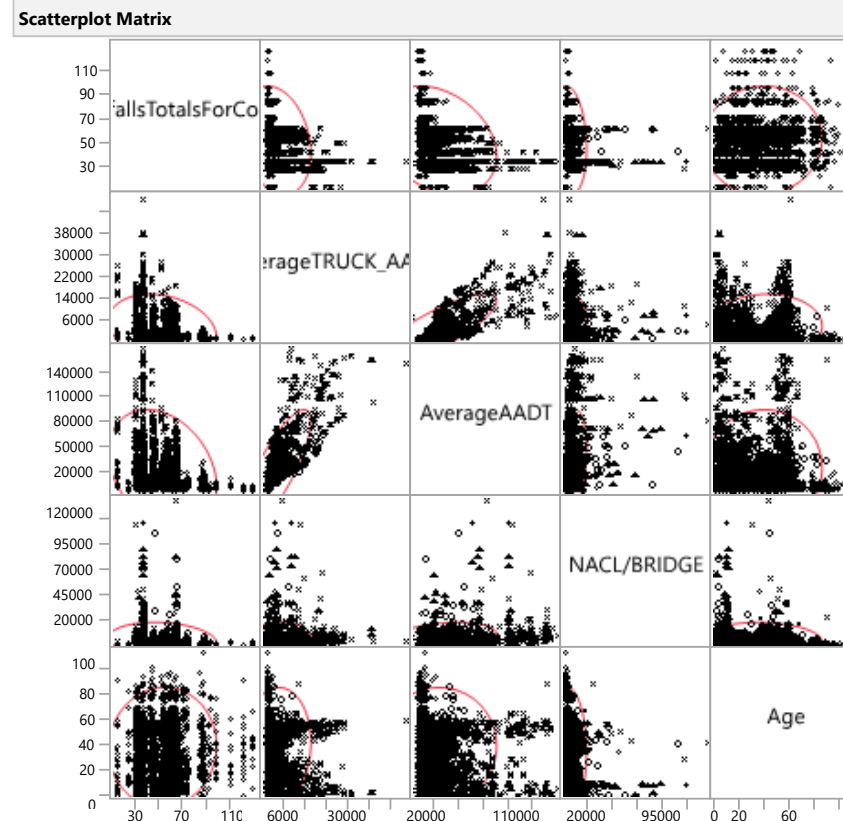
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- Correlations of variables

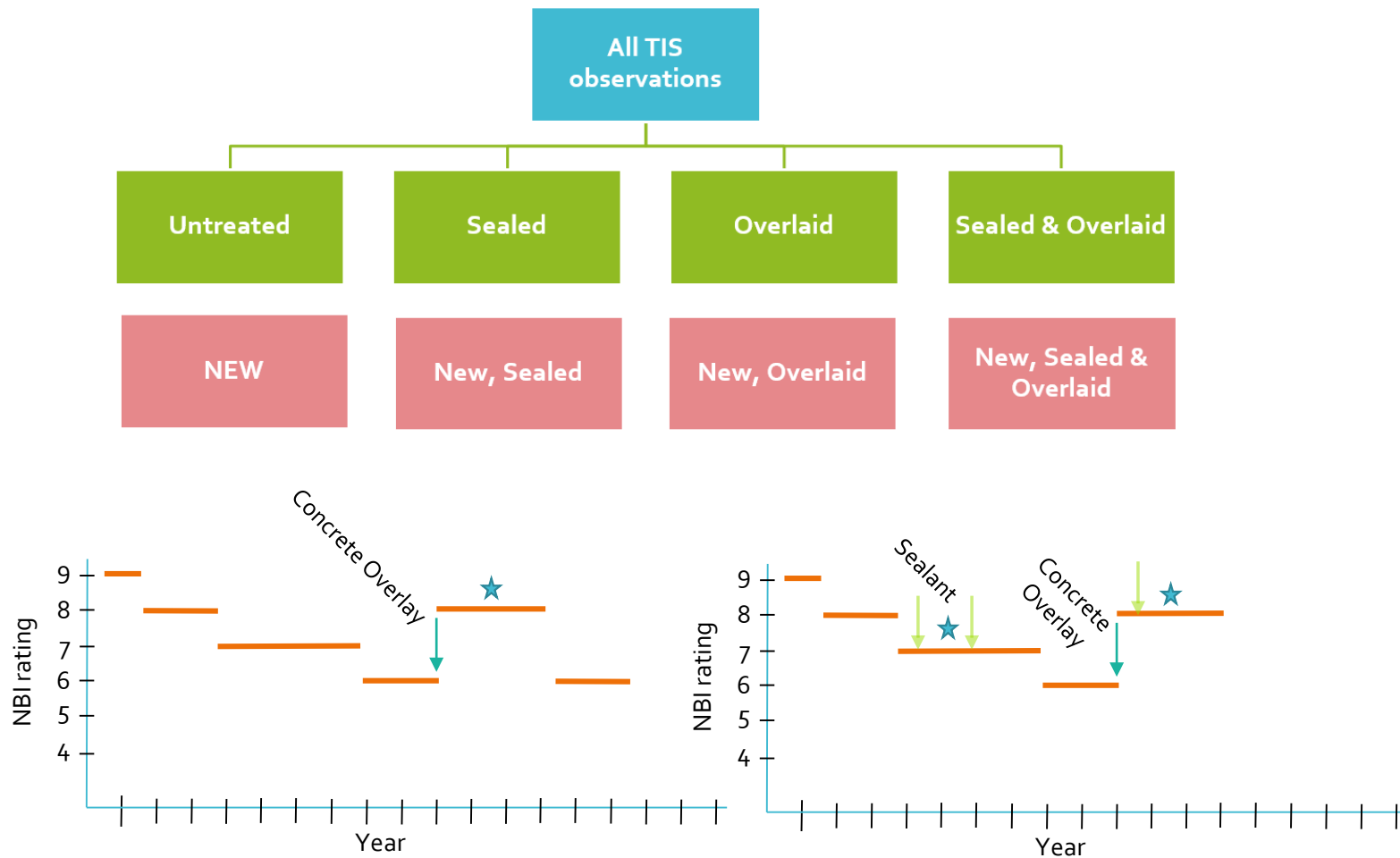
Correlations						
	SnowfallsTotalsForCounties	AverageTRUCK_AADT	AverageAADT	NACL/BRIDGE	Age	
SnowfallsTotalsForCounties	1.0000	-0.2419	-0.2935	-0.1535	0.0292	
AverageTRUCK_AADT	-0.2419	1.0000	0.8091	0.1578	0.0809	
AverageAADT	-0.2935	0.8091	1.0000	0.3585	0.0281	
NACL/BRIDGE	-0.1535	0.1578	0.3585	1.0000	-0.0748	
Age	0.0292	0.0809	0.0281	-0.0748	1.0000	

There are 1948 missing values.

The correlations are estimated by Pairwise method



Data Processing
Additional Factors
Data Categorization
Data Analysis
Future Work



Data Sources
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Rating-level classification, questionable observations excluded.
This is a one-dimensional analysis of TIS.

	Median for each NBI rating					
Type (Bridge-level)	4	5	6	7	8	9
New	3	4	5	6	4	2
Overlaid	3	4	4	5	4	2
Sealed	4	4	4	6	5	2
Sealed & Overlaid	2	3	4	5	3	2
Untreated	4	4	4	4	3	2

	Mean for each NBI rating					
Type (Bridge-level)	4	5	6	7	8	9
New	3.84	4.76	6.64	7.56	5.92	2.22
Overlaid	4.23	5.35	6.28	6.58	4.81	2.31
Sealed	3.73	4.52	6.24	8.29	6.32	2.32
Sealed & Overlaid	2.74	4.18	5.03	6.58	4.20	2.31
No Treatment	3.67	4.16	4.20	4.96	3.68	1.65

Data Sources
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	Median for each NBI rating					
Type (TIS-level)	4	5	6	7	8	9
New	5	6	6	6	4	2
Overlayed	4	5	6	6	4	2
Sealed	5	4	5	7	5	2
Sealed & Overlayed	2	4	4.5	6	3	2
Untreated	2	2	3	4	3	2

	Mean for each NBI rating						
Type (TIS-level)	4	5	6	7	8	9	Sum
New	5.47	6.19	7.67	7.79	5.97	2.23	35.32
Overlayed	5.00	6.45	7.84	7.41	5.00	2.33	34.03
Sealed	4.48	4.91	6.62	8.53	6.38	2.32	33.24
Sealed & Overlayed	3.21	5.06	6.24	7.30	4.04	2.31	28.16
Untreated	3.15	3.51	4.11	4.92	4.10	1.69	21.48

Future Analyses

			NBI Rating																							
			4	5	6	7	8	9	4	5	6	7	8	9	4	5	6	7	8	9						
Type	NACL/Brid	Snowfall	AADT/Low (140-7583)						AADT/Med (7583-23466)						AADT/High (23466-167810)											
Untreated	Low (0 - 275.35)	Low (14.8-44.4)	3	13	31	69	82	17	0	1	4	23	28	15	0	1	4	10	13	15						
		Med(44.4-60.4)	8	11	31	60	97	30	10	13	24	36	50	16	0	0	6	10	13	3						
		High (60.4-131.9)	7	26	62	114	172	41	6	14	41	78	84	17	2	4	6	30	25	9						
Low		1	9	31	68	67	27	0	1	1	3	3	0	0	0	0	0	0	0							
Med		7	15	67	134	145	59	0	5	12	18	13	9	1	2	2	10	7	5							
High		5	22	57	110	118	47	0	3	10	15	20	6	3	6	7	11	12	1							
Low		1	16	31	25	15	0	3	9	17	26	18	0	1	3	11	9	3	0							
Med		4	17	34	45	39	4	4	29	70	76	45	1	6	21	31	26	9	1							
High		6	35	62	82	61	8	13	59	98	109	74	5	1	5	9	3	2	0							
Low		4	13	36	39	28	4	0	0	0	0	0	0	0	0	0	0	0	0							
Med		6	20	37	38	31	3	1	5	17	27	22	0	2	13	33	33	10	3							
High		4	10	25	50	29	13	2	12	17	9	7	0	0	2	4	3	1	0							
Untreated	Med (275.35 -2480.9)	Low	0	5	13	50	56	26	7	12	28	60	69	46	5	18	49	68	88	48						
Med		1	2	13	48	39	20	2	3	6	38	59	31	1	3	11	30	41	12							
High		0	3	12	22	20	7	0	3	2	15	21	3	0	0	2	3	6	4							
Low		2	3	9	42	50	31	0	1	2	23	29	32	0	0	0	3	5	5							
Med		5	6	17	70	59	27	3	3	14	66	77	39	2	7	19	32	30	13							
High		6	17	50	102	85	31	1	4	13	34	27	8	0	4	4	9	9	4							
Low		5	14	30	23	14	1	3	25	48	45	35	0	23	42	70	69	32	6							
Med		9	18	32	39	23	9	1	14	43	51	42	7	5	29	77	92	79	16							
High		9	19	43	52	27	6	1	24	40	44	32	8	0	9	8	9	3	0							
Low		0	7	19	25	20	2	0	2	11	36	25	0	2	4	10	12	8	1							
Med		2	8	16	20	17	4	5	22	51	74	53	7	0	3	6	13	4	1							
High		9	23	52	57	10	7	5	22	51	74	53	7	0	3	6	13	4	1							
Untreated	High (2480.9 - 138197)	Low	0	2	4	17	19	9	6	10	36	74	73	59	20	26	76	202	180	119						
Med		1	2	4	14	16	10	0	4	12	38	37	26	0	5	18	59	71	18							
High		0	0	1	1	2	0	2	0	2	4	11	1	1	3	1	13	57	1							
Low		1	2	3	12	10	10	0	0	7	37	36	26	9	13	26	37	26	27							
Med		1	3	6	12	10	3	0	1	14	44	48	22	3	6	30	49	39	7							
High		1	4	20	21	10	4	0	3	19	39	28	5	0	1	3	17	18	8							
Low		1	5	16	10	2	0	11	47	95	59	24	3	38	147	232	154	89	56							
Med		0	1	3	6	3	1	0	2	4	8	4	3	4	22	41	31	29	3							
High		4	12	15	25	16	1	2	7	40	46	34	5	3	19	75	132	122	8							
Low		0	1	0	1	1	0	5	13	54	56	23	2	3	5	27	25	14	1							
Med		1	3	3	7	7	2	0	1	4	3	4	0	2	3	17	14	10	0							
High		0	4	9	11	7	0	3	8	32	52	34	2	0	6	16	45	37	0							



Analyses with South Dakota Data



Data Sources

Data Processing

Data Categorization

Results & Analysis

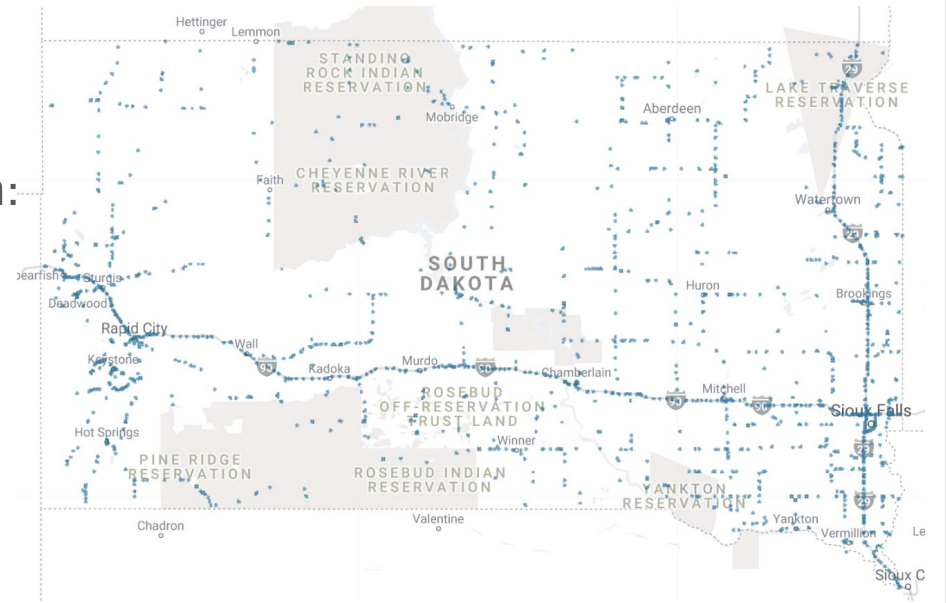
Additional Factors

Conclusions

NBI

Condition Ratings Data

- **5,824** Structures
 - **1,795** State-owned
- A tool was employed to obtain:
 - Time-in-State (TIS)
 - Condition ratings from 1990 to 2017
 - Each bridge could have multiple observations



Data Sources

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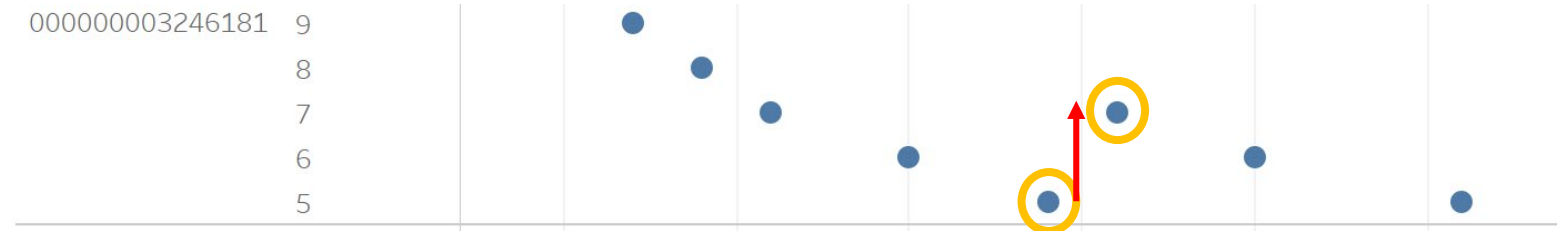
Results & Analysis

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Data Investigation

Data Issues



A Bridge Timeline

Such observations were removed from the analysis since no treatment records were recorded.

- Culverts were removed from the analysis

Data Sources
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Treatment Groups

Overlays Applied

Concrete
Overlay

LSDC

High
Performance
Concrete (HPC)

LMC

Asphalt
Overlay

RACS

Membrane with
2" AC overlay

Asphalt mat over
RACS

Epoxy

Epoxy Seal Coat
(2nd layer)

Epoxy seal coat
over Epoxy Bars

Epoxy seal coat
over LMC

Epoxy-
coated
rebars

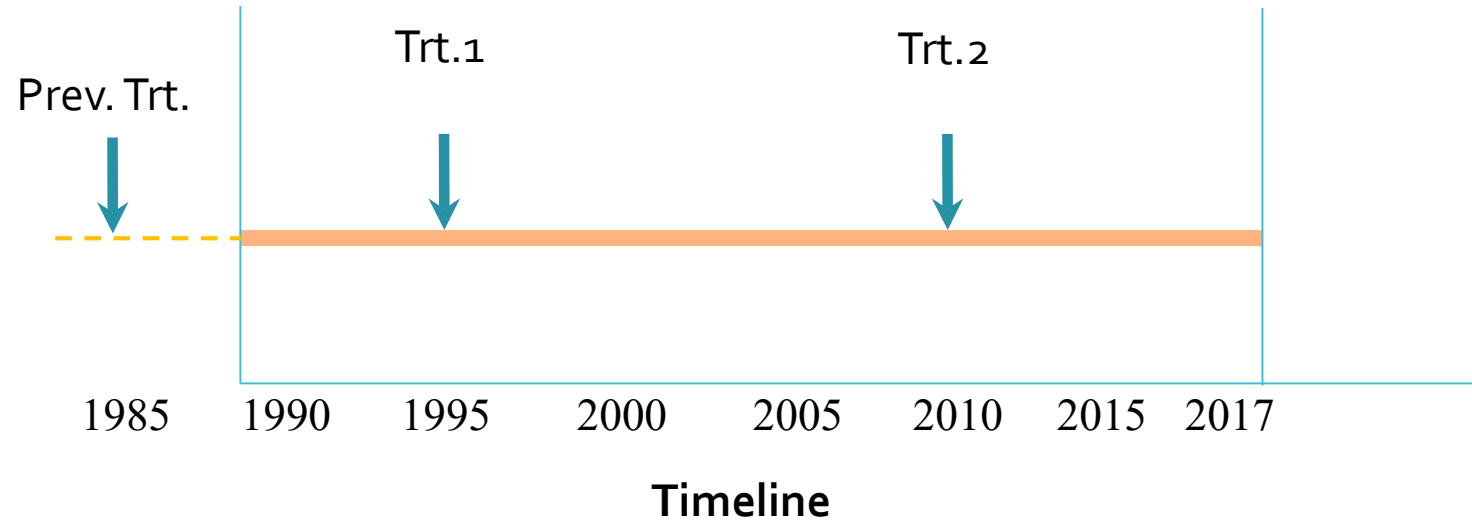
EB (TOP MAT
ONLY)

EB
W/POLYOLEFIN
FIBERS

Data Sources
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Treatment Combinations

Overlays Applied



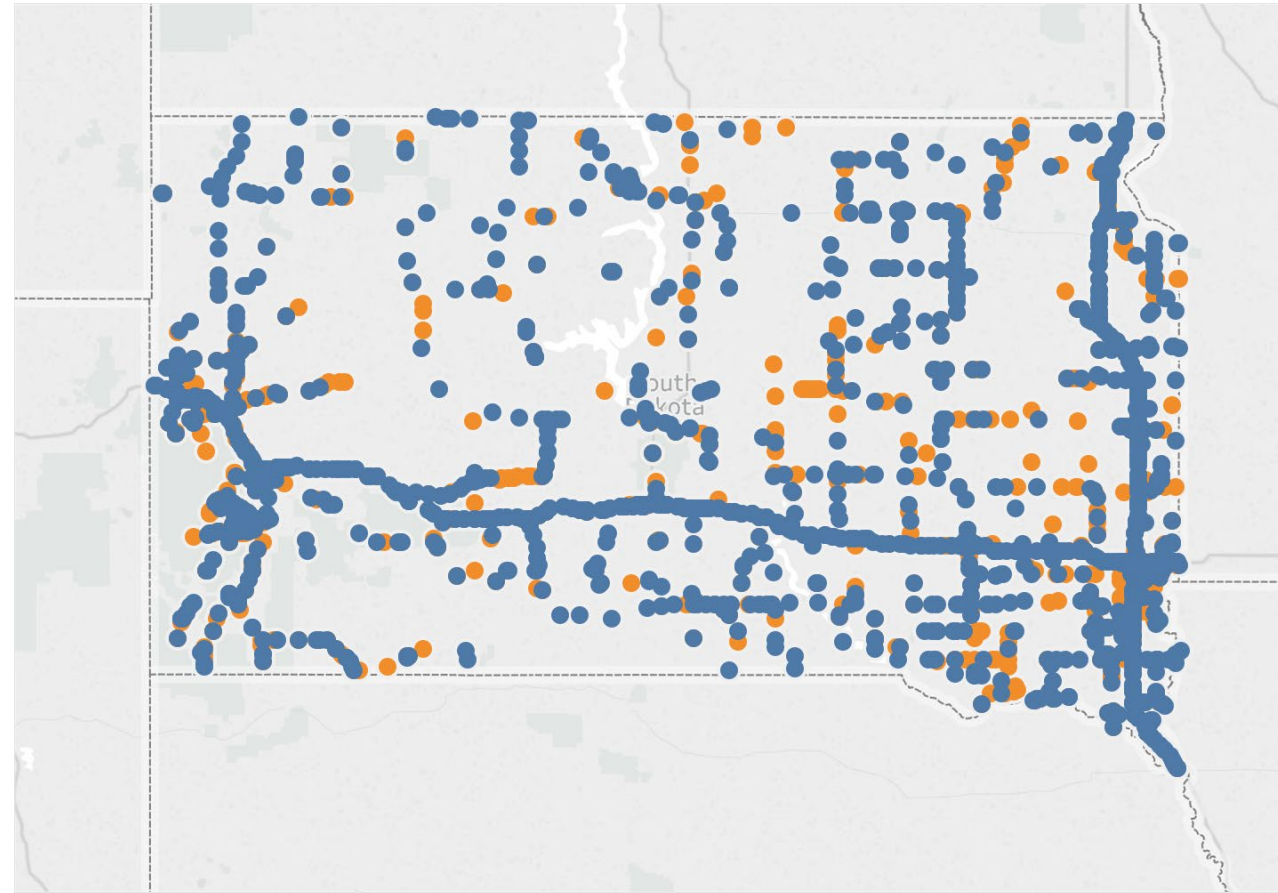
Treatments Combination = Prev. Trt. >> Trt.1 >> Trt.2

E.g. Concrete Overlay >> Asphalt Overlay >> Asphalt Overlay

Data Sources
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Action on Data Issue

■ Keep

■ Remove

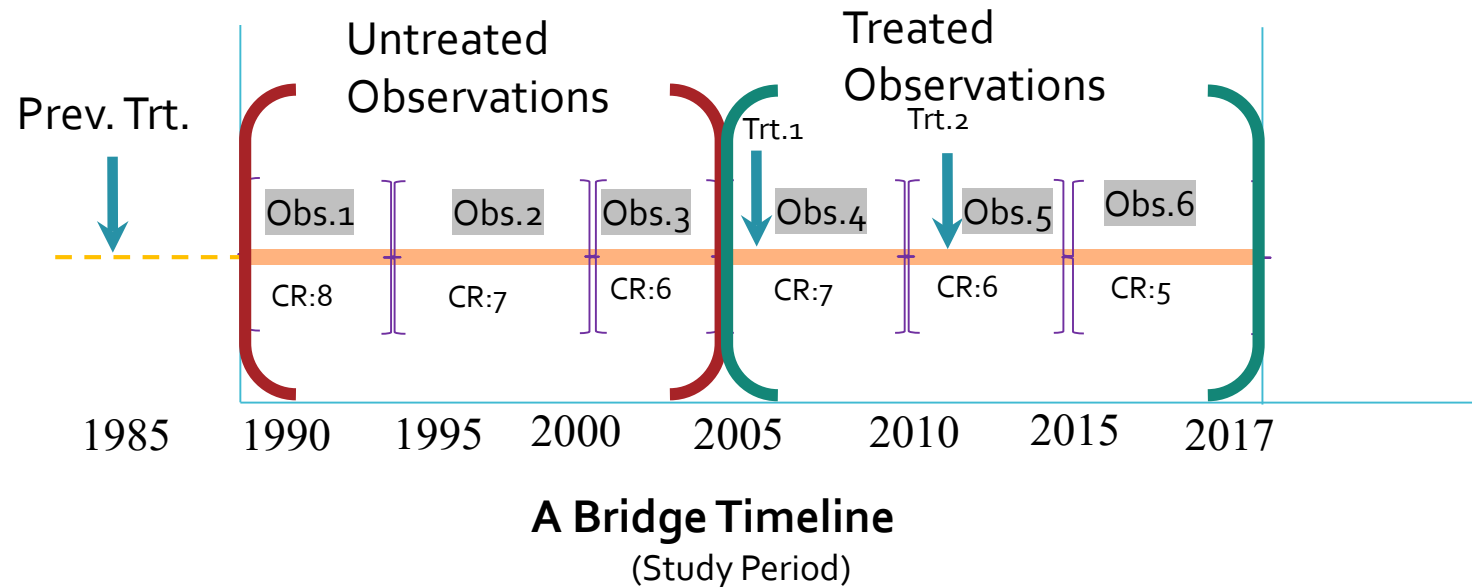
- Total Number of observations = 6,273
- Number of observations without culverts or data issues = 5,407

Map based on Longitude and Latitude. Color shows details about Action on Data Issue.

Data Sources
Data Processing
Data Categorization
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Treatments Combination

Multiple observations for
one bridge



Observation= Time in state (TIS)

E.g. Obs.1 remained 4 years in CR8 before transitioning to CR7

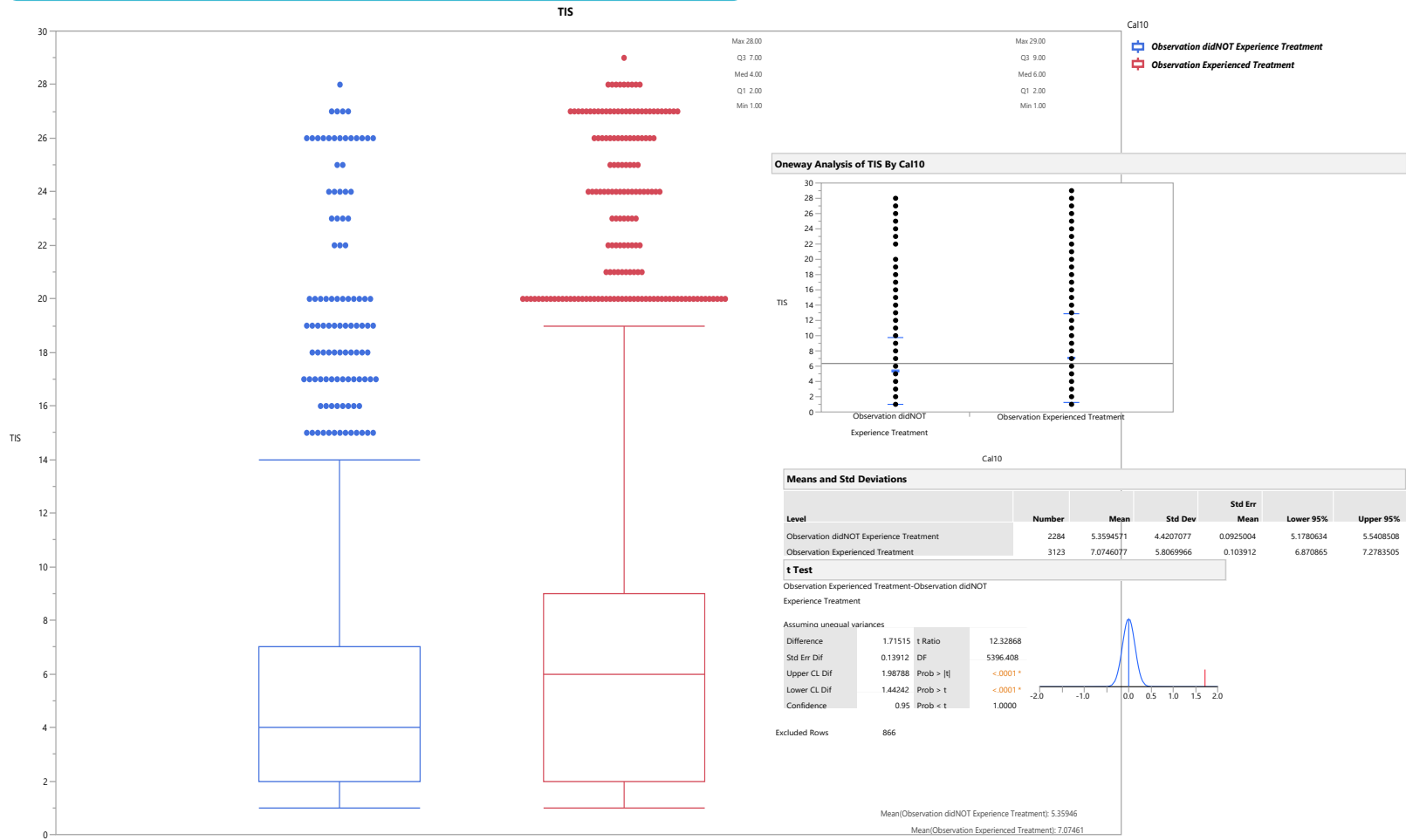
- **A bridge is considered untreated if it has not experienced treatments in any observation.**

[] • Observation did not experience treatment
[] • Observation experienced treatment

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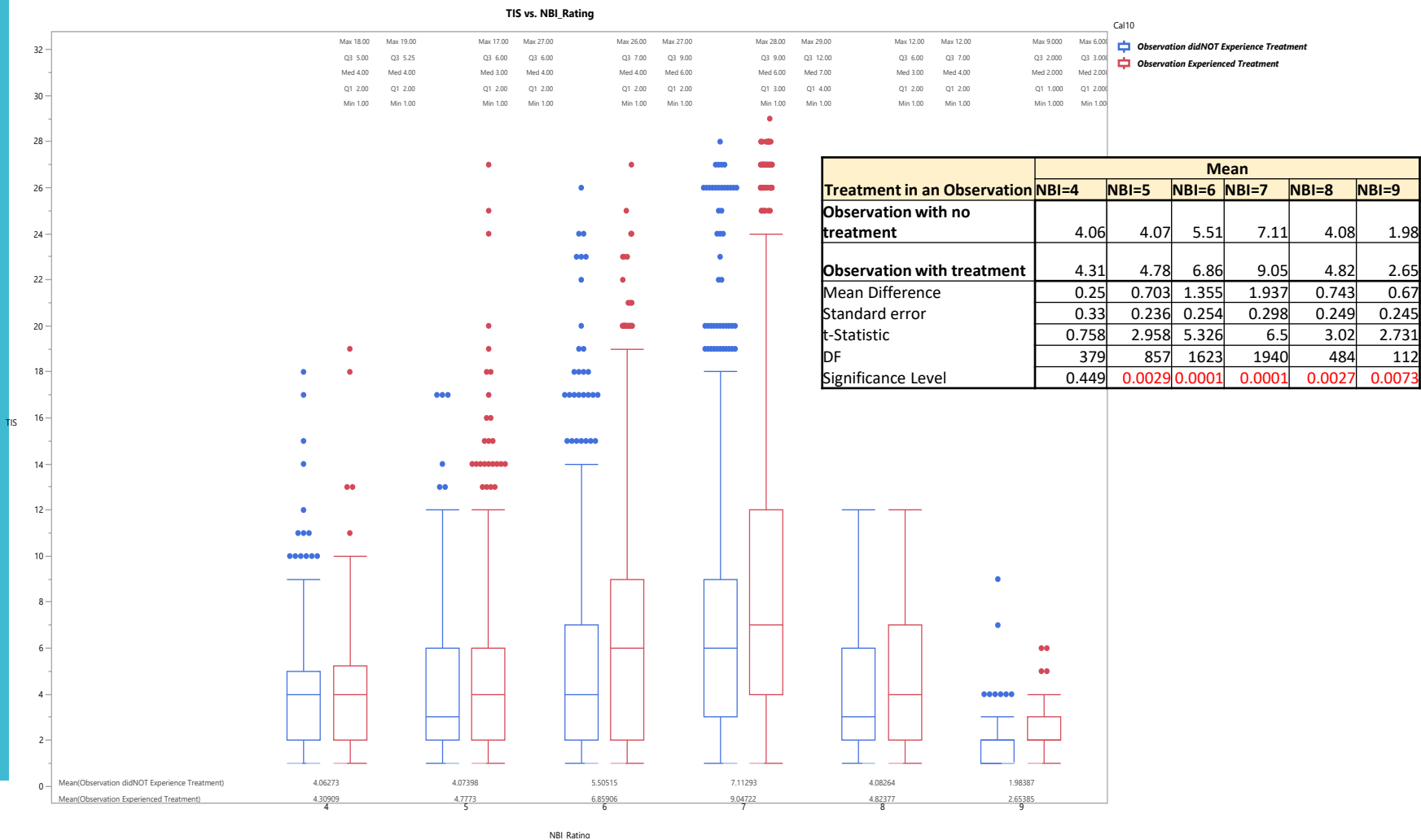
Treated vs. Untreated



Data Sources
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Data Analysis

Treated Vs. Untreated By
CR



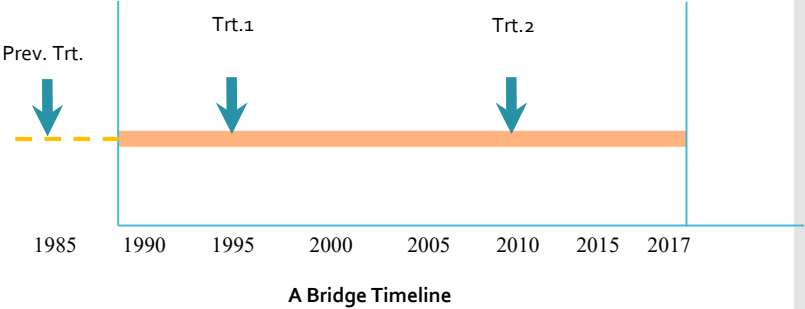
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Data Analysis

Means Comparisons		
Comparisons with a control using Dunnett's Method		
Control Group = No Treatment in Observation		
Confidence Quantile		
d		Alpha
3.10662		0.05
LSD Threshold Matrix		
Level	Abs(Diff)	p-Value
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	3.045	0.0003 *
Epoxy>>[Concrete Overlay>Epoxy]	2.917	<.0001 *
Epoxy-coated rebars	2.446	<.0001 *
[Concrete Overlay>Epoxy]	1.292	<.0001 *
Epoxy>>Epoxy	-2.78	0.9431
Asphalt Overlay	0.617	0.0015 *
[Concrete Overlay>Epoxy]>>Epoxy-coated rebars	-2.34	0.9823
[Concrete Overlay>Epoxy]>>Asphalt Overlay	-0.99	0.6666
Concrete Overlay>>Epoxy	0.808	<.0001 *
Epoxy	0.75	<.0001 *
Concrete Overlay	0.897	<.0001 *
Asphalt overlay>>Asphalt overlay	-4.41	1.0000
Unidentified>>Epoxy-coated rebars	-15.1	1.0000
Concrete Overlay>>Concrete Overlay>>Epoxy	-1.96	0.9983
Epoxy>>Epoxy-coated rebars	-5.48	1.0000
Concrete Overlay>>Asphalt Overlay>>Asphalt Overlay	-3.01	1.0000
[Concrete Overlay>Epoxy]>>Epoxy	-3.27	1.0000
Asphalt Overlay>>Epoxy	-2.82	1.0000
No Treatment in Observation	-0.52	1.0000
Epoxy>>Asphalt Overlay	-5.22	1.0000
Asphalt Overlay>>[Concrete Overlay>Epoxy]	-3.64	1.0000
Concrete Overlay>>Concrete Overlay	-1.47	1.0000
Asphalt Overlay>>Asphalt Overlay	-2.32	1.0000
Concrete Overlay>>Asphalt Overlay	-3.49	1.0000
Unidentified	-11.2	1.0000
Epoxy-coated rebars>>Epoxy-coated rebars	-4.29	1.0000
Asphalt Overlay>>Asphalt Overlay>>Asphalt Overlay>>Asphalt Overlay	-5.89	1.0000
Epoxy>>Concrete Overlay	-7.71	1.0000

Positive values show pairs of means that are significantly different.

Treatment Combinations



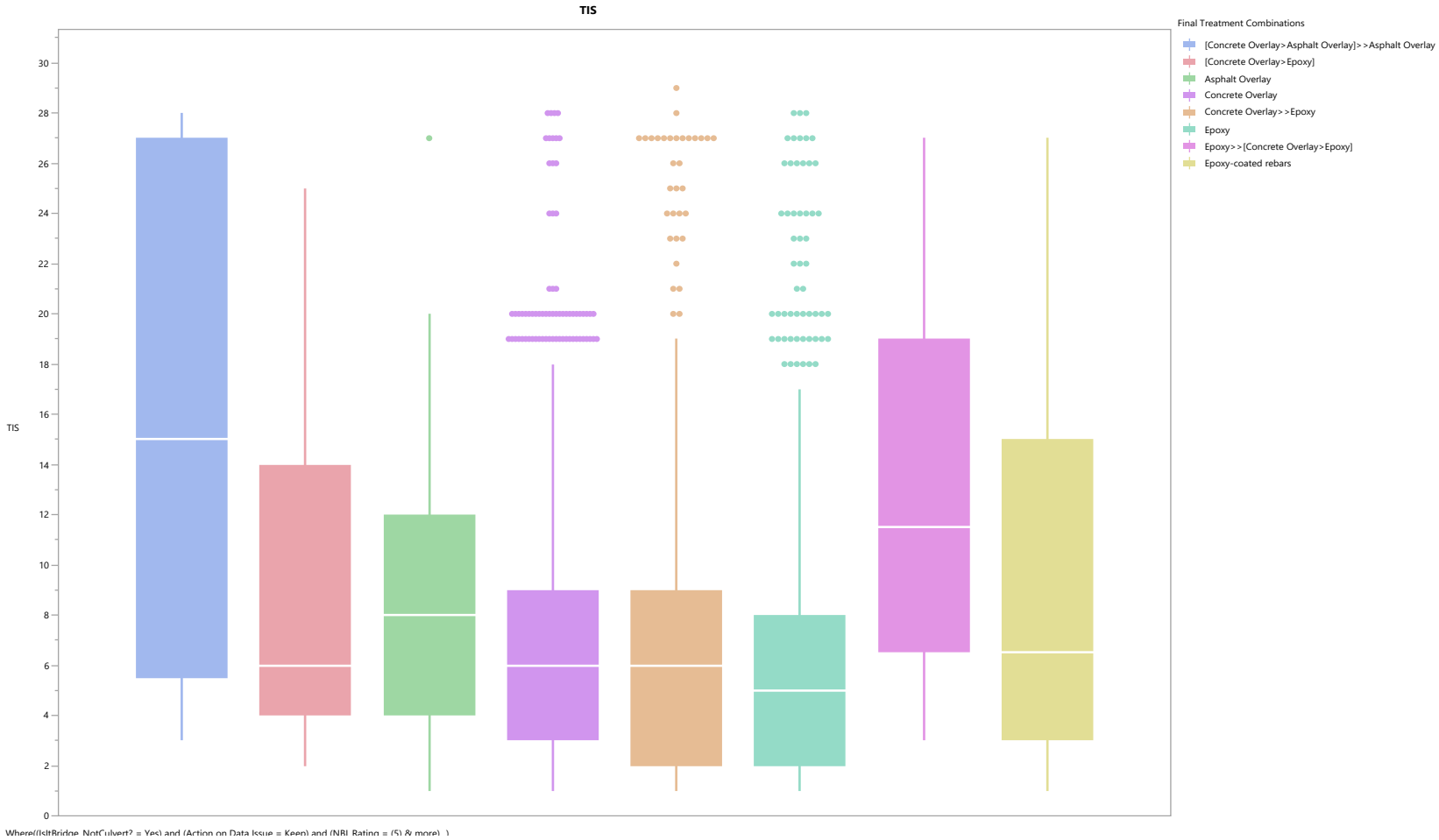
Treatments Combination = Prev. Trt. >> Trt.1 >> Trt.2

E.g. Concrete Overlay >> Asphalt Overlay >> Asphalt Overlay

Data Analysis

Treatment Combinations

Data Sources
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Data Analysis

Treatment Combinations

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	Concrete Overlay	8.936782	2.668554	3.70408	14.16948	0.0008*	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	Concrete Overlay	8.927690	2.673899	3.68451	14.17087	0.0009*	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	Concrete Overlay	8.903937	2.672647	3.66321	14.14466	0.0009*	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	Concrete Overlay	7.791045	2.759734	2.37955	13.20254	0.0048*	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	A	6.909091	2.780563	1.45676	12.36142	0.0130*	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	A	6.870690	2.690721	1.59453	12.14685	0.0107*	
Epoxy>>Epoxy-coated rebars	B	6.186782	1.728282	2.79784	9.57572	0.0004*	
Epoxy>>[Concrete Overlay>Epoxy]	B	6.177690	1.736523	2.77259	9.58279	0.0004*	
Epoxy>>Asphalt Overlay	B C	6.153937	1.734595	2.75262	9.55526	0.0004*	
Epoxy>>Concrete Overlay>>Epoxy	C	5.041045	1.865989	1.38208	8.70001	0.0069*	
Epoxy>>Epoxy	C	4.159091	1.896657	0.43999	7.87820	0.0284*	
Epoxy>>Concrete Overlay	C	4.120690	1.762316	0.66501	7.57637	0.0195*	
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay		2.750000	3.168636	-3.46329	8.96329	0.3855	
Epoxy-coated rebars		2.066092	0.432070	1.21886	2.91333	<.0001*	
Epoxy-coated rebars							
Epoxy-coated rebars							
[Concrete Overlay>Epoxy]							
[Concrete Overlay>Epoxy]							
[Concrete Overlay>Epoxy]							
Asphalt Overlay							
Asphalt Overlay							
Asphalt Overlay							
Epoxy-coated rebars							
[Concrete Overlay>Epoxy]							
Epoxy-coated rebars							
Concrete Overlay>>Epoxy							
Concrete Overlay>>Epoxy							
Epoxy							
Concrete Overlay							

Connecting Letters Report

Level	Mean
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	A
Epoxy>>[Concrete Overlay>Epoxy]	A
Epoxy-coated rebars	B
[Concrete Overlay>Epoxy]	B
Asphalt Overlay	B C
Concrete Overlay>>Epoxy	C
Epoxy	C
Concrete Overlay	C

Levels not connected by same letter are significantly different.

Final Treatment Combinations

	N	Mean
[Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay	5	16
[Concrete Overlay>Epoxy]	55	9.090909
Asphalt Overlay	67	8.208955
Concrete Overlay	1051	7.107517
Concrete Overlay>>Epoxy	635	7.096063
Epoxy	560	6.989286
Epoxy>>[Concrete Overlay>Epoxy]	12	13.25
Epoxy-coated rebars	232	9.12931

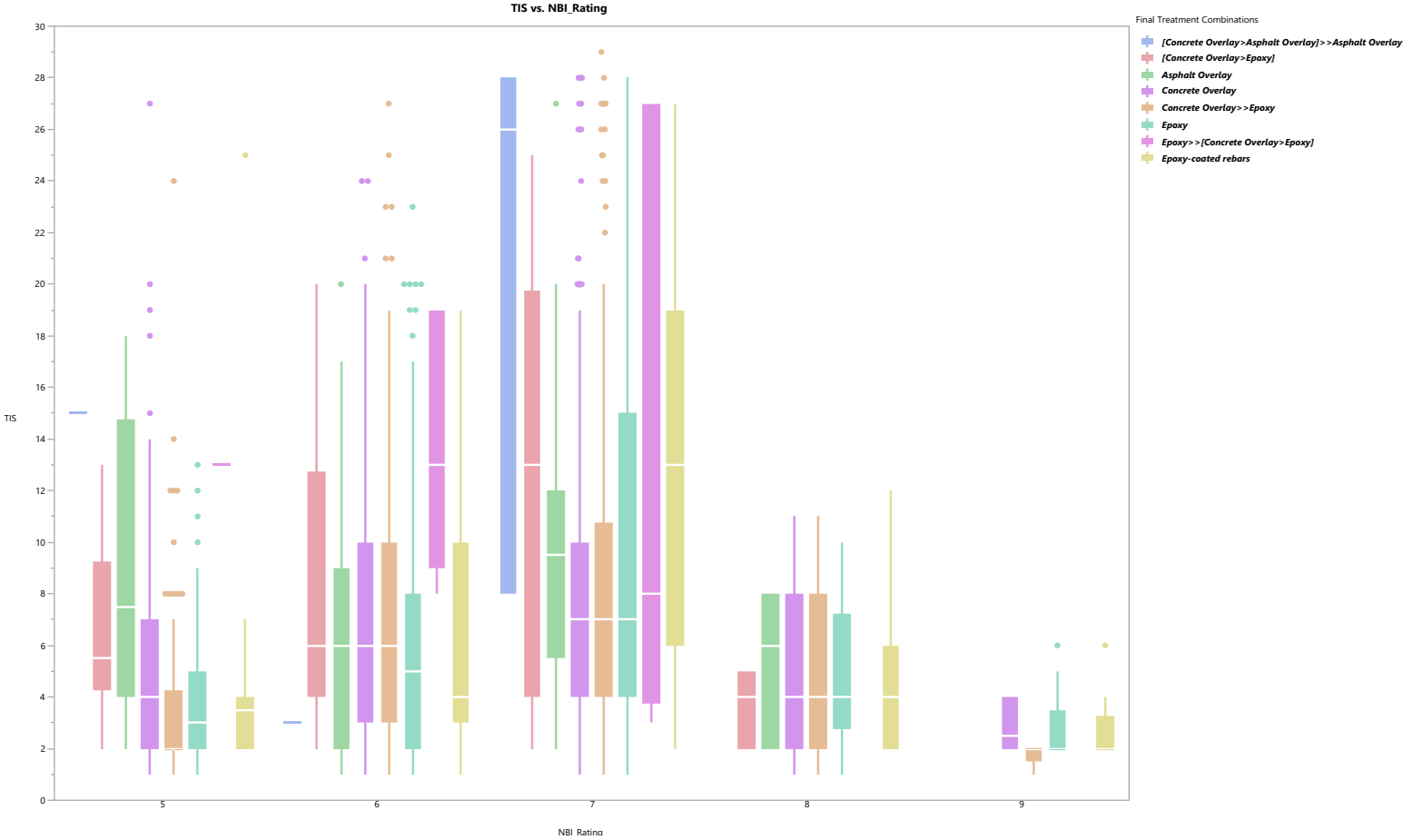
Epoxy	0.023753	0.343952	-0.65069	0.69820	0.9449
Concrete Overlay	0.009092	0.310549	-0.59985	0.61804	0.9766

Reference TIS (Untreated) 5.4

Data Sources
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Results & Analysis
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Data Analysis

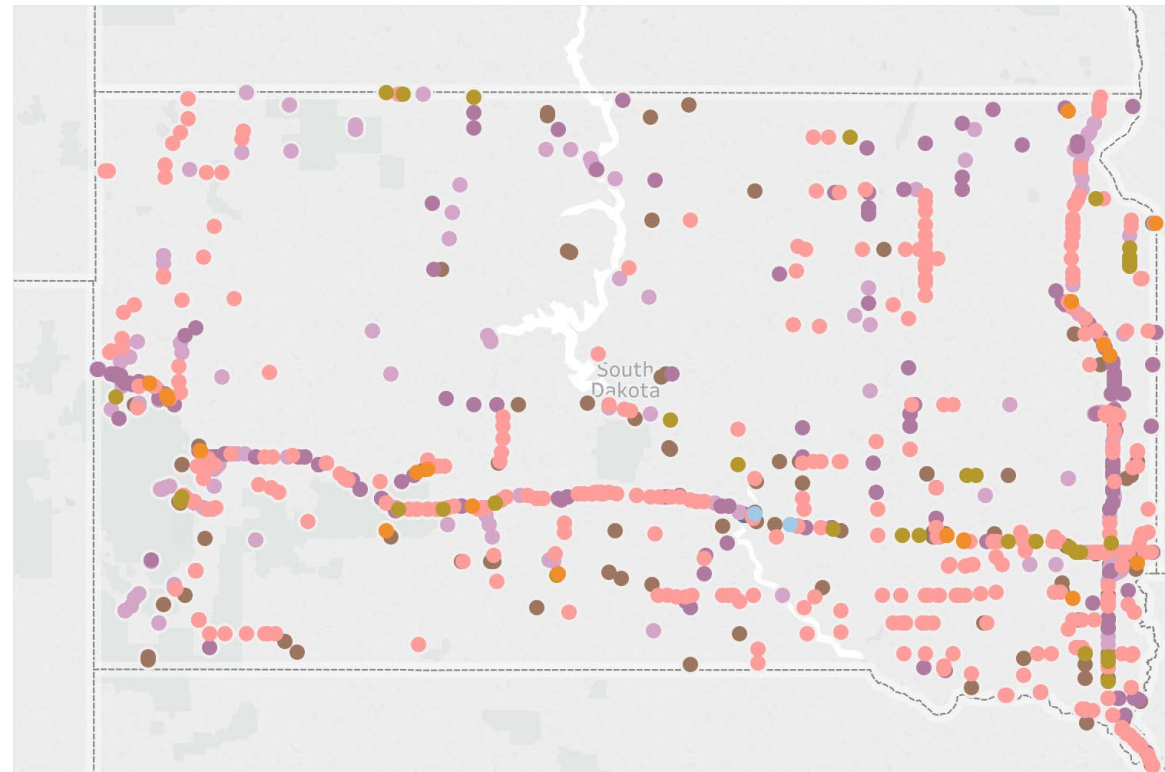
Sig. Treatment
Combinations TIS by CR



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Treatment Combinations Map



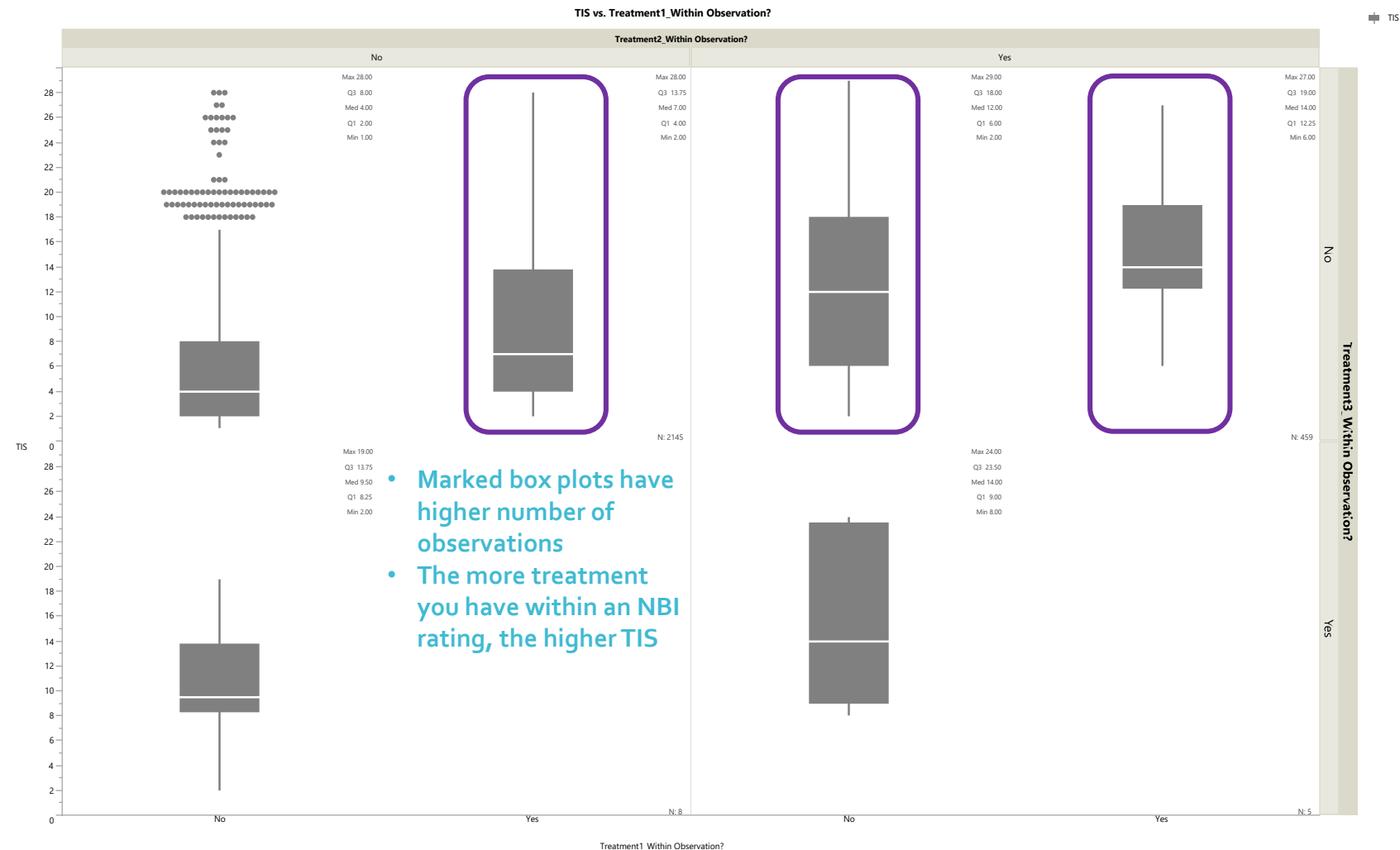
Final Treatment Combinations

- [Concrete Overlay>Asphalt Overlay]>>Asphalt Overlay
- [Concrete Overlay>Epoxy]
- Asphalt Overlay
- Concrete Overlay
- Concrete Overlay>>Epoxy
- Epoxy
- Epoxy-coated rebar
- Epoxy>>[Concrete Overlay>Epoxy]

Map based on Longitude and Latitude. Color shows details about Final Treatment Combinations. The data is filtered on Action on Data Issue, NBI Rating, Cal10 and Analysis Focus Treatments combination?. The Action on Data Issue filter keeps Keep. The NBI Rating filter keeps 5, 6, 7, 8 and 9. The Cal10 filter keeps Observation Experienced Treatment. The Analysis Focus Treatments combination? filter keeps Statistically Significant Treatment.

Data Analysis

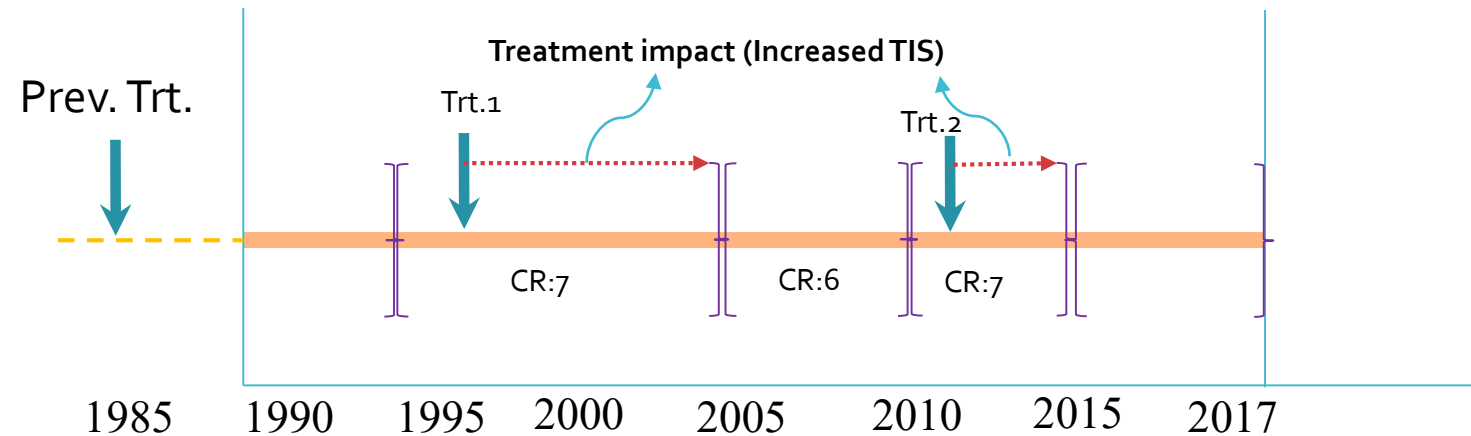
Treatments within observations



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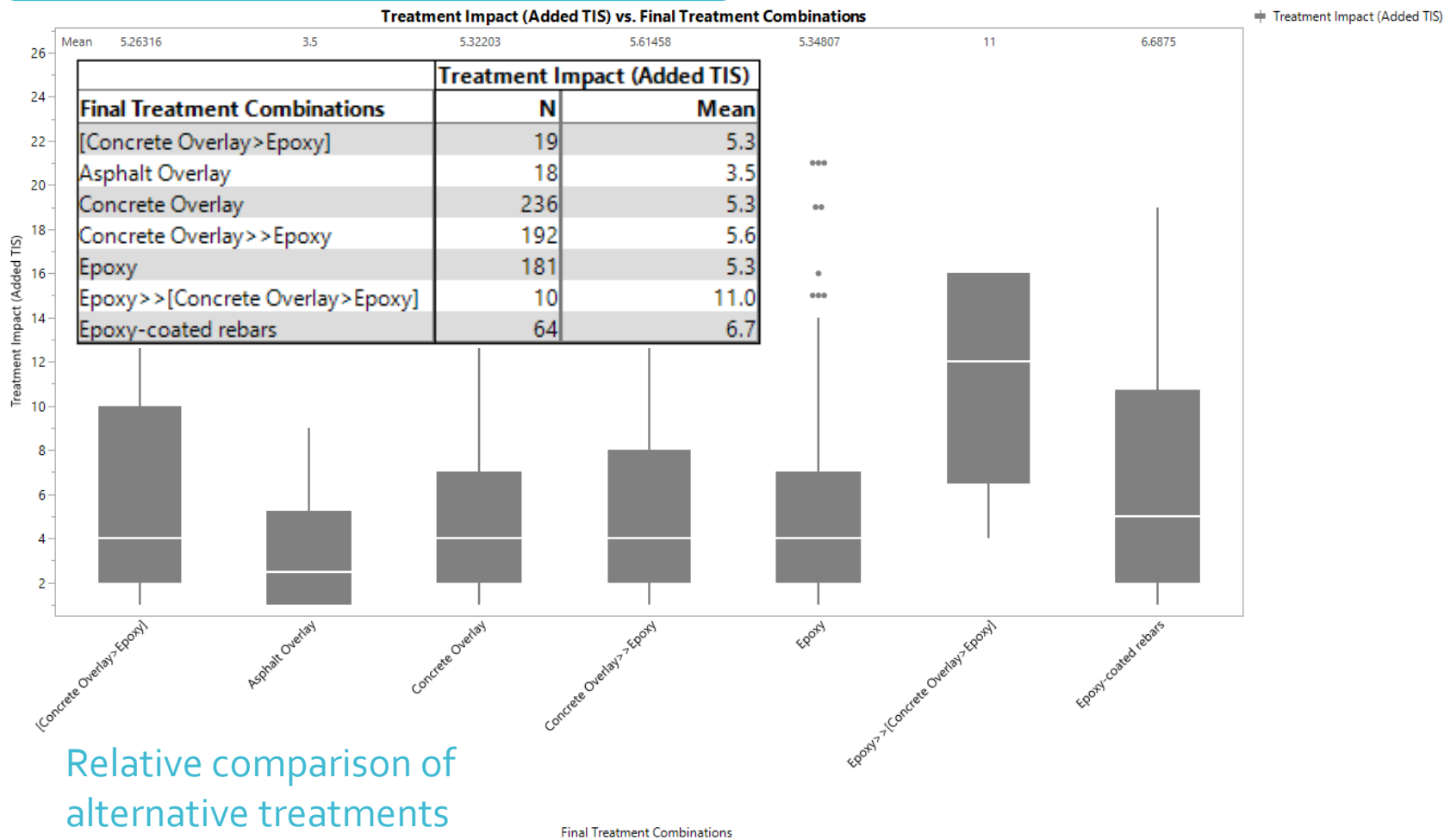
Treatment Impact



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Data Analysis

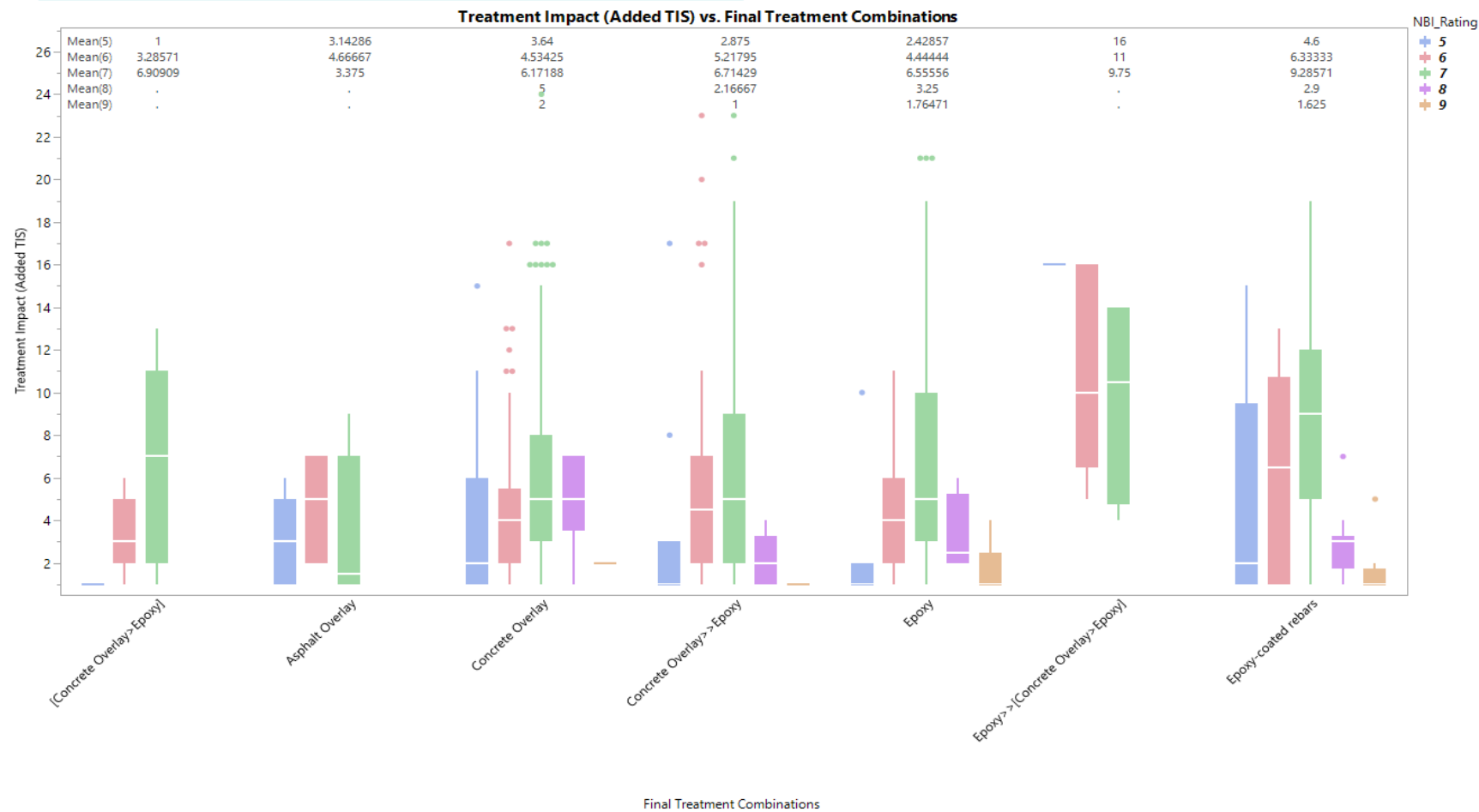
Treatment Impact for Significant Treatment Combinations



Data Sources
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Data Analysis

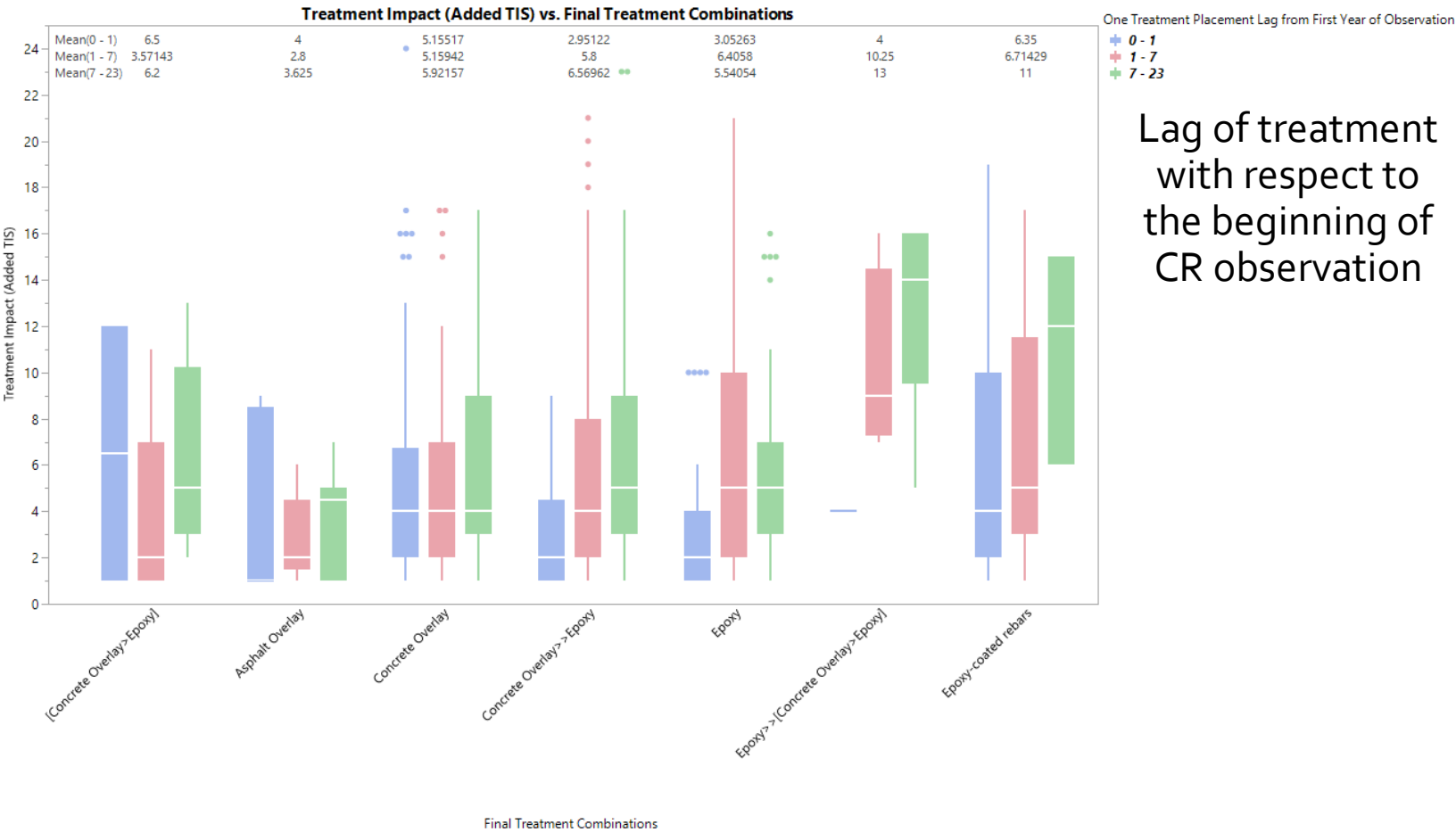
Sig. Treatment
Combinations vs. Treatment
Impact by CR



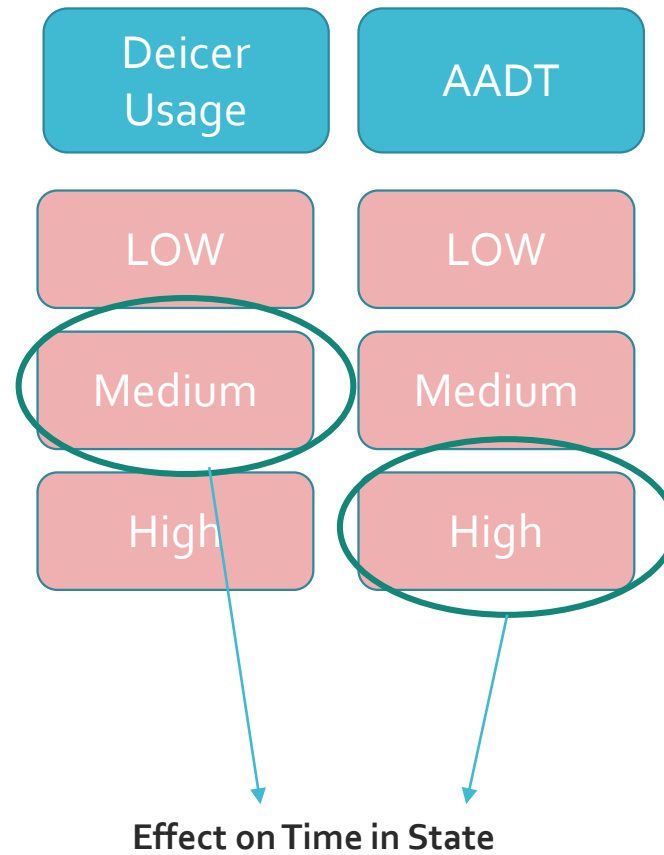
Data Analysis

Impact of Treatment Timing

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Data Sources
Data Processing
Data Categorization
Results & Analysis
Additional Factors
Conclusions



Future Work

- Refinement of Wisconsin performance and deterioration models
 - Impact of traffic, snowfall and deicer usage on performance
- Analyses for Minnesota and Michigan
 - Michigan bridge numbers
- Combining the analyses results for a cost effective LCP for Wisconsin decks and decision making guidelines
 - Ideal timing of treatments
 - Combination of treatments
 - Added life
- Project completion: July, 2020



Thank you!

- Questions?
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