NCHRP Project 17-65

Improved Analysis of Two-Lane Highway Capacity and Operational Performance

Project Summary

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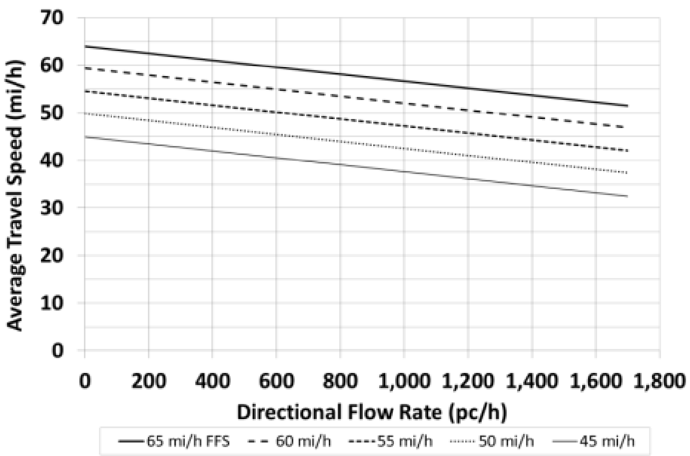
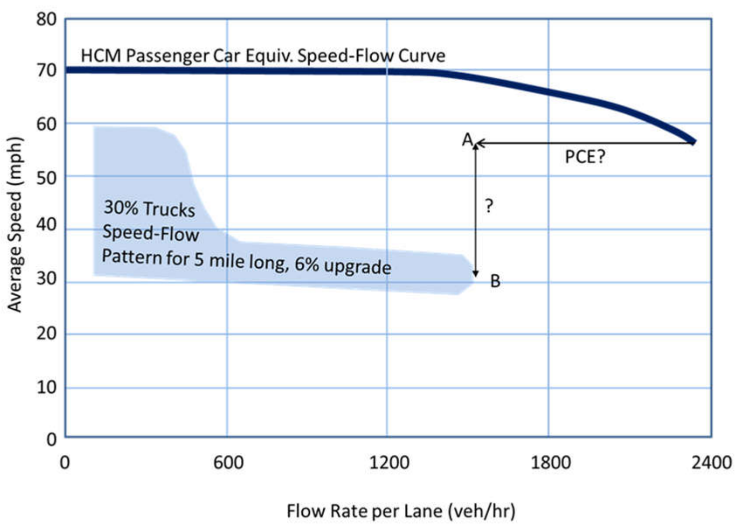
Problem Statement
(Existing HCM Methodology Limitations/Issues)



- Speed-flow curve
  - Linear
  - Slope is not affected by FFS
- BFFS
  - Very limited guidance
- PTSF Service Measure
  - Very difficult to measure in field
  - Can be misleading in some cases (e.g., low volume, high truck %)
  - 3-s following headway surrogate criterion questionable
- ATS Service Measure
  - Does not necessarily correlate well with operational efficiency (e.g., low volume/high truck %, changing roadway conditions)

Problem Statement
(Existing HCM Methodology Limitations/Issues)

- Truck impacts
  - PCEs differ by service measure (Speed, PTSF)
  - Not a function of % trucks
  - Originally iterative approach due to units
  - Do not properly account for moderate to steep grades
- Passing lane overestimates impact on service measures
- %No-Passing Zones input not sensitive to lengths of passing zones for a given %
- Capacity value based on very limited field data
- Not facility-oriented



Problem Statement (Existing HCM Methodology Limitations/Issues)

- Methodology ease of use
  - Multiple classifications and multiple service measures
  - PCE values that vary by service measure
  - Many adjustment factors in tabular format, often requiring interpolation (some 2-way and 3-way)

LOS	Class I Highways ATS (mi/h)	Class I Highways PTSF (%)	Class II Highways PTSF (%)	Class III Highways PFFS (%)
A	>55	≤35	≤40	>91.7
B	>50–55	>35–50	>40–55	>83.3–91.7
C	>45–50	>50–65	>55–70	>75.0–83.3
D	>40–45	>65–80	>70–85	>66.7–75.0
E	≤40	>80	>85	≤66.7
F	Demand exceeds capacity			

Note: For Class I highways, LOS is determined by the worse of ATS-based LOS and PTSF-based LOS.

Objectives

- The objective of this research was to
  1) identify appropriate performance measures for operational and capacity analyses of two-lane highways and develop models to produce these performance measures in an HCM context, and
  2) develop or modify a simulation-based analysis method for two-lane highways and offer guidance for when to apply a simulation versus HCM method.
- The resulting methods/models should lead to a two-lane highway analysis procedure suitable for incorporation into the HCM, that also addresses as many of the limitations/issues with the current HCM analysis methodology as possible.

Project Status

- Project finished March 2018
- Final report published here:
  - https://www.nap.edu/catalog/25179/improved-analysis-of-two-lane-highway-capacity-and-operational-performance

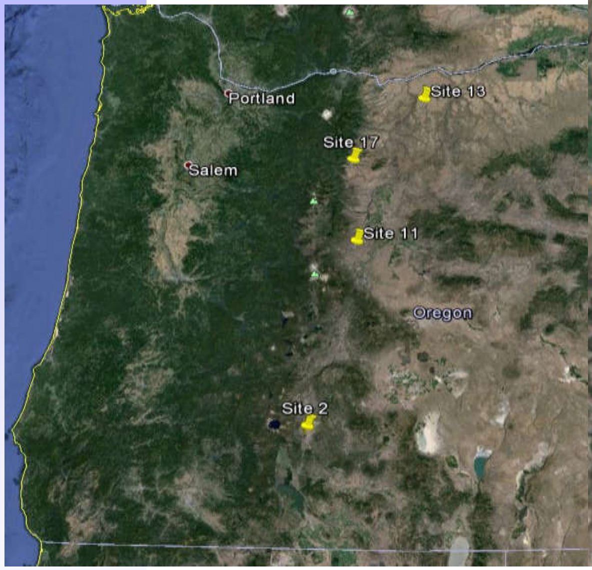
Field Data

Study Sites

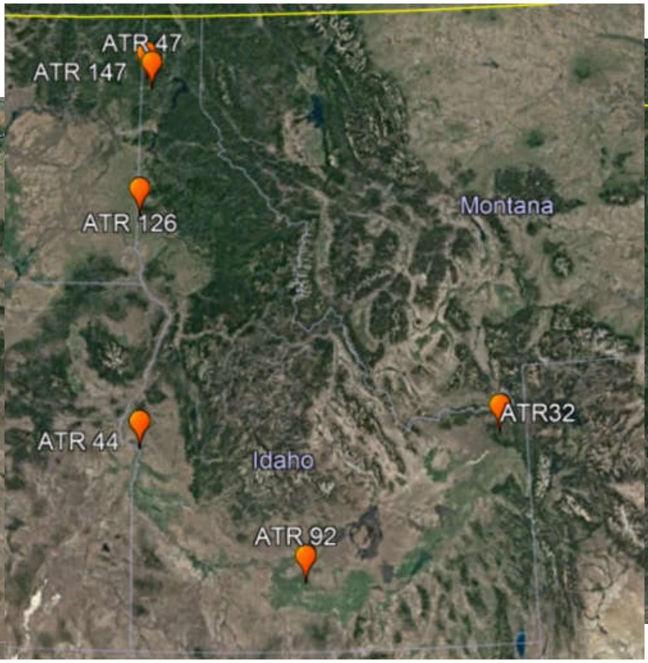
Two-lane highway sites in five different states:

- Oregon – 4 Passing lane sites (Portable ATRs)
- Montana – 7 ATR and WIM sites (Permanent stations)
- Idaho – 6 ATR and WIM sites (Permanent stations)
- North Carolina – 7 sites (Portable ATRs)
- California – 1 site (Portable ATR)

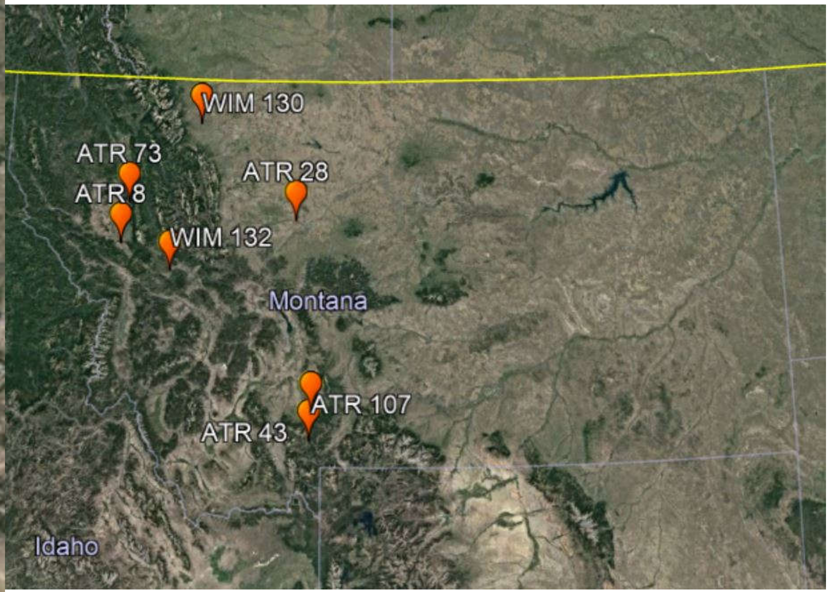
Study Sites



Oregon
All passing lane sites

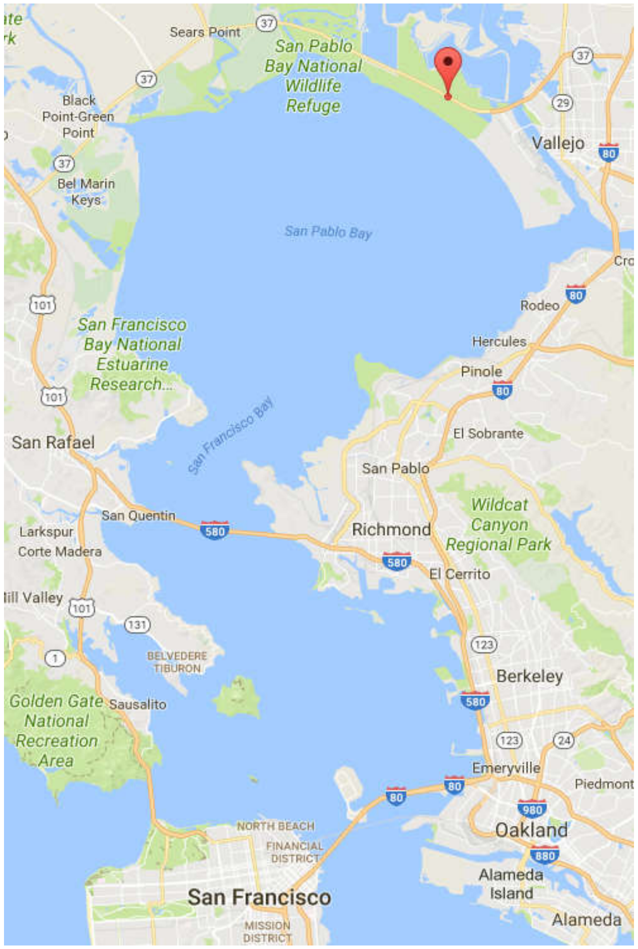


Idaho



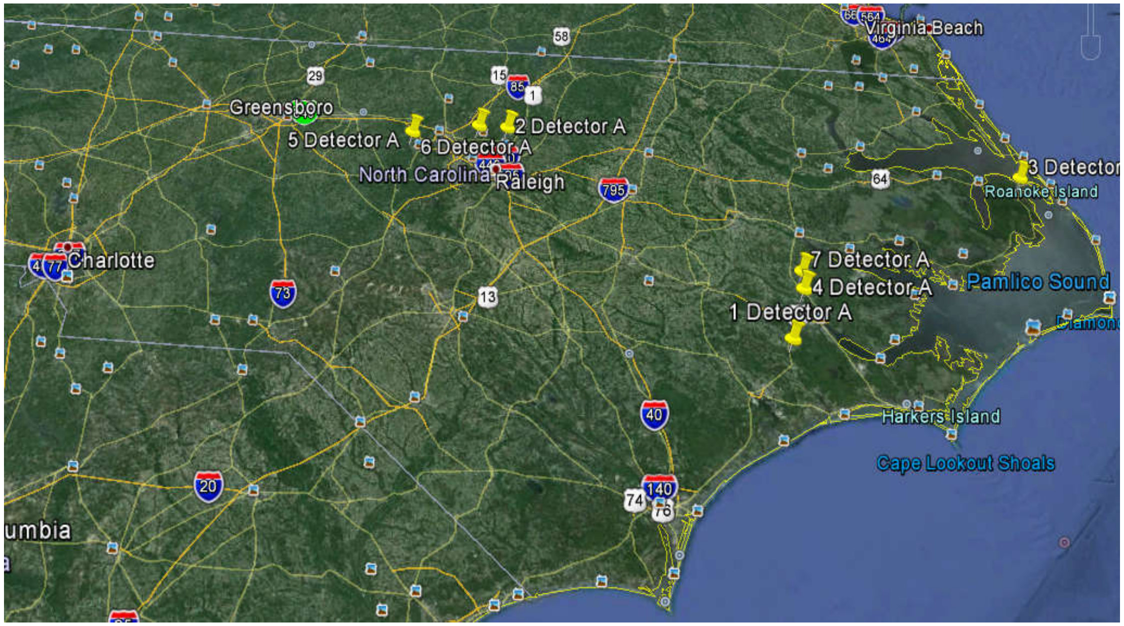
Montana

Study Sites

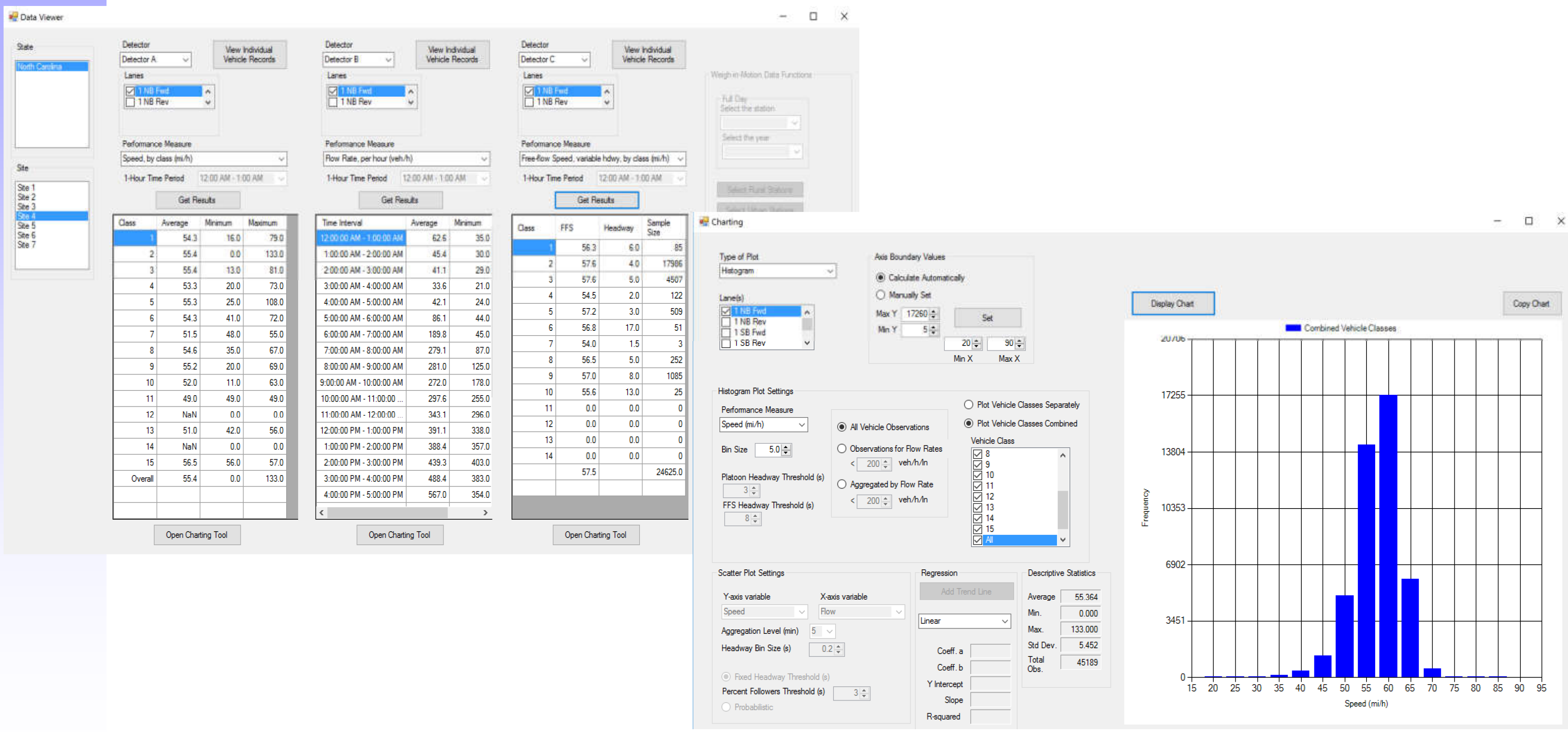


California

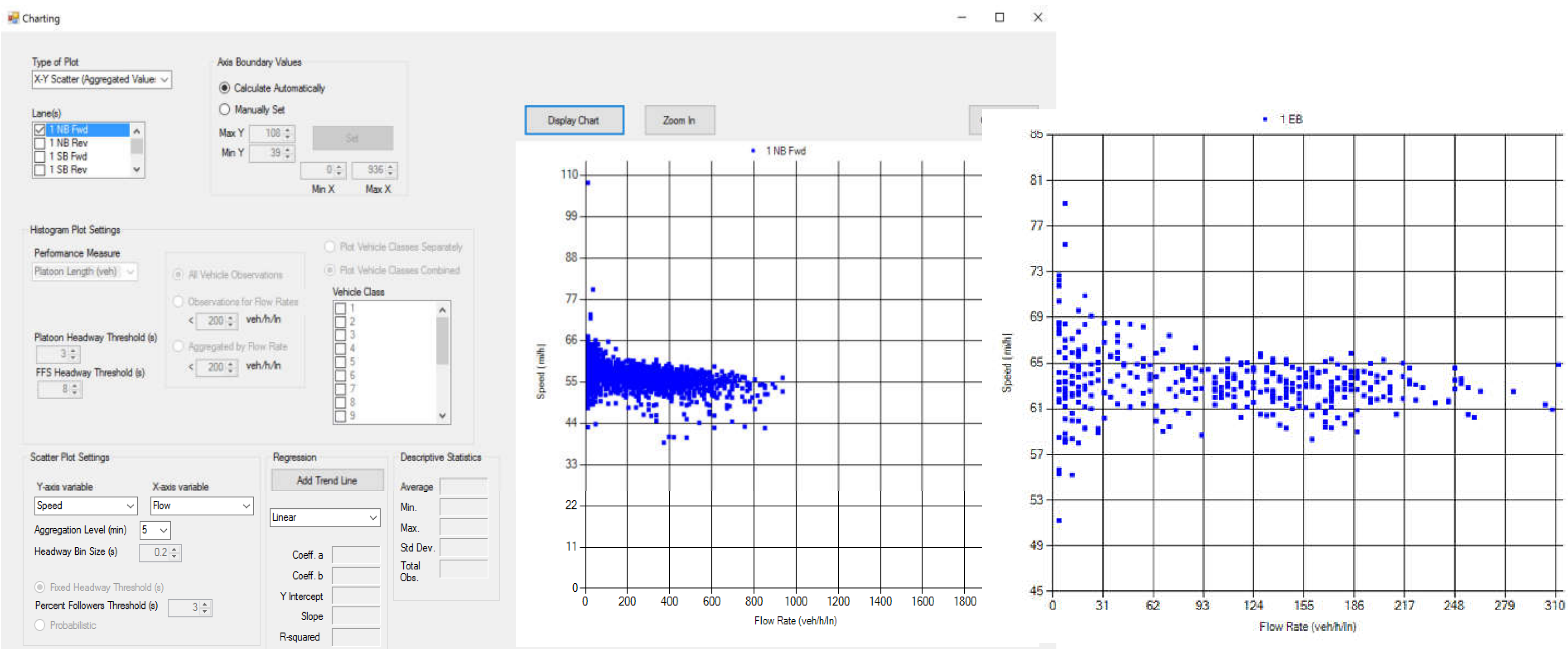
North Carolina



Custom Data Processing Software Tool

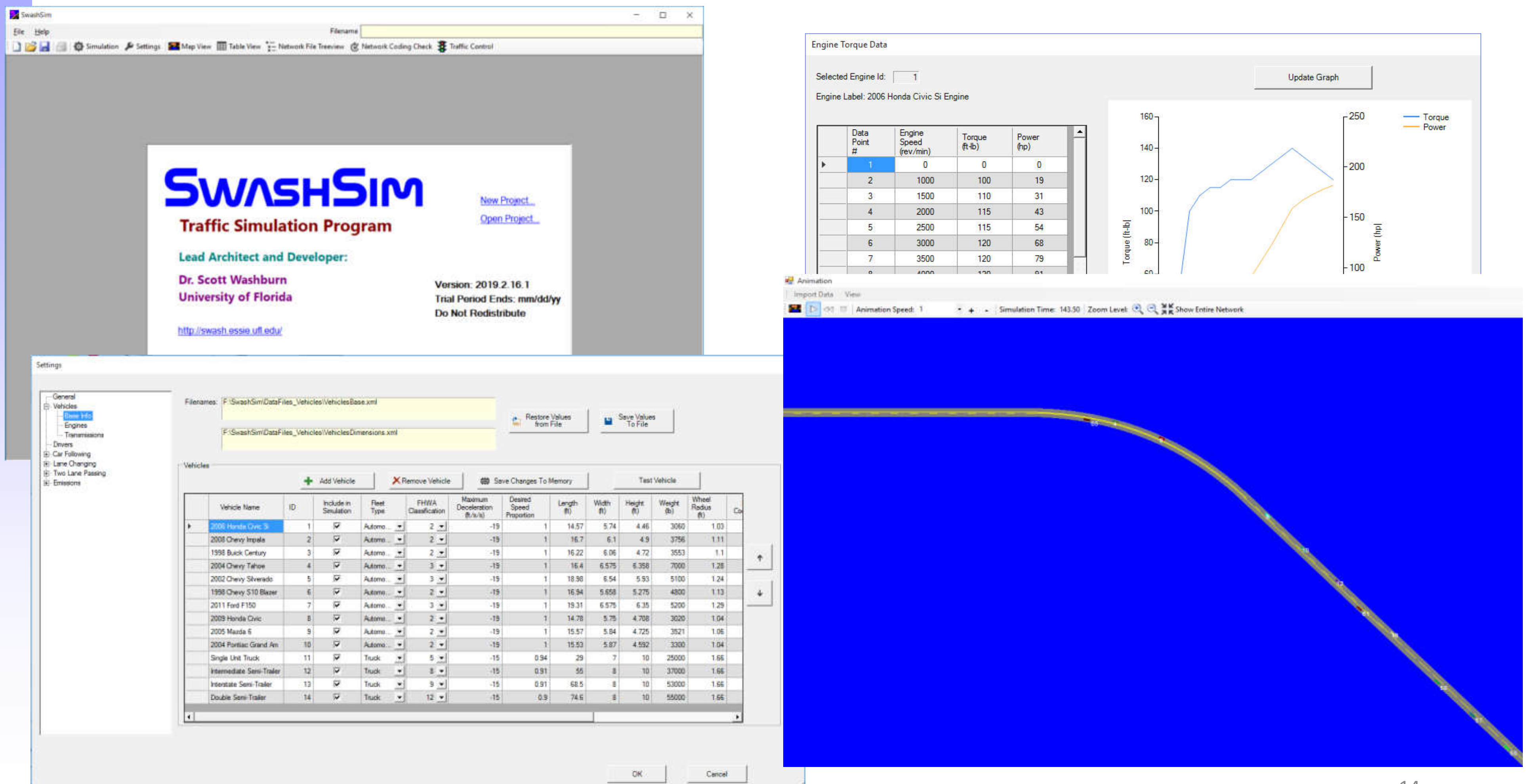


Custom Data Processing Software Tool

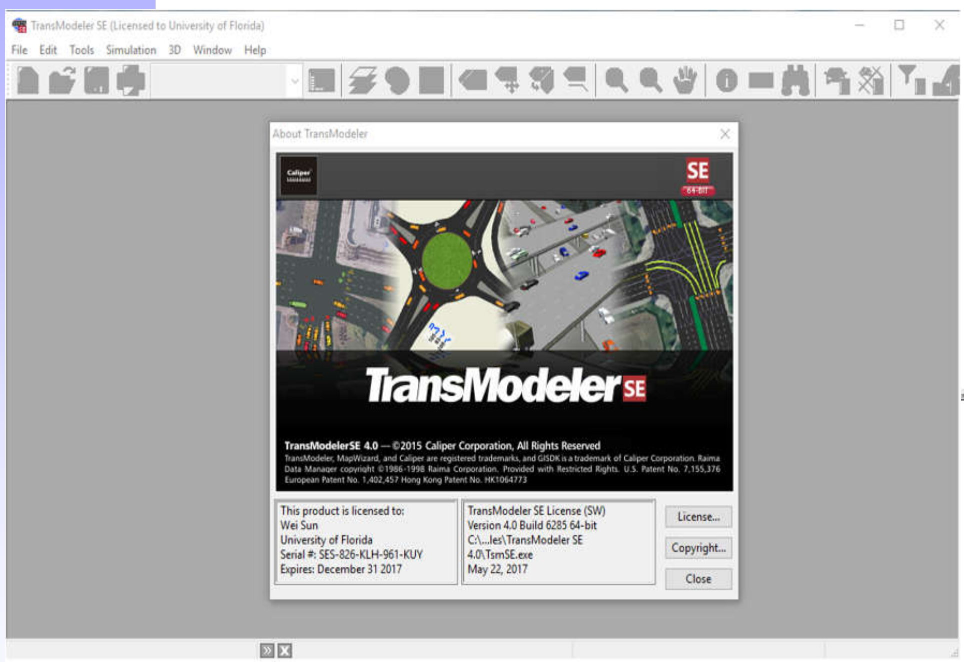


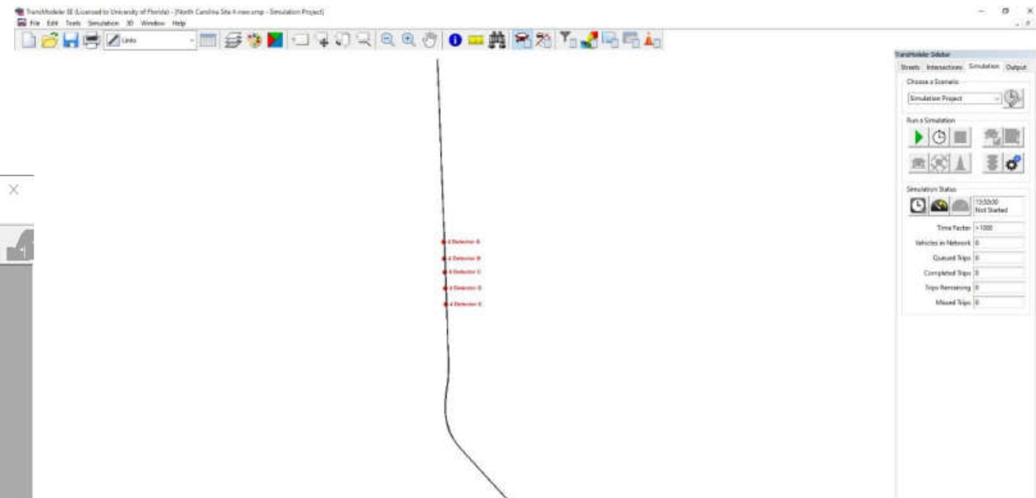
Simulation

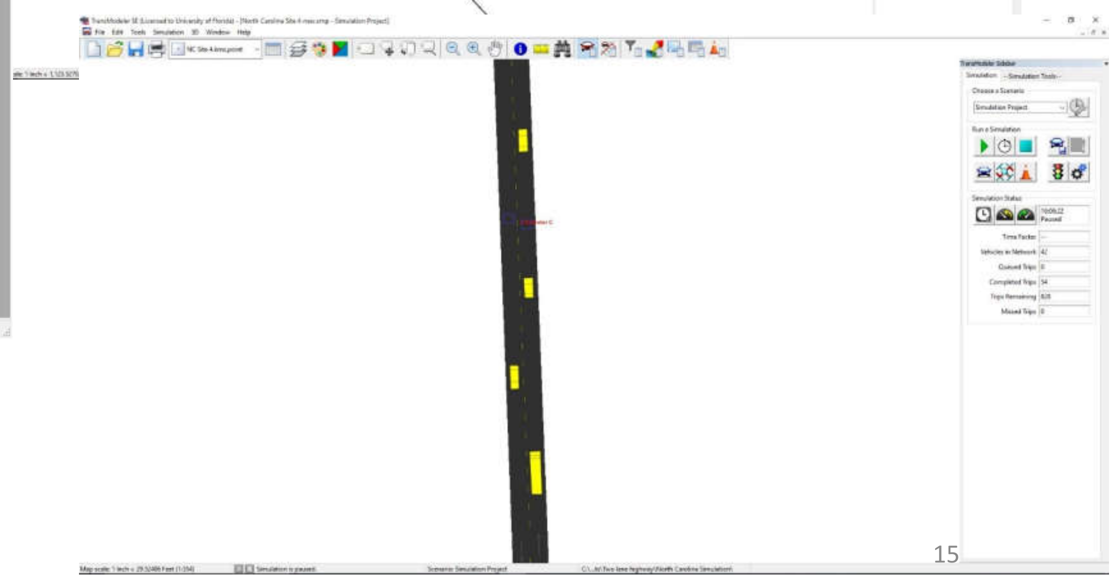
SwashSim


SwashSim
Traffic Simulation Program
Lead Architect and Developer:
Dr. Scott Washburn
University of Florida
New Project...
Open Project...
Version: 2019.2.16.1
Trial Period Ends: mm/dd/yy
Do Not Redistribute
http://swash.essie.ufl.edu/
Engine Torque Data
Selected Engine Id: 1
Update Graph
Engine Label: 2006 Honda Civic Si Engine
Torque
Power
Settings
Vehicles
Add Vehicle
Remove Vehicle
Save Changes To Memory
Test Vehicle
OK
Cancel
Animation

TransModeler







Simulation Programs

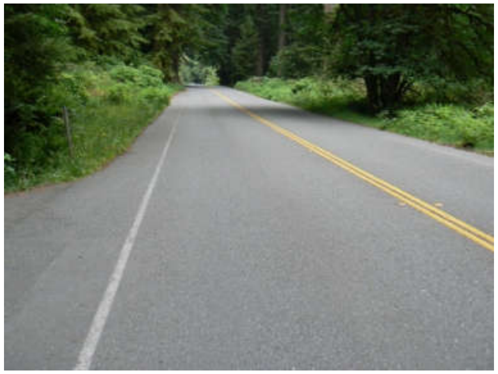
- SwashSim
  - Download information
    - https://github.com/swash17/SwashSim
  - Documentation Wiki
    - https://swashsim.miraheze.org

- TransModeler
  - Download information
    - https://www.caliper.com/TransModeler/default.htm

Analysis Methodology Concepts

Segmentation

- Based on changes in terrain or passing opportunities and presence of intersections.
- Types
  - Passing constrained
    - Extended length of two-lane highway in which passing in the oncoming lane is either prohibited or effectively negligible due to lack of passing opportunities.
  - Passing zone
    - Section of two-lane highway for which passing in the oncoming lane is permitted, and the length and location of such passing zone provides for reasonable accommodation of passing maneuvers under certain traffic conditions.
  - Passing lane
    - This segment type consists of an added lane in the same direction as the analysis direction, with the intent to break up platoons that have formed upstream by allowing faster vehicles to pass slower vehicles.

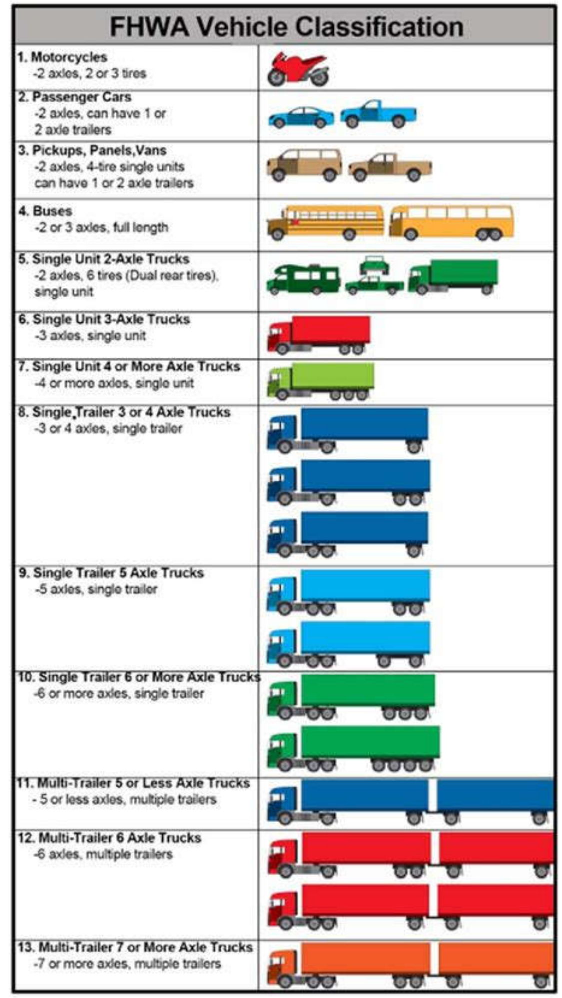


Segmentation

- Eliminates use of ‘percent no-passing zones’.
- Explicitly accounts for length of passing zones.
- Supports facility-level analysis (i.e., multiple contiguous segments)

Treatment of Trucks

- Explicitly account for heavy vehicles in MOE-flow curves, rather than converting to passenger cars.
- Based on 50/25/25 split for SUT/Class 8/Class 9



Source: Texas Department of Transportation
http://onlinemanuals.txdot.gov/txdotmanuals/tri/vehicle_classification_using_fhwa_13category_scheme.htm

Treatment of Terrain

- 5 vertical classes

Classifications for Vertical Alignment (Downgrades in Parentheses)

Segment Length (mi)	Segment Slope (%)									
	≤1	>1 ≤2	>2 ≤3	>3 ≤4	>4 ≤5	>5 ≤6	>6 ≤7	>7 ≤8	>8 ≤9	>9
≤0.1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	2 (1)	2 (2)	2 (2)
>0.1 ≤0.2	1 (1)	1 (1)	1 (1)	1 (1)	2 (1)	2 (2)	2 (2)	3 (2)	3 (3)	3 (3)
>0.2 ≤0.3	1 (1)	1 (1)	1 (1)	2 (1)	2 (2)	3 (2)	3 (3)	4 (3)	4 (4)	5 (5)
>0.3 ≤0.4	1 (1)	1 (1)	2 (1)	2 (2)	3 (2)	3 (3)	4 (4)	5 (4)	5 (5)	5 (5)
>0.4 ≤0.5	1 (1)	1 (1)	2 (1)	2 (2)	3 (3)	4 (3)	5 (4)	5 (5)	5 (5)	5 (5)
>0.5 ≤0.6	1 (1)	1 (1)	2 (1)	3 (2)	3 (3)	4 (4)	5 (5)	5 (5)	5 (5)	5 (5)
>0.6 ≤0.7	1 (1)	1 (1)	2 (1)	3 (2)	4 (3)	4 (4)	5 (5)	5 (5)	5 (5)	5 (5)
>0.7 ≤0.8	1 (1)	1 (1)	2 (1)	3 (3)	4 (4)	5 (4)	5 (5)	5 (5)	5 (5)	5 (5)
>0.8 ≤0.9	1 (1)	1 (1)	2 (1)	3 (3)	4 (4)	5 (5)	5 (5)	5 (5)	5 (5)	5 (5)
>0.9 ≤1.0	1 (1)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	5 (5)	5 (5)	5 (5)	5 (5)
>1.0 ≤1.0	1 (1)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	5 (5)	5 (5)	5 (5)	5 (5)
>1.1	1 (1)	1 (1)	2 (2)	4 (4)	4 (4)	5 (5)	5 (5)	5 (5)	5 (5)	5 (5)

Treatment of Terrain

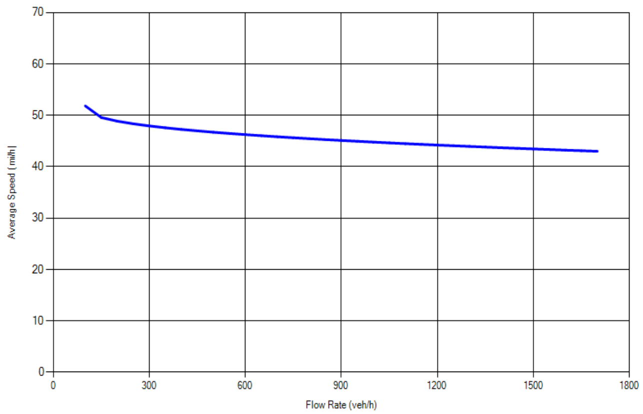
- 5 horizontal classes

Classifications for Horizontal Alignment

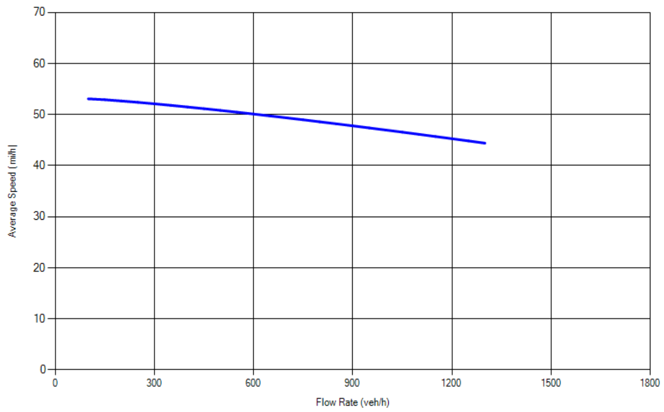
Radius (ft)	Superelevation (%)										
	<1	≥1 <2	≥2 <3	≥3 <4	≥4 <5	≥5 <6	≥6 <7	≥7 <8	≥8 <9	≥9 <10	≥10
<300	5	5	5	5	5	5	5	5	5	5	5
≥300 <450	4	4	4	4	4	4	4	4	4	4	4
≥450 <600	4	3	3	3	3	3	3	3	3	3	3
≥600 <750	3	3	3	3	3	3	2	2	2	2	2
≥750 <900	2	2	2	2	2	2	2	2	2	2	2
≥900 <1050	2	2	2	2	2	2	2	2	1	1	1
≥1050 <1200	2	2	2	2	1	1	1	1	1	1	1
≥1200 <1350	2	2	1	1	1	1	1	1	1	1	1
≥1350 <1500	1	1	1	1	1	1	1	1	1	1	--
≥1500 <1650	1	1	1	1	1	1	1	1	--	--	--
≥1650 <1800	1	1	1	1	1	1	--	--	--	--	--
≥1800 <1950	1	1	1	1	1	--	--	--	--	--	--
≥1950 <2100	1	1	1	1	--	--	--	--	--	--	--
≥2100 <2250	1	1	1	--	--	--	--	--	--	--	--
≥2250 <2400	1	1	--	--	--	--	--	--	--	--	--
≥2400 <2550	1	--	--	--	--	--	--	--	--	--	--
≥2550	--	--	--	--	--	--	--	--	--	--	--

Applicable Performance Measures

Speed



Passing Constrained Segment



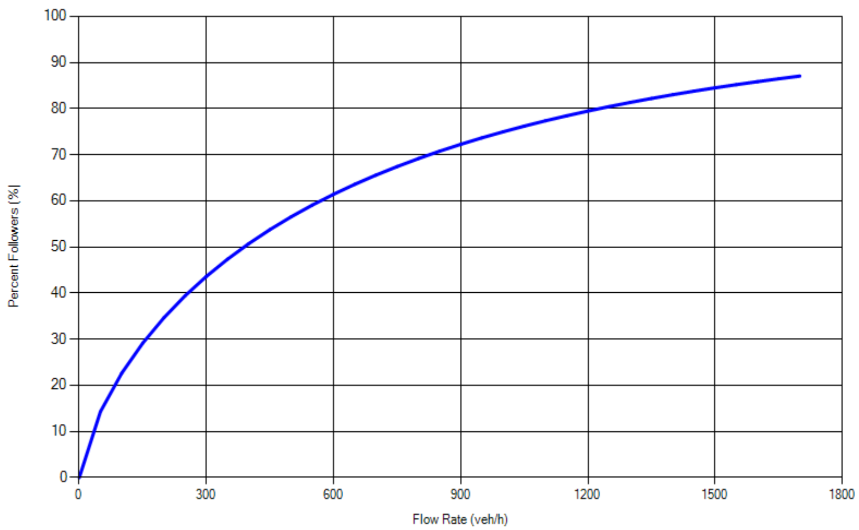
Passing Lane Segment

$$S = \begin{cases} FFS & |v_d \leq 100 \\ FFS - m\left(\frac{v_d}{1000} - 0.1\right)^p & |v_d > 100 \end{cases}$$

Slope (*m*) and power (*p*) coefficients are a function of vertical class, FFS, flow rate, HV%, segment type and length

Applicable Performance Measures

% Followers



$$PF = 100 \times \left[1 - e^{\left(m \times \left[\frac{v_d}{1000}\right]^p\right)}\right]$$

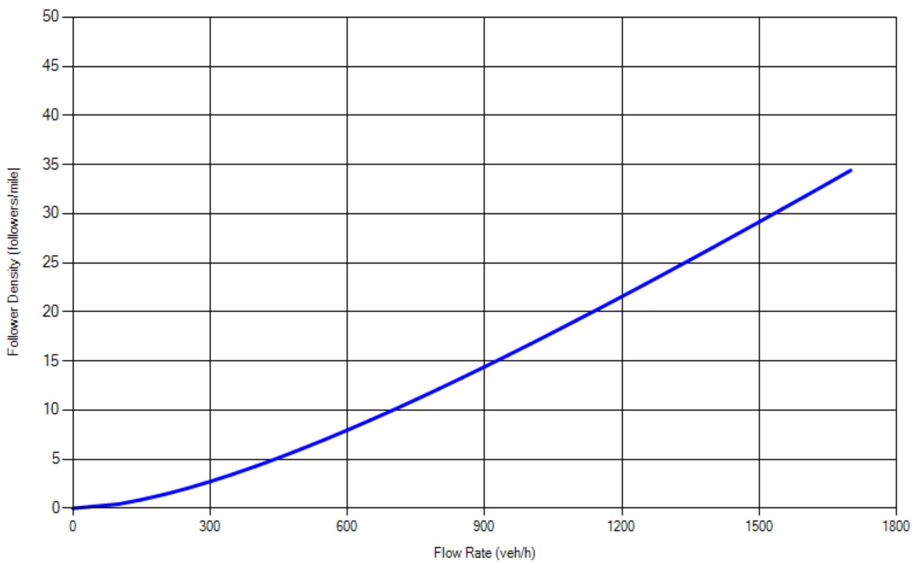
Slope (m) and power (p) coefficients are a function of vertical class, FFS, flow rate, HV%, segment type and length

Follower status

- 2.5-second headway
- favored simplicity, this value gets us close to results from more complicated methods

Applicable Performance Measures

Follower Density



$$FD = \frac{PF}{100} \times \frac{v}{S}$$

where:

FD = follower density in the analysis direction (followers/mi/ln),

PF = percent followers in the analysis direction,

v = flow rate in the analysis direction (veh/h/ln), and

S = average speed in the analysis direction (mi/h).

- Performance measure values are estimated for the end of the segment.
- Also estimated at mid-point of passing lane segment.

Level of Service

- Follower Density used as service measure
- Different thresholds for higher speed versus lower speed highways

LOS	Follower Density (followers/mi/ln) Higher-Speed Highways Posted Speed Limit ≥ 50 mi/h	Lower-Speed Highways Posted Speed Limit < 50 mi/h
A	≤ 2.0	≤ 2.5
B	> 2.0 – 4.0	> 2.5 – 5.0
C	> 4.0 – 8.0	> 5.0 – 10.0
D	> 8.0 – 12.0	> 10.0 – 15.0
E	> 12.0	> 15.0
F	Demand exceeds capacity	

Capacity

- Non-passing lane segments
  - No change (1700 veh/h)
  - Not enough evidence
- Passing lane
  - Merging friction causes reduction, consistent with observations from 2+1 European installations

Heavy Vehicle Percentage (%)	Maximum Flow Rate (in veh/h) by Vertical Classification				
	1	2	3	4	5
< 5	1500	1500	1500	1500	1500
$\geq 5 < 10$	1500	1500	1500	1500	1400
$\geq 10 < 15$	1400	1400	1400	1300	1300
$\geq 15 < 20$	1300	1300	1300	1300	1200
$\geq 20 < 25$	1300	1300	1300	1200	1100
≥ 25	1100	1100	1100	1100	1100

Analysis Methodology Steps (Overview)

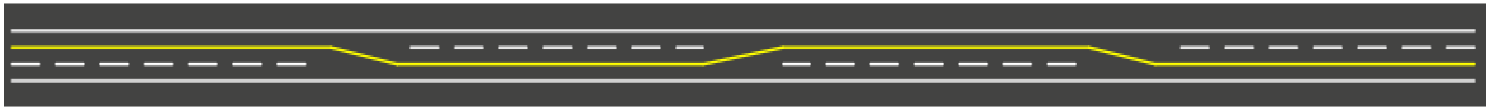
Analysis Methodology Steps

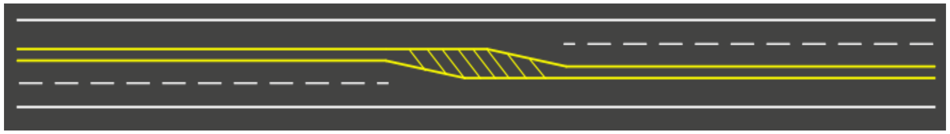
- Step 1: Identify facility study boundaries and corresponding segmentation
- Step 2: Determine demand flow rates, capacity, and d/c ratio
- Step 3: Determine vertical alignment classification
- Step 4: Determine the free-flow speed
  - Base FFS (function of posted speed limit)
  - Retains lane/shoulder width and access point adjustments
- Step 5: Estimate the average speed
  - Adjust Speed for Horizontal Alignment
- Step 6: Estimate the percent followers

Analysis Methodology Steps

- Step 7: Calculate additional passing lane segment performance measures
- Step 8: Estimate follower density
- Step 9: Determine potential adjustment to follower density from upstream passing lane segment
- Step 10: Determine LOS
- Step 11: Calculate facility follower density and LOS

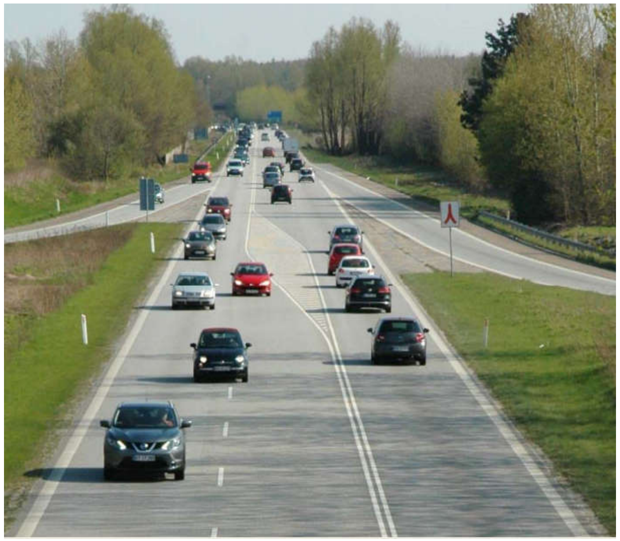
‘2+1’ Configuration





Germany

Sweden



Denmark

‘2+1’ Configuration

- Equations for estimating the change in performance between a 2+1 configuration and a comparable two-lane highway with no passing lanes, approximately 50% passing zones, and 16-18 miles in length.

$$\begin{aligned}\%Improve_{\%\text{Followers},2+1} &= 147.5 - 15.8 \times ln(FlowRate) + 0.05 \times FFS + 0.11 \times \%HV \\ &- 3.1 \times \ln(0.3, PassLaneLength)\end{aligned}$$

$$\begin{aligned}\%Improve_{AvgSpeed,2+1} &= \max(0, 21.8 - 1.86 \times \ln(FlowRate) - 0.1 \\ &\times \max[0,\min(FFS, 70) - 30] - 0.05 \times \max[0,30 - \%HV] + 1.1 \\ &\times \ln[\max(0.3, PassLaneLength)])\end{aligned}$$

$$\begin{aligned}FollowerDensity_{adj,2+1} &= \frac{\%Followers}{100} \times \left(1 - \frac{\%Improve_{\%\text{Followers},2+1}}{100}\right) \\ &\times \frac{FlowRate}{S \times \left(1 + \frac{\%Improve_{AvgSpeed,2+1}}{100}\right)}\end{aligned}$$

HCM Adoption Status

- Draft chapter 15 for Highway Capacity Manual formally adopted by HCQS committee, Jan. 2019
- Chapter underwent TRB editorial review and was approved for formal release in HCM Version 6.1

Summary: Methodology

- BFFS a function of posted speed limit
- More realistic speed-flow relationship
- Eliminated PTSF
- Added %followers
- 1 service measure, but 2 different sets of LOS thresholds
- Follower threshold of 2.5 s

Summary: Methodology (cont.)

- Units of vehicles, not passenger cars (HV% used directly)
- Some sensitivity to horizontal curvature
- Performance assessed at end of segment, rather than segment-length average (except both for passing lane segment)
- Initial material for addressing 2+1 configuration
- Accommodate facility scope
- Consistency with modern simulation tool(s)

Summary: Ease of Use

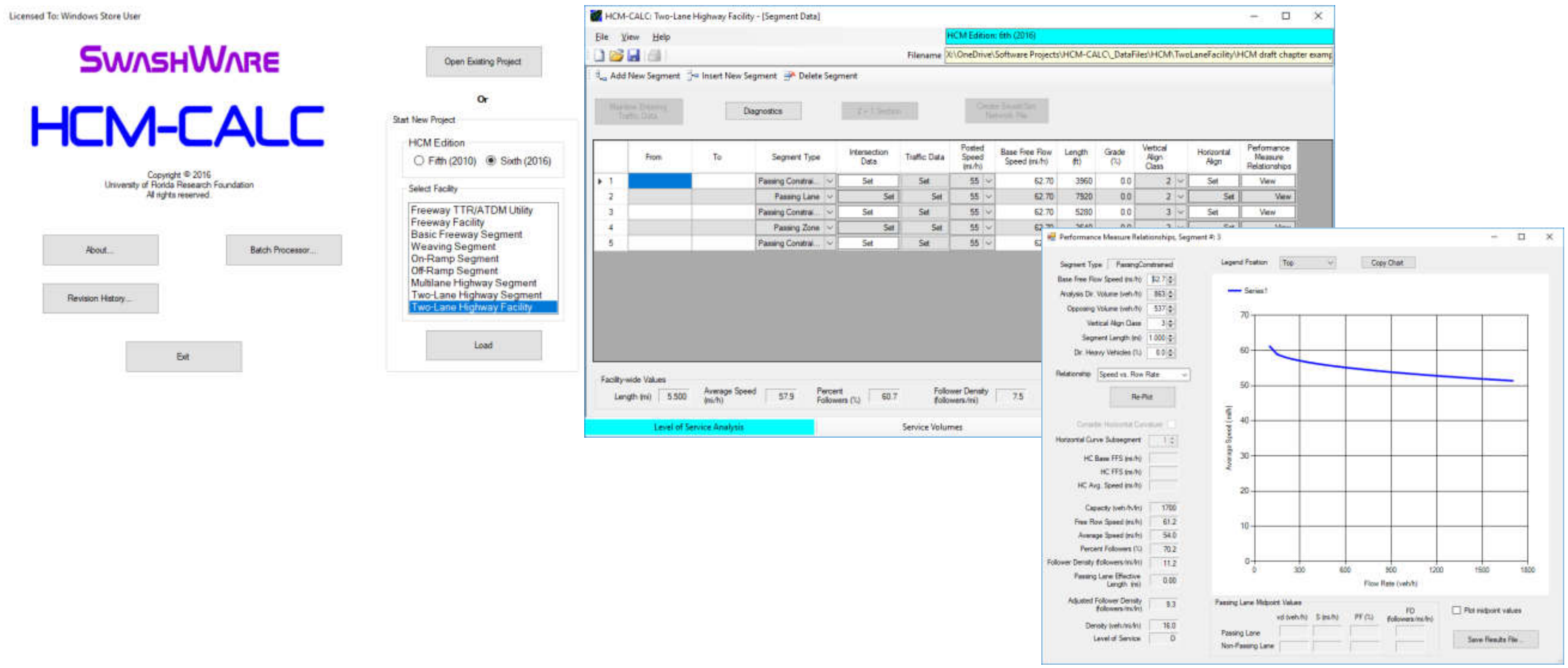
- Elimination of tables that require interpolation
- Treating trucks explicitly, rather than through PCE values
- Single service measure; No separate analysis flow rate calculations for different service measures
- No %No-Passing Zones input
- Elimination of the PTSF measure, which was difficult, if not impossible, to measure in the field

Summary: Simulation

- This project has identified two modern simulation tools that are capable of effectively and accurately modeling two-lane highways: SwashSim and TransModeler.
- SwashSim was used to generate the data for model development, while TransModeler was used to test the results of SwashSim for a sampling of the experimental design scenarios.

Software Implementation

- Analysis methodology implementation in HCM-CALC
- See https://github.com/swash17/HCM-CALC



The End

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