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Calibration / Development of Safety Performance Functions for New Jersey

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Overview

- Background on Safety Performance Functions and Highway Safety Manual
- Project Objectives
- Literature Review
- Compiled Dataset
- Rural Two-Lane Intersections
- Rural Two-Lane Segments
- Next Steps

Brief Review of the Safety Performance Functions (SPF)

- **SPF Fundamentals**
  - The basic of the predictive models in the Highway Safety Manual (HSM)
  - Estimates the predicted average frequency of individual roadway segments or intersections for specific base conditions.
  - Developed with observed crash data for a set of similar sites (intersections or homogenous roadway segments)
- **Calibration**
  - General level of crash frequencies may vary for different jurisdictions
  - SPFs in the HSM are developed using data from other states, cannot be transferred directly to other locations and times
- **Crash Modification Factors (CMFs)**
  - To account for differences between the base conditions and the specific conditions of the facility site

Brief Review of the Safety Performance Functions (SPF)

- Functional Form of SPFs in the HSM

Rural 2-lane segments

$$N = (AADT)(L)(365)(10^{-6})(e^{-a})$$

Rural multilane and urban segments

$$N = \exp(a + b.\ln(AADT) + \ln(L)$$

Intersections

$$N = \exp(a + b.\ln(AADT_{maj}) + c.\ln(AADT_{min})$$

Where, *N* is the predicted number of crashes, *L* is segment length, *AADT* is annual average daily traffic of roadway segment, $AADT_{maj}$ and $AADT_{min}$ is AADT on major and minor intersection legs, respectively.

Facilities in the HSM

Rural Two-Lane, Two-Way Roads

Type	HSM	NJ	Acronyms	Definition
Roadway Segments	√	√	R2U	Rural two lane roads
Intersections	√	√	R23ST	Three-leg minor road stop controlled intersections on rural two lane roads
		√	R23SG	Three-leg signalized intersections on rural two lane roads
	√	√	R24ST	Four-leg minor road stop controlled intersections on rural two lane roads
	√	√	R24SG	Four-leg signalized intersections on rural two lane roads

Rural Multilane Highways

Type	HSM	NJ	Acronyms	Definition
Roadway Segments	√	√	R4U(RMU)	Rural four-lane undivided roads
	√	√	R4D(RMD)	Rural four-lane divided roads
			R4F	Rural four-lane freeways
			R6+F	Rural six+ lanes freeways
Intersections	√	√	RM3ST	Three-leg minor road stop controlled intersections on rural four lane roads
		√	RM3SG	Three-leg signalized intersections on rural four lane roads
	√	√	RM4ST	Four-leg minor road stop controlled intersections on rural four lane roads
	√	√	RM4SG(R44SG)	Four-leg signalized intersections on rural four lane roads
			RAST	Rural all-way stop controlled intersections

Facilities in the HSM

Urban and Suburban Arterials

Type	HSM	NJ	Acronyms	Definition
Roadway Segments	√	√	U2U	Two lane urban and suburban arterials
	√	√	U3T	Three lane (with center TWLTL) urban and suburban arterials
	√	√	U4U(UMU)	Four lane undivided urban and suburban arterials
	√	√	U4D(UMD)	Four lane divided urban and suburban arterials
			U4F	Four-lane urban freeways
	√	√	U5T	Five lane (with center TWLTL) urban and suburban arterials
			U6F	Six-Lane urban Freeways
			U8+F	Eight-Lane urban Freeways
			U1A	Urban one-Way Arterials
Intersections	√	√	U3ST	Three-leg minor road stop controlled intersections on urban and suburban arterials
	√	√	U4ST	Four-leg minor road stop controlled intersections on urban and suburban arterials
	√	√	U3SG	Three-leg signalized intersections on urban and suburban arterials
	√	√	U4SG	Four-leg signalized intersections on urban and suburban arterials
			UAST	Urban all-way stop controlled intersections

Data Requirements

- Data needed for Calibration SPF per Facility Type in HSM

  ★-required

  ☆-desired

Data Elements	Data Requirements per Facility Type																	
	Rural Two-Lane, Two-way Roads				Rural Multilane Highways					Urban and Suburban Arterials								
	R2U	R23ST	R24ST	R24SG	R4U	R4D	RM3ST	RM4ST	RM4SG	U2U	U3T	U4D	U4U	U5T	U3ST	U4ST	U3SG	U4SG
AADT of Major Road	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
AADT of Minor Road		★	★	★			★	★	★						★	★	★	★
Segment Length	★				★	★				★	★	★	★	★				
Lane Width	★				★	★												
Shoulder Width	★				★	★												
Shoulder Type	★				★													
Horizontal Curve Data	★																	
Vertical Grades	☆																	
Driveway Density	☆									★	★	★	★	★				
Centerline Rumble Strips	☆																	
Passing Lanes	☆																	
Four-lane Section	☆																	
TWLTLs	★																	
Roadside Hazard Rating	☆																	
Side Slope					★													
Roadside Fixed Object Density										☆	☆	☆	☆	☆				
Median Type and Width						★				★	★	★	★	★				
Lighting	☆	★	★	★	☆	☆	★	★		☆	☆	☆	☆	☆	★	★	★	★
Posted Speed Limit										★	★	★	★	★				
Automated Speed Enforcement	☆				☆	☆				☆	☆	☆	☆	☆			★	★
Intersection Skew Angle		☆	☆				☆	☆										
Left_Turn Signal Phsing																	★	★
Right_Turn Signal Phasing																	★	★
Intersection Left-Turn Lane		★	★	★			★	★							★	★	★	★
Intersection Right-Turn Lane		★	★	★			★	★							★	★	★	★
Right-turn-on-red Prohibited																	★	★
On-street Parking Type										★	★	★	★	★				
Maximum lanes for pedestrian crossing																	☆	☆
Pedestrian Volumes																	☆	☆
Bus Stops within 1000 ft																	☆	☆
Schools within 1000 ft																	☆	☆
Alcohol sales establishments within 1000 ft																	☆	☆

Objectives

- To let the SPFs better accommodate the local data, two strategies are usually taken:
  - To calibrate SPFs provided in HSM so that the contents of HSM can be fully leveraged.
  - To develop location-specific SPFs regardless of the predictive modeling framework in the HSM.

- The main objective of this research project is to either (1) calibrate the SPFs provided in the HSM using New Jersey (NJ) data or (2) develop new NJ-specific SPFs.

- A total of 20 facilities are considered in this project.

- Calibrating the SPFs used in the predictive models of the HSM requires data from a limited number of sites (for each facility type) from NJ.

- Developing NJ-specific SPFs would provide more accurate results but requires data from a larger sample of sites, and also involve the application of statistical techniques.

Progress

Literature Review

- A comprehensive review of the relevant literature has been conducted.
- A common theme in most studies is the ambiguity of some of the HSM guidelines.
- For example, HSM requires homogeneous roadway segments of 0.1 mile or longer. Many studies reported difficulty in following this guideline.
- HSM requires that 30-50 facilities should be used with a total of more than 100 crashes per year for the calibration process. Some studies reported less number of crashes, yet proceeded with the calibration process (e.g. Alluri et al., 2014 – FL study).
- Some studies raised the issue of crash reporting thresholds in the states that the HSM SPFs are based on. (e.g. in OR only crashes with over $1,500 damage are reported as PDO)

Literature Review

- Lack of AADT values, especially at non-state roadways were a common issue. For example, the Oregon study (Dixon et al, 2012) developed model to estimate AADT minor for rural and urban intersections.

- Some studies, such as NC study (Srinivasan and Carter, 2011 and Shin et al. 2014), reported inconsistencies between the electronic database, and suggested manual double-checking the data points.

- The most common issue is the fact that states' data sets were not built for the HSM, and extracting the required and desired data requires excessive manual work. (e.g. curvature data).

- The issues can be broadly classified as (a) Vague HSM guidelines, (b) adequate coverage of traffic data, (c) incomplete data, (d) lack of roadway inventory data, and (e) data integration and interoperability.

Interviews

- The research team reached out to the researchers who conducted SPF projects for other state DOTs, and set up in person meetings (PA, SC, MO, KS, KT, NY).

The following are a few important notes from these interviews:

- Manual data extraction is almost required. The most common tools used are the state-developed video referencing tools and the Google Maps.
- The crash locations as reported by the police officers are found to be erroneous, especially at intersections.
- None of the interviewed states investigated the validity of the AADT for major and minor legs at the intersections. They mentioned that they used the AADT shown in the database and not further looked into proximity of AADT stations to the intersections.

Compiled Data

Available Data Sources

- Data are required for determining homogeneous roadway segments and intersections, calibrating the SPFs, and applying the SPFs to specific roadway segments and intersections.
- The available data sources are:

- Volume Data
  - New Jersey Traffic Monitoring Program 2009-2015
  - TMC at urban intersections
- Road Features Data
  - Straight Line Diagrams (2017)
  - Video Log (Website)
  - Horizontal curvature data on select rural roads
- Voyager Crash Data
  - 2009 to 2016

Additional roadway feature data need to be manually extracted

Data Elements	Rural Two-Lane, Two-way Roads				Rural Multilane Highways				
	R2U	R23ST	R24ST	R24SG	R4U	R4D	RM3ST	RM4ST	RM4SG
Crash	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager
AADT of Major Road	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data
AADT of Minor Road		Traffic Count Data	Traffic Count Data	Traffic Count Data			Traffic Count Data	Traffic Count Data	Traffic Count Data
Segment Length	Segmentation				Segmentation	Segmentation			
Lane Width	SLD->ln_pave_width				SLD->ln_pave_width	SLD->ln_pave_width			
Shoulder Width	SLD->ln_shou_width				SLD->ln_shou_width	SLD->ln_shou_width			
Shoulder Type	SLD->ln_shoulder_type				SLD->ln_shoulder_type				
Horizontal Curve Data	GIS Shape Files								
Vertical Grades	☆								
Driveway Density	SLD->pt_intersection								
Centerline Rumble Strips	SLD->rumble_strip								
Passing Lanes	SLD->ln_passing_zone								
Four-lane Section	SLD->ln_lane_count								
TWLTLs	SLD->ln_lane_count								
Roadside Hazard Rating	☆								
Side Slope					★				
Roadside Fixed Object Density									
Median Type and Width						SLD->ln_median_type SLD->ln_median_width			
Lighting	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	
Posted Speed Limit									
Automated Speed Enforcement	☆				☆	☆			
Intersection Skew Angle		pt_int_approach	pt_int_approach				pt_int_approach	pt_int_approach	
Left_Turn Signal Phasing									
Right_Turn Signal Phasing									
Intersection Left-Turn Lane		manual->google_earth	manual->google_earth	manual->google_earth			manual->google_earth	manual->google_earth	
Intersection Right-Turn Lane		manual->google_earth	manual->google_earth	manual->google_earth			manual->google_earth	manual->google_earth	
Right-turn-on-red Prohibited									
On-street Parking Type									
Maximum lanes for pedestrian crossing									
Pedestrian Volumes									
Bus Stops within 1000 ft									
Schools within 1000 ft									
Alcohol sales establishments within 1000 ft									

Urban and Suburban Arterials								
U2U	U3T	U4D	U4U	U5T	U3ST	U4ST	U3SG	U4SG
Voyager	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager	Voyager
Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data
					Traffic Count Data	Traffic Count Data	Traffic Count Data	Traffic Count Data
Segmentation	Segmentation	Segmentation	Segmentation	Segmentation				
SLD->pt_intersection	SLD->pt_intersection	SLD->pt_intersection	SLD->pt_intersection	SLD->pt_intersection				
☆	☆	☆	☆	☆				
SLD->ln_median_type SLD->ln_median_width	SLD->ln_median_type SLD->ln_median_width	SLD->ln_median_type SLD->ln_median_width	SLD->ln_median_type SLD->ln_median_width	SLD->ln_median_type SLD->ln_median_width				
manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth
SLD->ln_speed	SLD->ln_speed	SLD->ln_speed	SLD->ln_speed	SLD->ln_speed				
☆	☆	☆	☆	☆			n/a	n/a
							manual->google_earth	manual->google_earth
							manual->google_earth	manual->google_earth
					manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth
					manual->google_earth	manual->google_earth	manual->google_earth	manual->google_earth
							manual->google_earth	manual->google_earth
★	★	★	★	★				
							☆	☆
							☆	☆
							GIS Shape Files	GIS Shape Files
							GIS Shape Files	GIS Shape Files
							☆	☆

Rural Two-Lane (R2) Intersections

Background on R2 Intersections

- The HSM has SPF for three types of intersections for R2 roadways:
  - Three-leg stop-controlled intersections (R23ST);
  - Four-leg stop-controlled intersections (R24ST);
  - Four-leg signalized intersections (R24SG).
- Data required by the HSM:

Data Elements	R23ST	R24ST	R24SG
AADT of Major Road	★	★	★
AADT of Minor Road	★	★	★
Lighting	★	★	★
Intersection Skew Angle	☆	☆	
Intersection Left-Turn Lane	★	★	★
Intersection Right-Turn Lane	★	★	★

Note: ★required, ☆ desirable

- The base conditions are: Zero skew angle, no left-turn and right-turn lanes and no lighting present.

Background on R2 Intersections

- SPF-Base Condition

Type	SPF	Reliable AADT Range
R23ST	$N_{spf\ 3ST} = exp[-9.86 + 0.79 \times ln(AADT_{maj}) + 0.49 \times ln(AADT_{min})]$	$AADT_{maj} \in [0,19500]$ $AADT_{min} \in [0,4300]$
R24ST	$N_{spf\ 4ST} = exp[-8.56 + 0.60 \times ln(AADT_{maj}) + 0.61 \times ln(AADT_{min})]$	$AADT_{maj} \in [0,14700]$ $AADT_{min} \in [0,3500]$
R24SG	$N_{spf\ 4SG} = exp[-5.13 + 0.60 \times ln(AADT_{maj}) + 0.20 \times ln(AADT_{min})]$	$AADT_{maj} \in [0,25200]$ $AADT_{min} \in [0,12500]$

- CMF-Specified Condition
  - Four CMFs including intersection skew angle, intersection left-turn lanes, intersection right-turn lanes, lighting are used.

Automatic Identification of Intersections

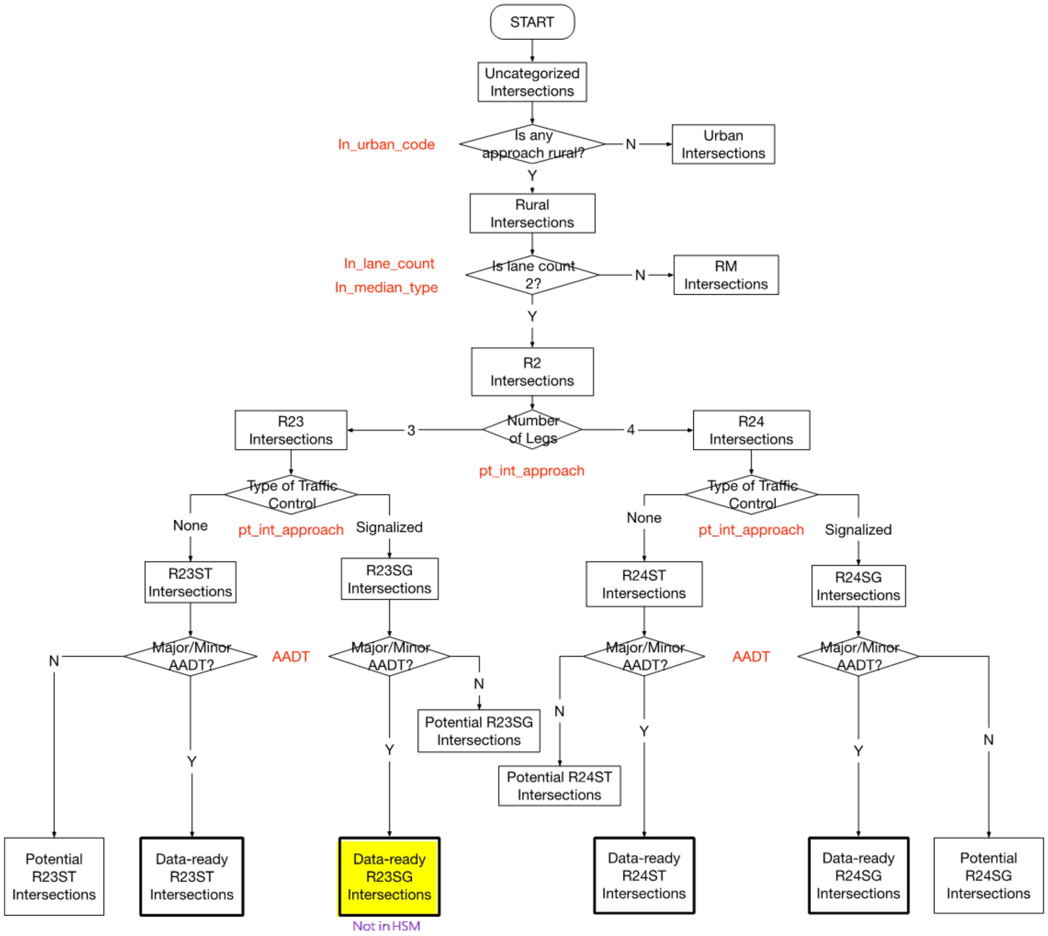
- The latest version of the Straight Line Diagrams (SLD) was selected since it includes a new table that indicates the type of intersections.

- All the tables embodying the required information were exported as CSV files from Microsoft Access. The names of the tables are: *ln_urban_code*, *ln_lane_count*, *ln_median_type*, *ln_pave_width*, *ln_shou_width*, *lst_sign_code*, *lst_sign_type*, *pt_highway_lighting*, *pt_int_approach*, *pt_intersection*, *pt_sign*.

- Intersections were identified automatically by the developed code in R language.

- The video logs provided by the NJDOT and Google Earth street view were utilized to complement the occasionally missing information in for some intersections and for verification purposes.

Automatic Identification of Intersections - Flowchart



R2 Intersection Sampling

Type	R23ST	R23SG	R24ST	R24SG
Preliminary Sample Size	422	21	220	94
Final Sample Size	**314**	**15**	**149**	**45**

Type	Average Major AADT	Average Minor AADT	Average Intersection Number between Major station and the target intersection	Average Intersection Number between Minor Station and the Target Intersection	Average Distance between Major Station and the Target Intersection (mile)	Average Distance between Minor Station and the Target Intersection (mile)
R23ST	4,703	1,109	1.17	1.30	0.75	1.22
R23SG	13,720	5,414	0.86	1.27	0.48	0.63
R24ST	4,453	958	1.00	1.13	0.68	1.09
R24SG	10,969	3,594	1.68	1.27	0.60	0.61

Calculating the Calibration Factor

The calibration factor is calculated by:

$$C = \frac{N_{observed}}{N_{estimated}}$$

Where, C is the calibration factor, $N_{observed}$ is the total observed crash frequency and $N_{estimated}$ is the total crash frequency calculated by the SPF.

Data used to estimate the calibration factors for R2 intersections include:

- Geometric data from SLD.
- Geometric data extracted using Google Earth™ (e.g. left turn, right turn lanes and lighting).
- AADT data from sensor database.
- Crash data between 2011-2015 from the Safety Voyager database.

Calibration Results

- The Calibrator tool developed by the FHWA was used to calculate calibration factors and also measure their goodness of fit.

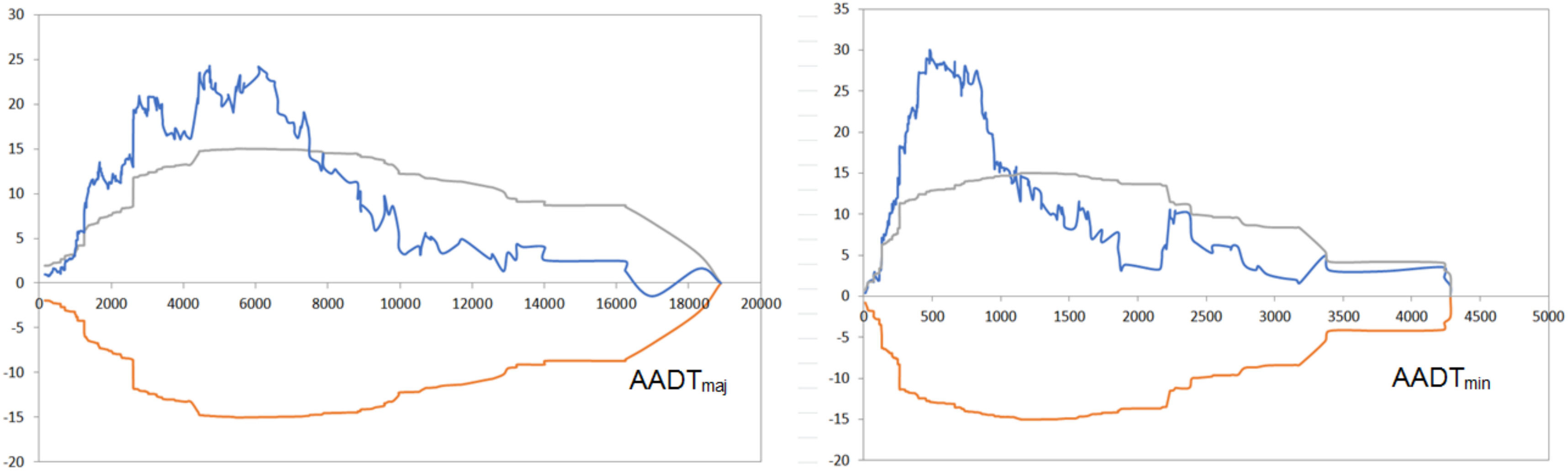
Intersection Type	Calibration Factor	Standard Error	Coefficient of Variation
R23ST	0.882	±0.072	0.084
R24ST	0.919	±0.093	0.104
R24SG	0.883	±0.120	0.140

- According to the FHWA report*, a reasonable upper threshold for the Coefficient of Variation (CV) of a calibration factor is 0.10 to 0.15.

- In that respect, the results are found to be acceptable.

*Lyon, C., Persaud, B. and Gross, F.(2016). "The Calibrator: An SPF Calibration and Assessment Tool User Guide. FHWA-SA-17-016

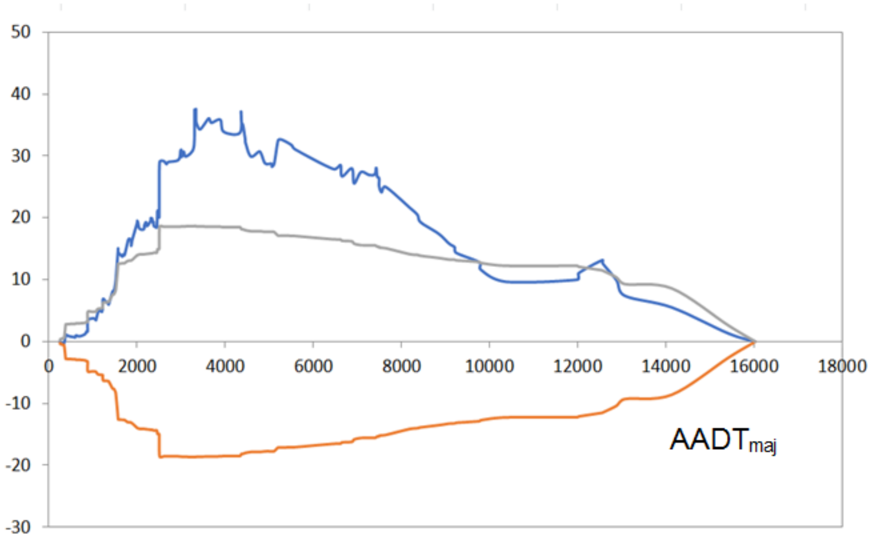
Calibration Results

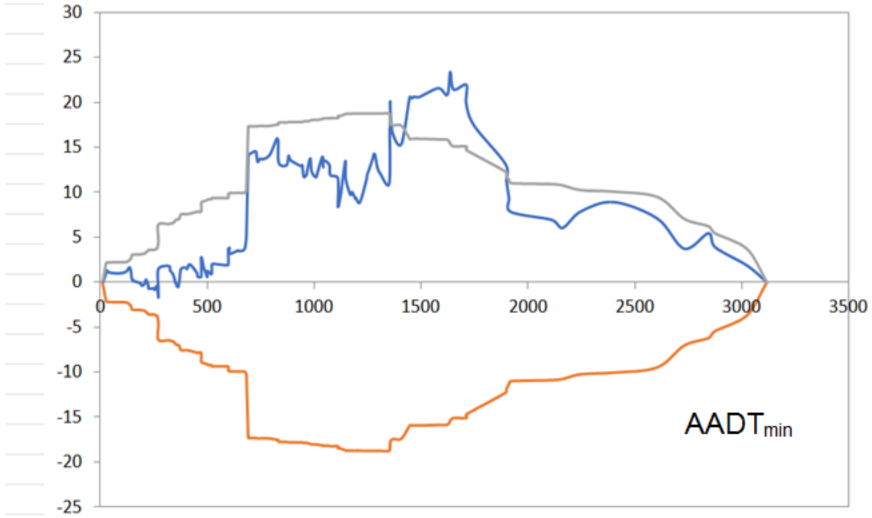


CURE plots of **R23ST** with respect to $AADT_{maj}$ and $AADT_{min}$ variables.

Sample Size: 314

Calibration Results

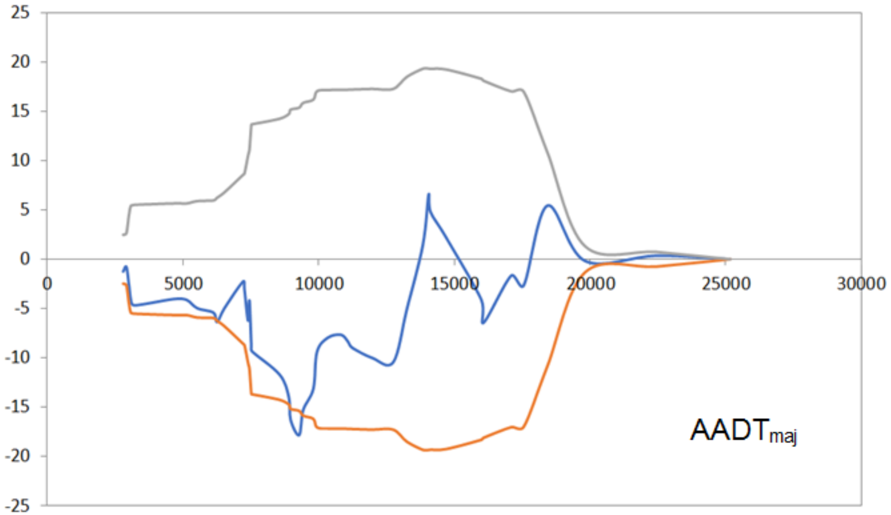


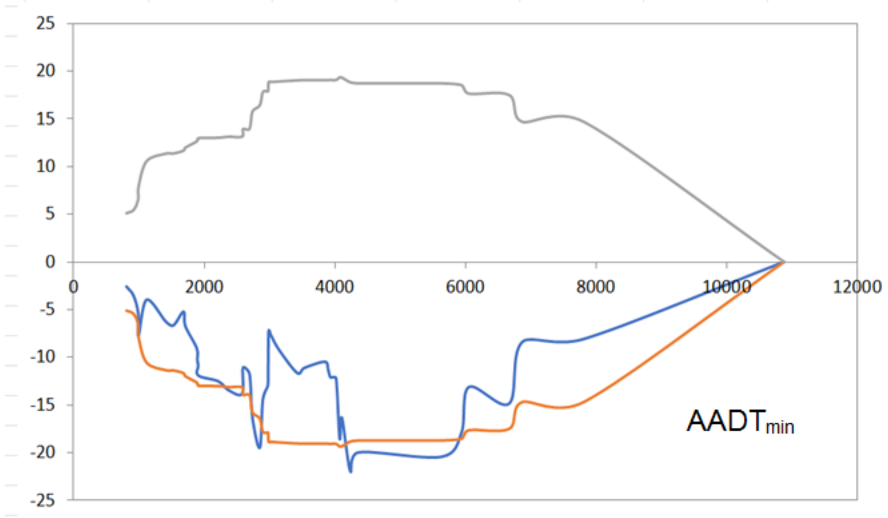


CURE plots of **R24ST** with respect to $AADT_{maj}$ and $AADT_{min}$ variables.

Sample Size: 149

Calibration Results



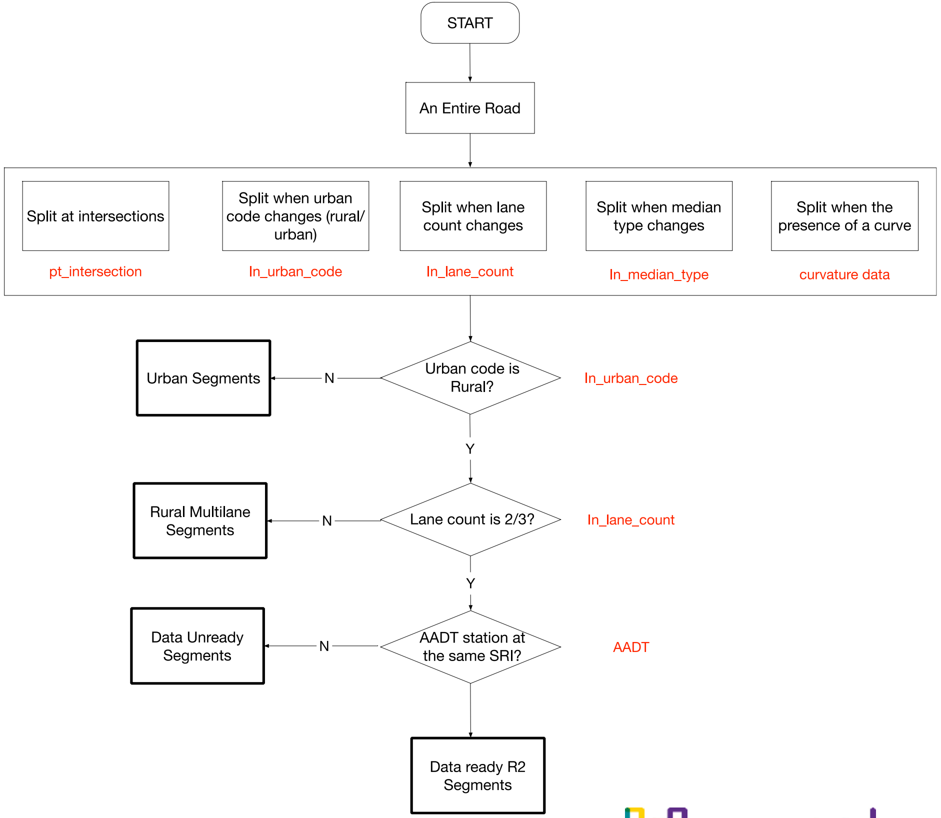


CURE plots of **R24SG** with respect to AADT$_{maj}$ and AADT$_{min}$ variables.

Sample Size: 45

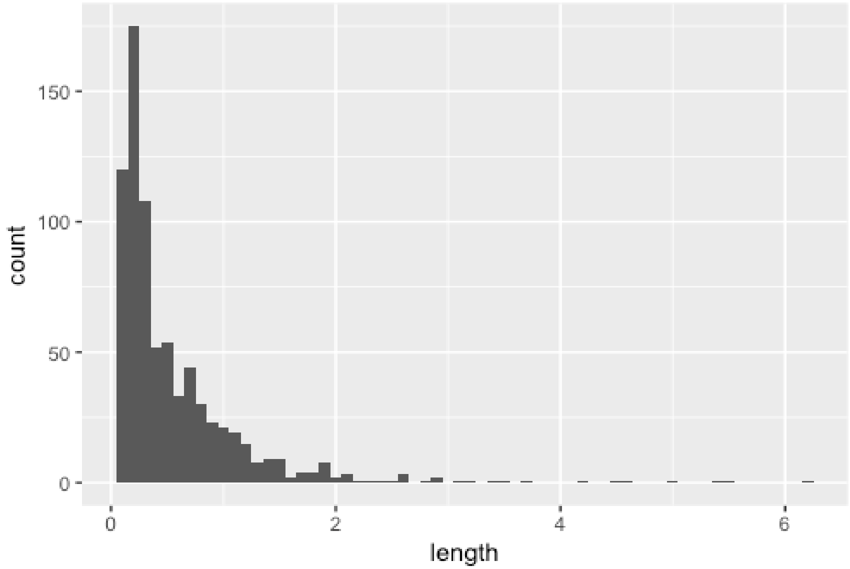
Rural Two-Lane (R2) Segments

Automatic Identification of R2 Segments



R2 Segments

- The research team conducted a preliminary segmentation of R2 segments via a computer code developed in R statistical package.
- R2 segments (with AADT)
  - Total count: 13,886
  - Length> 0.1 mile: 5,847 (42.1%)
  - AADT station inside and length > 0.1: 756
- The R2Us with AADT station inside were used in calibration
  - Average segment length: 0.58
  - AADT out of range percentage: 1.96%



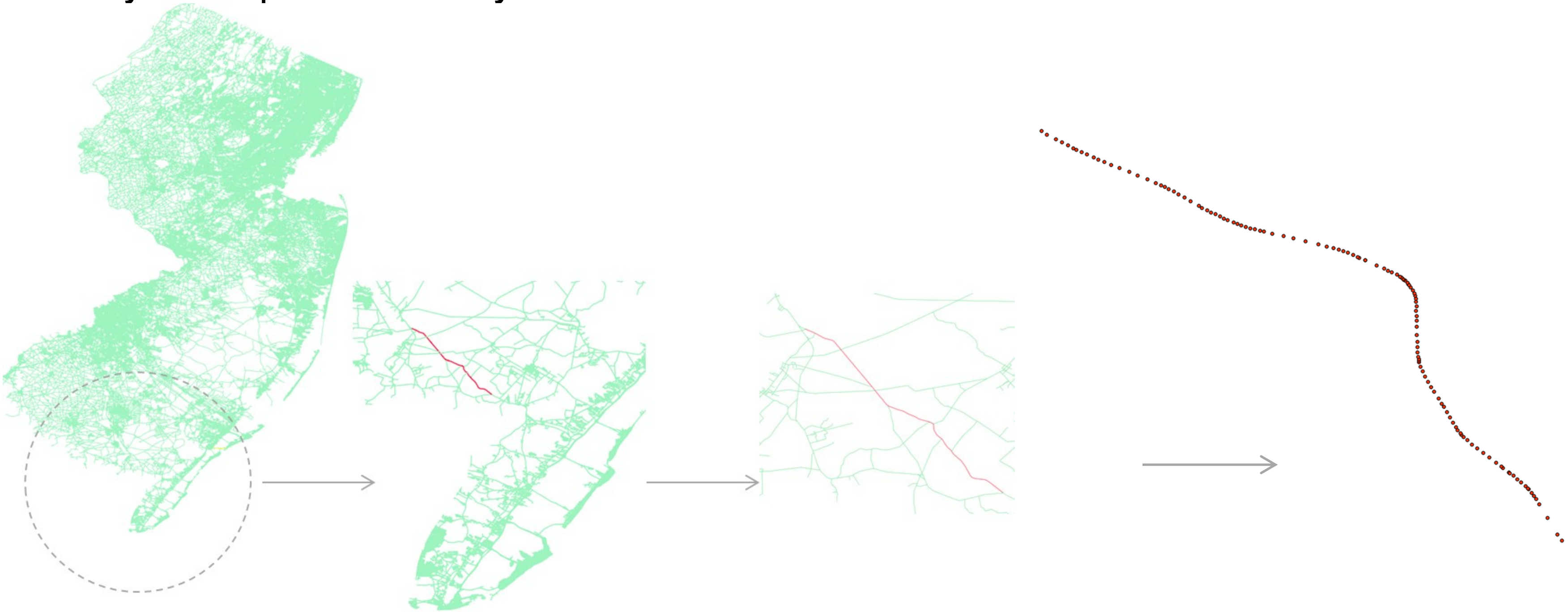
The Histogram of R2U length with AADT station inside

Horizontal Curvature Data

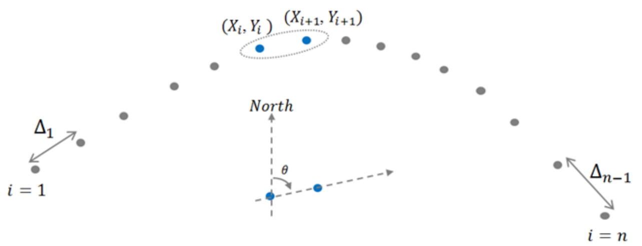
- The research team decided to extract the horizontal curvature data of R2 segments using the GIS map of NJ roadways.
- This approach is to minimize the manual labor and increase the accuracy of data extraction.
- It was found that horizontal data extraction using Google Earth as performed in previous studies are prone to errors, especially in detecting and measuring radii of compound curves.
- In order to extract this important dataset, the team used a novel clustering based approach.
- It identifies horizontal curves by using approximated curvature values of data points from GIS roadway centerline maps.

Horizontal Curvature Data

- NJ GIS map available at NJDOT website is used to extract horizontal curvature data



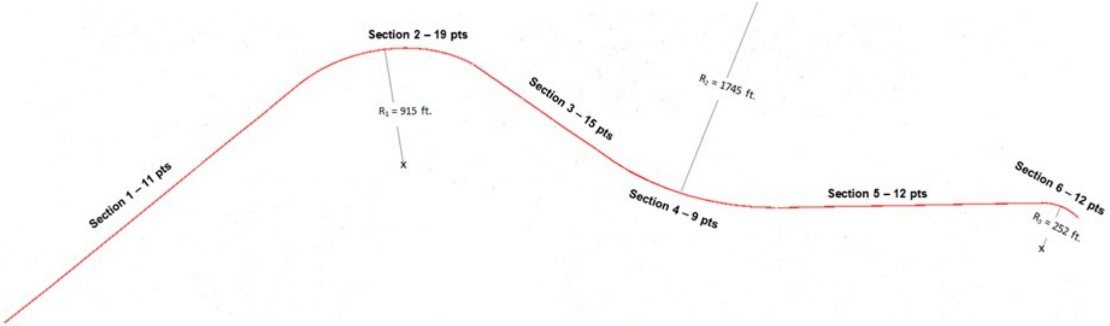
Horizontal Curvature Data

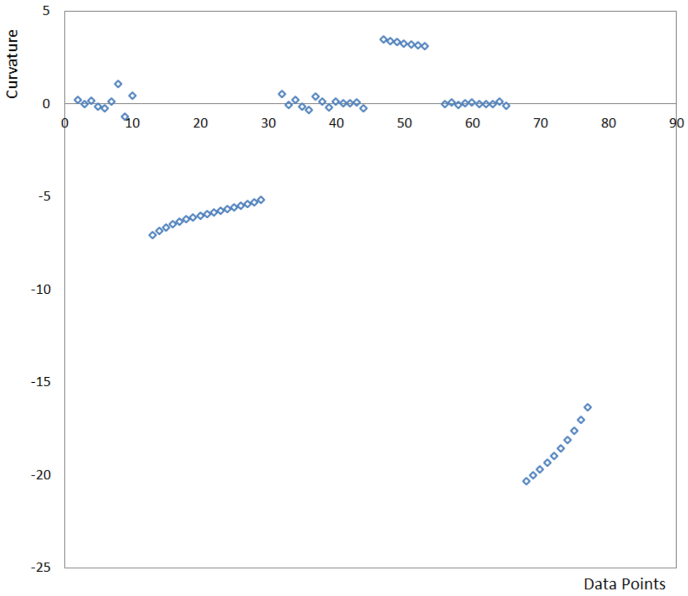


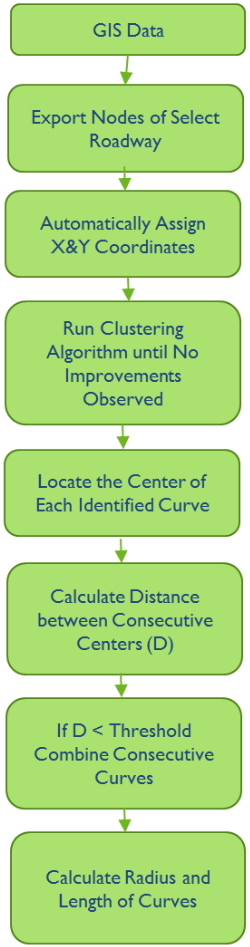
$$f'(i) \approx \frac{Y_{i+1} - Y_i}{X_{i+1} - X_i}$$

$$f''(i) \approx \frac{f'(i) - f'(i-1)}{X_{i+1} - X_i}$$

$$\kappa_i \approx \frac{f''(i)}{[1 + f'(i)^2]^{\frac{3}{2}}}$$







Horizontal Curvature Data

- In order to identify contiguous segments with similar changes in bearing angles, a modified global k-means clustering algorithm is implemented in C programming language.
- Below table compares the curvature data processed by the approach of the research team versus the data collected on the field.

	Field Measurement			Clustering Approach		
Curve	Start MP	End MP	Radius	Start MP	End MP	Radius
1	0.57	0.74	1,268	0.59	0.75	1,275
2	0.95	1.1	1,109	0.93	1.16	1,127
3	1.71	1.75	1,309	1.70	1.80	1,592
4	1.97	2.04	2,032	2.01	2.07	1,508
5	2.15	2.21	1,226	2.16	2.23	1,608
6	2.29	2.35	2,107	2.23	2.38	3,215
7	2.61	2.68	1,255	2.60	2.71	1,211
8	2.81	2.85	726	2.82	2.90	853
9	3.03	3.08	845	3.05	3.10	1289
10	3.21	3.3	474	3.23	3.32	506
11	3.6	3.69	1,938	3.61	3.68	1,931
12	4.41	4.46	1,929	4.39	4.44	2,510
13	4.63	4.74	1,602	4.60	4.69	1,659
14	7.4	7.49	652	7.42	7.49	655
15	7.7	7.78	1,679	7.73	7.76	2,328

Horizontal Curvature Data

- The correlation coefficient between two methods is 0.86.
- There are some significant differences between the two approaches.
- These differences are based on differences in finding the start (PC) and the end (PT) of a horizontal curve. Such differences between different field observations are also reported in the literature*.

*Findley et al (2013). "Collecting Horizontal Curve Data: Mobile Asset Vehicles and Other Techniques". *Journal of Infrastructure Systems*. Vol. 19 Issue 1 pp. 74-84.

Horizontal Curvature Data

- The developed clustering program has been modified to process all rural roadways in NJ.
- Horizontal curves along these roadways were identified and the corresponding horizontal data were extracted automatically.
- Currently, the calibration / development of SPFs are in progress.

*Findley et al (2013). "Collecting Horizontal Curve Data: Mobile Asset Vehicles and Other Techniques". *Journal of Infrastructure Systems*. Vol. 19 Issue 1 pp. 74-84.

Next Steps

- Immediate Next Steps
  - Calibration / Development of R2 Segments
  - Calibration / Development of Urban Intersections
- Next Quarter
  - Calibration / Development of Urban Segments

Q & A

Thank you for listening.