



Investigation of Design Speed Characteristics on Freeway Ramps Using SHRP2 Naturalistic Driving Data

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Acknowledgement

- Based on research conducted on “Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps”
- Sponsored by:





Introduction

- Existing ramp design guidelines based on practices from decades past
- Recent research conclusions based on more recent field data, but data often limited
- Current research project uses naturalistic data from SHRP2 NDS
- Objective: identify relationships between roadway characteristics and speed, based on speeds of SHRP2 drivers



Current Policies

- AASHTO Green Book
 - Section 10.9.6: Desirable for ramp design speeds to approximate low-volume highway running speed, but not always practical
 - Table 10.1: Applies to the sharpest or controlling ramp curve

U.S. Customary											
Highway design speed (mph)	30	35	40	45	50	55	60	65	70	75	
Ramp design speed (mph)											
Upper range (85%)	25	30	35	40	45	48	50	55	60	65	
Middle range (70%)	20	25	30	33	35	40	45	45	50	55	
Lower range (50%)	15	18	20	23	25	28	30	30	35	40	
Corresponding minimum radius (ft)	See Green Book Table 3-7										



Current Policies

- AASHTO Green Book (7th Edition)
 - Section 10.9.6.2: Desirable for ramp design speeds to approximate low-volume highway running speed, but not always practical
 - Table 10.1: Applies to the sharpest or controlling ramp curve

U.S. Customary											
Highway design speed (mph)	30	35	40	45	50	55	60	65	70	75	80
Ramp design speed (mph)											
Upper range (85%)	25	30	35	40	45	50	50	55	60	65	70
Middle range (70%)	20	25	30	30	35	40	45	45	50	55	60
Lower range (50%)	15	20	20	25	25	30	30	30	35	40	45
Corresponding minimum radius (ft)	See Green Book Table 3-7										



Current Policies

- Individual states
 - Online search of 20 states in NCHRP 15-56
 - 16 states had design manuals with text corresponding to *Green Book*
 - 11 states nominally the same or specifically referred to *Green Book*
 - 5 states were very similar but had some unique features also (e.g., Table 10-1 was reproduced using only values that were multiples of 5 mph)



Previous Research

- Variety of models predict ramp speed
 - Curves on loop ramps (NCHRP 3-105, NCHRP 17-45/HSM)
 - Advisory speeds on exit ramps (Venglar, et al)
- Models are based on:
 - Factors such as lane/shoulder width, curve radius, SCL type, etc.
 - Data from a limited number of ramps and/or vehicles



Data Collection Considerations

- Methods
 - Lidar
 - Road sensors
 - Instrumented vehicles
- Pros and cons
 - Tradeoffs between number of vehicles/sites and detail in dataset





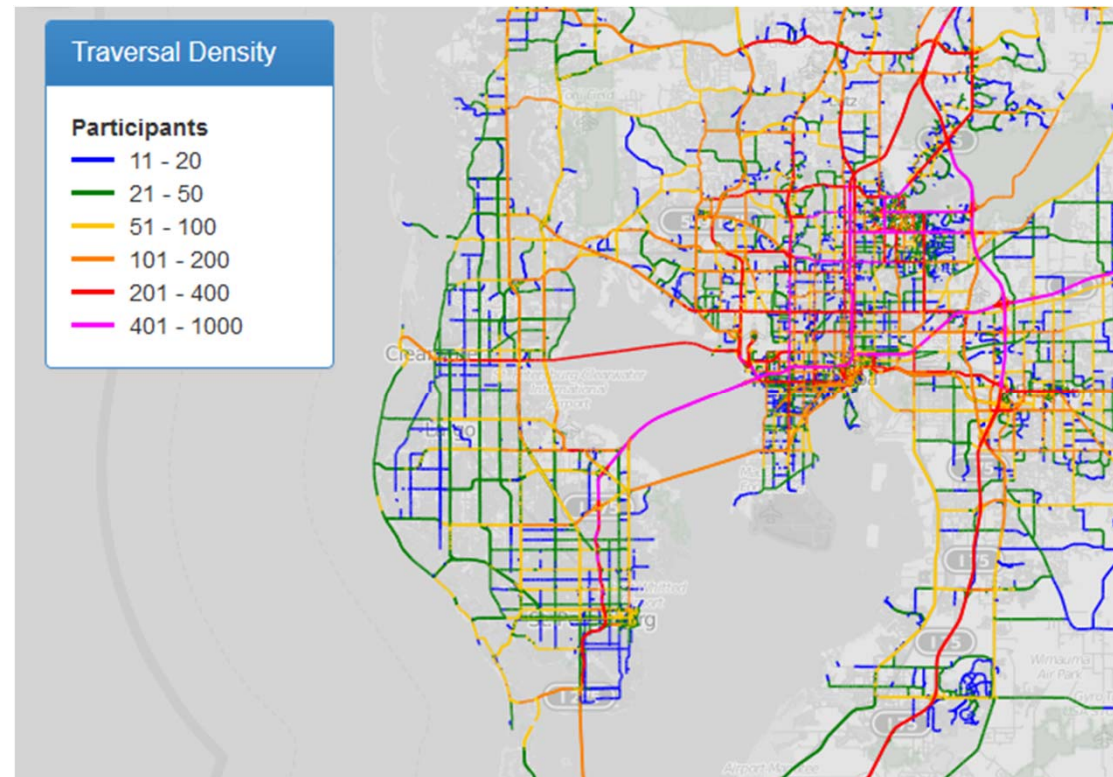
Benefits of SHRP2 Dataset

- Data from 3,000+ participants in six states
- ~ 3,500 human-years of time series data
- Reduced data primarily used to analyze crashes and near-crash events, but can also be used for detailed driving data for a large sample of drivers on a wide variety of roadway segments



Site Data Collection

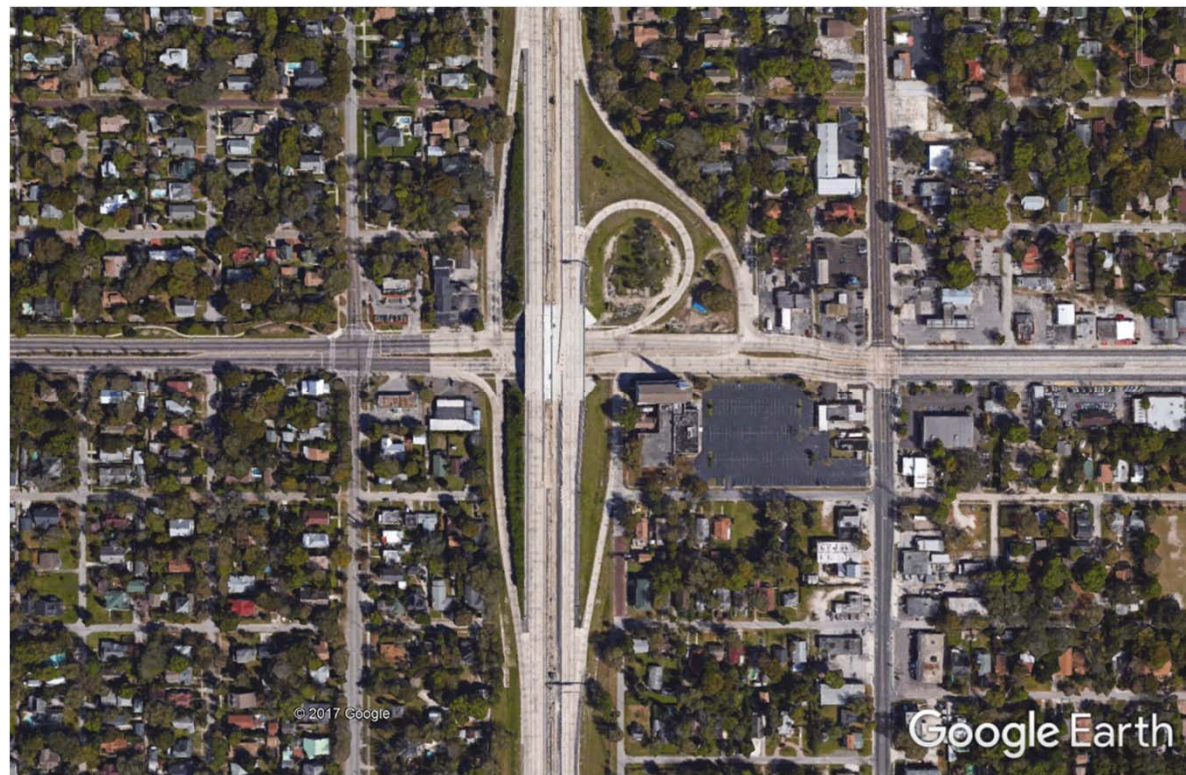
- InSight Trip Density Maps
 - Six participating states
 - Ramps with trips by 50-200 unique participants
 - Ramp configuration (e.g., diamond, loop, curve)
 - Entrance or exit ramp





Site Data Collection

- Google Earth
 - Same locations as InSight
 - GPS coordinates
 - Urban/rural
 - Confirm ramp type
 - Confirm origin/destination routes





Site Selection

- Identified 1686 ramps (>130 from each state)
 - About 1.4 million recorded trips
 - ~8 trips / participant / ramp
 - 173,000 unique participant-ramp combinations
- Filters and qualifiers removed:
 - Non-Interstate ramps, metered ramps, multiple ramps per interchange
 - Ramps with < 200 total trips, ramps with multiple LinkIDs



Site Selection

- Final list of 100 ramps, almost 11,000 participant-ramp combinations

State	Configuration			Direction of Travel		Total
	Curve	Diamond	Loop	Entrance	Exit	
FL	816	2049	624	1975	1514	3489
IN	0	150	51	201	0	201
NC	796	1770	993	1713	1846	3559
NY	475	391	527	875	518	1393
PA	406	523	84	164	849	1013
WA	398	842	0	369	871	1240
Total	2891	5725	2279	5297	5598	10895



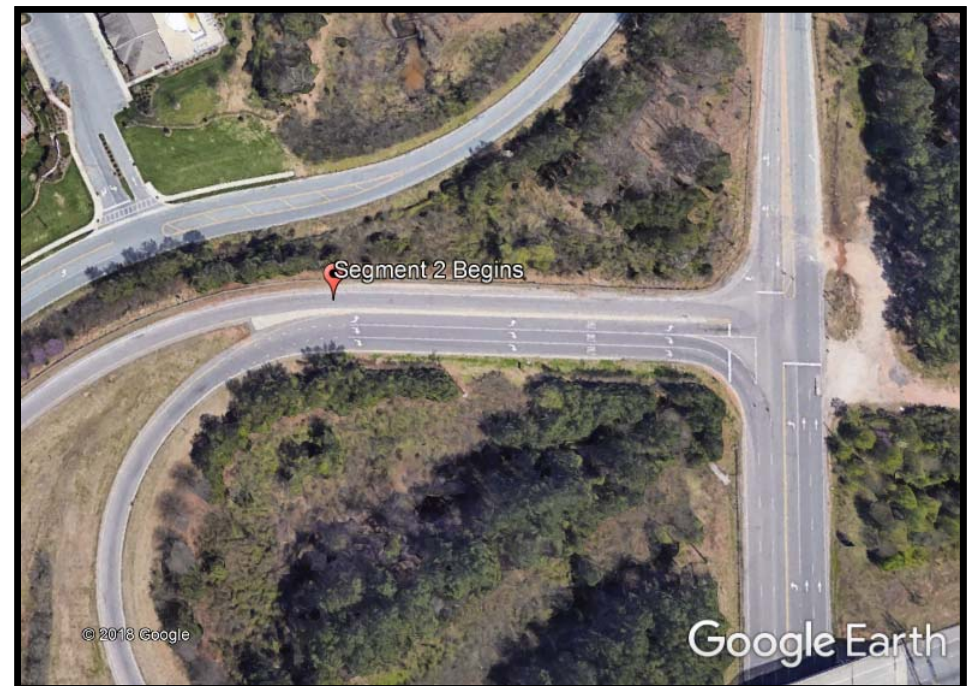
Trip Data Collection

- Requested detailed SHRP2 NDS time series data for first trip by each unique participant on each ramp
 - Time series recorded each 0.1 s
 - Primary vehicle variables (e.g., speed, 3D acceleration and rotation rates)
 - Secondary vehicle variables (e.g., steering wheel position, pedal position)
- Dataset included 2 s before the ramp and after the ramp



Roadway Data Collection

- First option: SHRP2 RID (very few ramps available)
- Second option: Google Earth
 - Divided ramps into curve and tangent segments, measured lengths and radii
 - Measured lane/shoulder widths
 - GPS coordinates for begin/end of each segment





Final Dataset

- Removed trips with sensor errors and other features that prevented complete speed profile
- Combined trip data with roadway data into series of spreadsheets with one row per 0.1 s interval of data
- Reduced dataset contained:
 - 10,834 trips on 100 ramps
 - 1,731,753 individual speed readings (statistically significant)



Speeds on Curved Ramp Segments

- $v_{curve,ent} = 0.51v_{fwy} + 56.5R - 41.5R^2 + 0.68TC_{FF} - 1.07$
- $v_{curve,exit} = 0.20v_{fwy} + 79.9R - 61.1R^2 - 0.154Ramp_{pct} + 11.75TC_{FF} + 10.17TC_{SIG} + 12.30$
- Average speed on the curve
- Good for radii up to 0.7 mi
- Destination has an intuitive effect



Speeds on Tangent Ramp Segments

- $v_{tangent,ent} = 0.84v_{PT} + 0.081 Seg_{pct} - 2.29 Next_C - 4.05 Prev_C + 10.78$
- $v_{tangent,exit} = 0.98v_{PT} - 0.115 Seg_{pct} + 2.31 Next_C + 0.83 Prev_C + 0.60$
- Speed anywhere on the segment
- Establishes a baseline speed to begin the segment



Speed Profile on Ramp Proper

- $v_{curve} = \beta_0 + \beta_1 v_{PC} + \beta_2 R + \beta_3 R^2 + \beta_4 TC_{Sig} + \beta_5 TC_{FF} + \beta_6 Pre_C + \beta_7 Pre_N + \beta_8 Next_C + \beta_9 Next_N$
- $v_{tangent} = \beta_0 + \beta_1 v_{PT} + \beta_2 TC_{Sig} + \beta_3 TC_{FF} + \beta_4 Pre_C + \beta_5 Pre_N + \beta_6 Next_C + \beta_8 Next_N$
- Speed at quarter points of each segment
- Eqns used in series with calibrated coefficients (listed in paper)



Conclusions

- SHRP2 NDS has potential to be used (with other data sources) to develop realistic speed models related to geometric design characteristics
- Robust data source, with caveat that “too much” data can affect model development
- Curve radius, as expected, had great (non-linear) effect
- Destination more influential than origin on speed selection



Questions?

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- Paper # 19-05395 (this paper)
- Paper # 19-05389 (data processing paper led by Jayson Stibbe)