New Rural Highway Facility Operations Analysis Methods and Tools

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Outline

- Background
- Level of Service Methodology
- Reliability Analysis Methodology
- Guidebook
- Resources

Background

Presentation is based on results of:

- NCHRP Project 08-135: Reliability and Quality of Service Evaluation Methods for Rural Highways
- https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4747

Background

Research Team

Name	Organization
Scott Washburn	University of Florida
Ahmed Al-Kaisy	Montana State University
Ana Moreno	Technical University of Munich
Bastian Schroeder	Kittelson & Associates, Inc.
Jorge Barrios	Kittelson & Associates, Inc.

Background

- Historically, development of HCM analysis methodologies started at the point or segment level.
- Such development did not necessarily consider how different segments might eventually be connected to one another.
- More recently, efforts have been made to connect points and segments to provide for a facility analysis.
- The HCM now includes an urban street facility methodology (arterial roadways that include signalized and unsignalized intersections) and a freeway facility methodology (combines basic, ramp, and weaving segments).
- The HCM currently lacks a highway facility analysis procedure.

Background

- Rural highway corridors have different characteristics than urban corridors…
  - Often longer distances
  - More variety in roadway configuration
    - horizontal, vertical alignment
    - multilane highway, two-lane highway, isolated signalized intersections, short stretches of arterial through small towns
  - Serve higher percentage of recreational traffic
  - Serve some bicycle traffic

Background

- Objectives
  - Develop automobile level of service (LOS) methodology
  - Develop automobile travel time reliability analysis methodology
  - Identify research/analysis needs for the bicycle mode (not discussed in this presentation)
  - Develop Practitioner Guidebook

Facility Segmentation

For the purposes of this project, a rural highway can consist of the following segment types . . .

Facility Segment Types: Multilane Highway

Facility Segment Types: Two-Lane Highway

Facility Segment Types: Signalized Intersection

Facility Segment Types: All Way Stop Intersection

Source: Map data ©2022 Google

Facility Segment Types: Roundabout Intersection

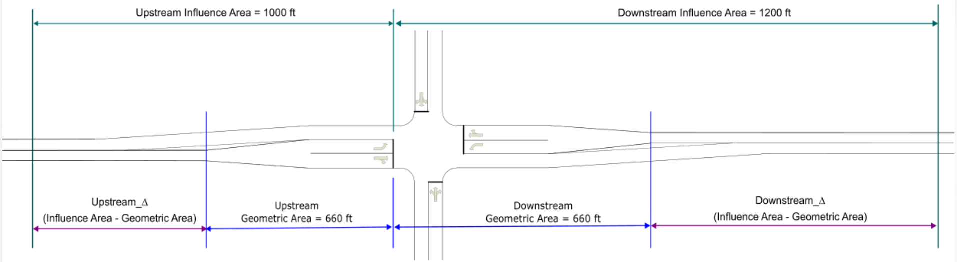
Source: Map data ©2022 Google

Facility Segment Types: Urban Street

- A short length of roadway (a few miles or less) that passes through a small town and also includes one or more intersections may warrant analysis with the urban streets methodology.
- This project developed additional guidance on when to apply the urban streets methodology, which is currently very limited in the HCM.

Facility Segmentation: Influence Area

- Determine upstream and downstream influence areas (IA) for intersections (signalized, roundabout, and all-way stop controlled)
- Adjust lengths of connecting multilane or two-Lane highway segments accordingly



$$IA\text{-}Signal_{US} = -923.89 + 35.92 \times UpstreamAvgSpeed + 1.23 \times PctHV - 374.05 \times I_{ML}$$
$$IA\text{-}Signal_{DS} = -1929.64 + 60.25 \times DownstreamAvgSpeed + 7.23 \times PctHV - 154.15 \times I_{ML}$$

Segment LOS

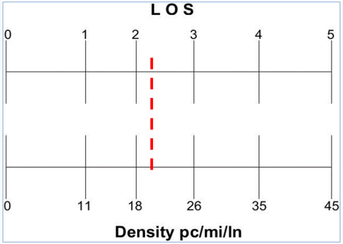
- The current HCM analysis methodologies for each segment type are used, with some simplifications.
- The current HCM service measures for each segment type are also used for segment LOS determination, as follows:
  - density for multilane highways
  - follower density for two-lane highways
  - control delay for intersections (signalized, stop control, roundabout)
  - average speed for urban streets

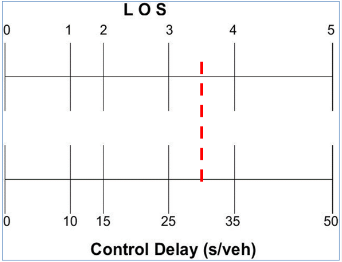
Segment LOS

- Due to disparate service measures, facility LOS determination cannot be accomplished by using an aggregation method of the segment service measure values.
- Instead, facility LOS determination is accomplished through an aggregation of the segment-level LOS values.

Segment LOS

- All segment service measure values are converted to a value between 0 and 5 (LOS A to F).
- A multilane highway segment with a density of 20 pc/mi/ln would result in a segment LOS score of 2.25.
- $LOS_{MLseg} = 2 + (3 - 2) \times \frac{20-18}{26-18} = 2.25$
- A stop-controlled intersection with a delay of 30 s/veh would result in a segment LOS score of 3.5.
- $LOS_{IntSeg} = 3 + (4 - 3) \times \frac{30-25}{35-25} = 3.5$





Facility LOS

- The segment LOS scores, weighted by travel time, are averaged to arrive at the facility LOS.

$$LOS_{Fac} = \sum_{i=1}^{n} LOSscore_i \times PropTravelTime_i$$

where,
LOS_{Fac} = Facility LOS score
$LOSscore_i$ = Numeric LOS score for segment *i*
n = Number of segments in the facility
$PropTravelTime_i$ = Proportion of travel time for segment *i* relative to the total travel time for the facility, calculated as

$$PropTravelTime_i = \frac{TravelTime_i}{TotalTravelTime}$$

Facility LOS

- The facility LOS score calculated from the previous equations is then adjusted to account for the consistency, or lack thereof, of LOS from one segment to another along the length of the facility.
- For example, a facility that consists of multiple segments all operating at LOS C except for one or two segments operating at LOS B or D, is considered preferable than the same facility with the same composite LOS but with frequent changes in segment LOS.
- The following measure is used to account for the fluctuation in segment-level LOS, both in frequency and magnitude.

$$LOSConstancy = \frac{\sum_{i=2}^{n} |LOSvalue_i - LOSvalue_{i-1}|}{n-1}$$

where,

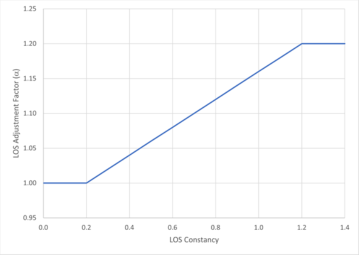
$LOSConstancy$ = Consistency of LOS while traversing successive facility segments

$LOSvalue_i$ = Level of service for segment i

$LOSvalue_{i-1}$ = Level of service for segment $i - 1$ (upstream of segment i)

Facility LOS

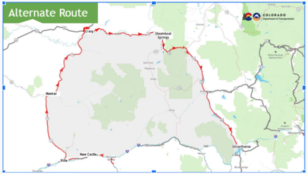
- The LOS adjustment factor is determined from LOS Constancy value.
- Final facility LOS score is based on unadjusted LOS score multiplied by LOS adjustment factor.



Adjustment Factor Value (α)	LOS Constancy Value
$\alpha = 1.0$	LOS Constancy ≤ 0.2
$\alpha = 0.96 + 0.2 \times$ LOS Constancy Value	$0.2 <$ LOS Constancy < 1.0
$\alpha = 1.2$	LOS Constancy ≥ 1.0

Facility LOS

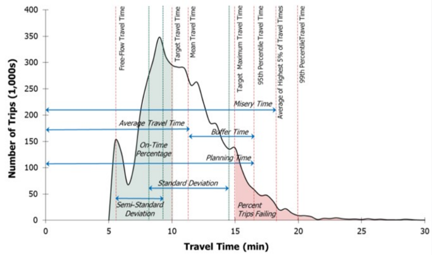
- Additional performance measures suggested for evaluation of atypical scenarios, such as:
  - Emergency traffic demand increase
  - Short-term traffic demand increase
  - Seasonal traffic demand increase
  - Long-term traffic demand increase
- For example, capacity may be a key factor in these situations, or even speed at capacity.



Lake Tahoe (Nevada) wildfire evacuation and I-70 at Glenwood Canyon (Colorado, west of Denver)

Background

- In the HCM, 'reliability' refers to travel time reliability (TTR). This concept currently is considered only in urban facility contexts (arterials, freeways).
- A TTR analysis method was developed, based on the use of historical probe vehicle data (e.g., INRIX, HERE).
- A current challenge for rural facilities is data availability (traffic demands, incident events, weather events), both spatially and temporally; thus, a predictive TTR methodology was not developed.



HCM Exhibit 11-3

Data

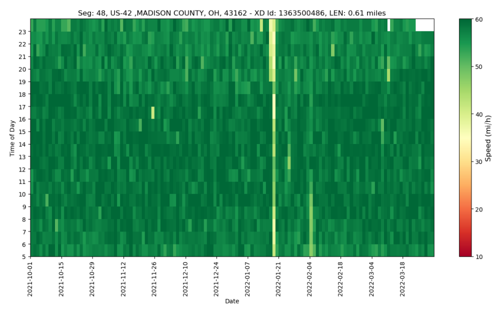
- Used INRIX XD ("higher definition") data.
- INRIX XD data is very similar to INRIX TMC (traffic message channel) data, but uses shorter spatial segments for data reporting.
- The XD data primarily consist of travel speeds and travel times. Because data are obtained from a sample of vehicles on the roadway, traffic flow rate is not obtained.

Methodology

- Five visualization techniques were developed that convert the INRIX XD speed and travel time data into charts and graphics for analysis and interpretation:
  - Speed heatmaps
  - Speed difference heatmaps
  - Box-and-whisker speed plots
  - Speed confidence band plots
  - Travel time index plots

TTR Visualization

- **Speed heatmaps** provide an overview of the overall facility and can be used to quickly identify recurring bottlenecks.
- Combined with local knowledge about facility geometry and information on weather, construction, activities, special events, etc., speed heatmaps can help paint a picture on facility reliability and potential patterns of recurring and non-recurring congestion.



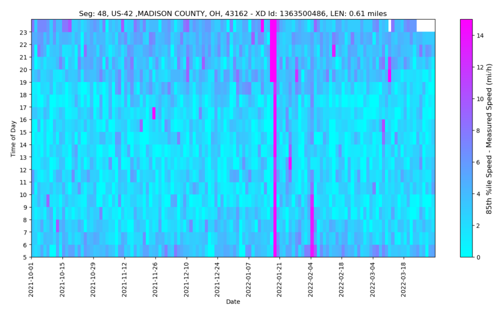
Speeds are aggregated to the hour and are visualized by a color scale from green (fast) to red (slow).

TTR Visualization

- **Speed difference heatmaps** normalize the heatmap patterns using a reference speed for each segment—the 85th percentile speed from the data as an approximation of free-flow speed. This technique is appropriate on long rural highways with a wide range of speed limits.

The speed difference heatmaps:

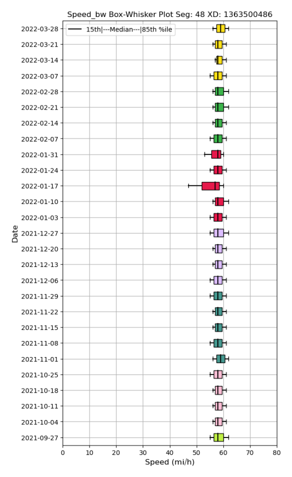
- more clearly highlight recurring and non-recurring congestion patterns across segments
- avoid potential visual bias introduced when traversing different speed limits and geometry-induced speed reductions along the corridor.



Speeds are aggregated to the hour and are visualized by a color scale from cyan (fast) to magenta (slow).

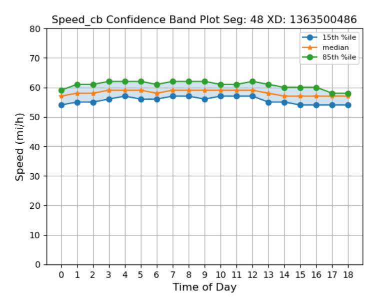
TTR Visualization

- **Box-and-whisker speed plots** help in identifying and narrowing down periods with poor reliability in the overall analysis period.
- They also complement inferences made using other visualizing metrics.



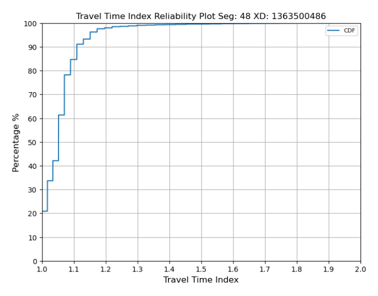
TTR Visualization

- **Speed confidence band plots** highlight the reliability of speeds at different hours using a years' worth of data. They simplify the interpreted visualization by removing the date dimension in the reliability data and showing reliability patterns by time-of-day only.
- The speed confidence band plots are especially useful when combined with a speed difference heatmap.
- In this combination, the speed confidence band plot can be used to infer which segment and which time periods experience unreliable travel; the speed difference heatmap can then be used to infer what date ranges contribute to the unreliability.



TTR Visualization

- **Travel time index plots** show the cumulative distribution of travel times along the segment, normalized by the free-flow travel time-estimated as the 15th percentile travel time.
- The travel time index (TTI) metric is commonly used in congestion and reliability reporting and is defined in the FHWA Travel Time Reliability guidance. Due to its simple line representation, a TTI plot can be an effective tool to convey before-after comparisons.



Guidebook

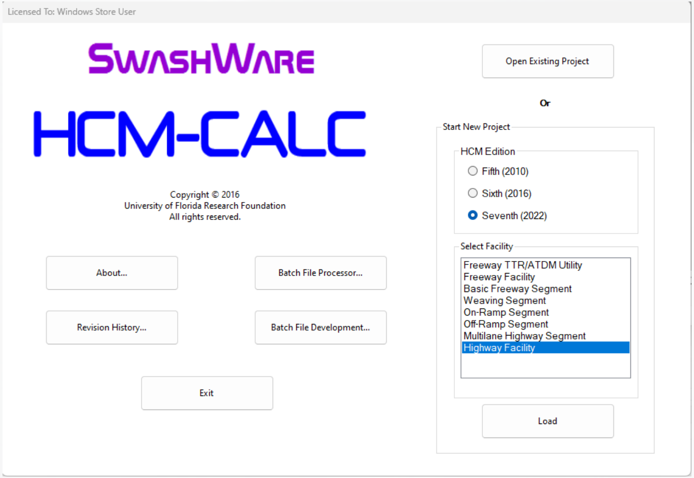
- PDF Version (https://dx.doi.org/10.17226/27895)
- HTML Version (https://nchrp-08-135.github.io/Guidebook)
  - Dynamic format
  - Easier to maintain/update
  - Easier for users to provide feedback and identify errors; i.e., can benefit from 'crowd sourcing'
  - Easy version control/revision tracking
- Also a final report (PDF), available at https://dx.doi.org/10.17226/27897

Resources

Project resources available at `https://github.com/NCHRP-08-135/Resources`. Includes:

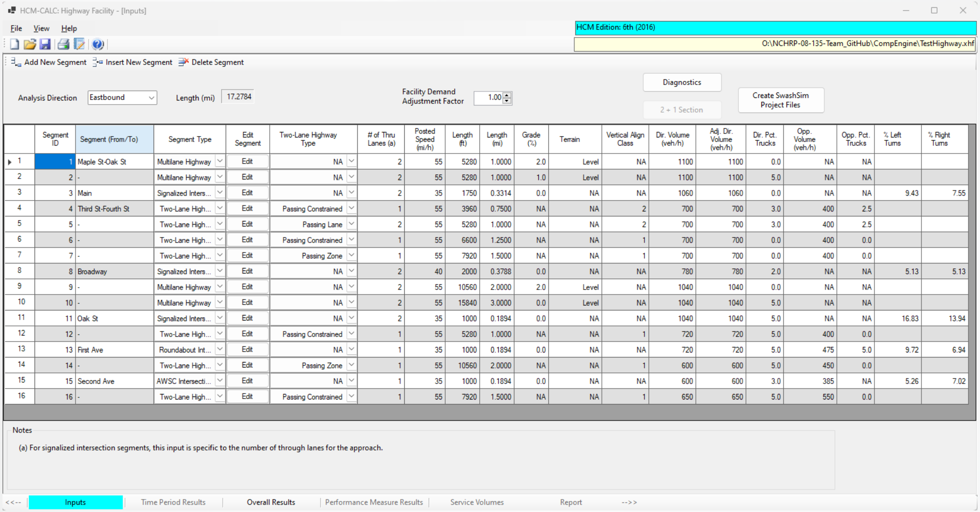
- HTML-formatted surveys used to collect rural highway bicycle information from practictioners and cyclists.
- Python code to load, analyze, and visualize probe data using the aforementioned techniques.
- Google Earth KML files for the four case studies included in the Guidebook.
- HCM calculations R code for multilane highway segments, two-lane highway segments, signalized intersections, all-way stop-controlled intersections, roundabout intersections, and intersection influence area.
- Input files for computational engine for the four case studies included in the Guidebook.

Computational Engine



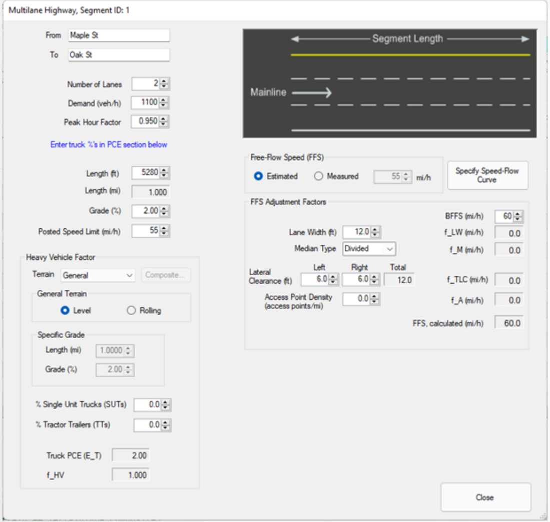
Available for free download at https://github.com/swash17/HCM-CALC

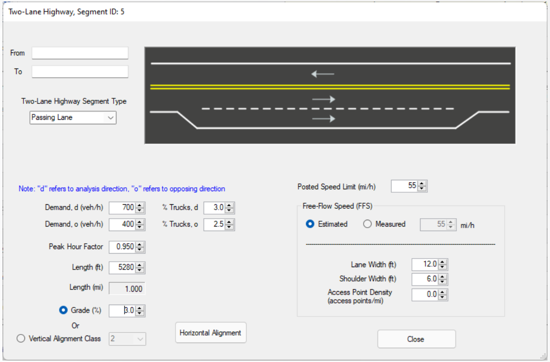
Computational Engine



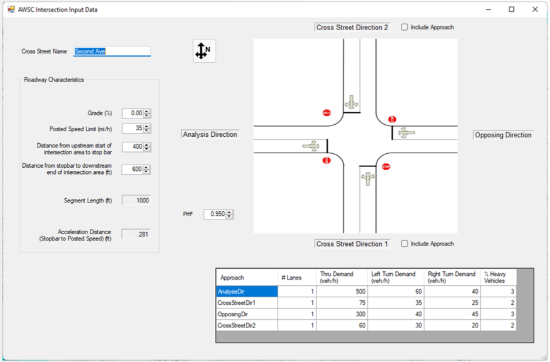
	Segment ID	Segment (From/To)	Segment Type	Edit Segment	Two-Lane Highway Type	# of Thru Lanes (a)	Posted Speed (mi/h)	Length (ft)	Length (mi)	Grade (%)	Terrain	Vertical Align Class	Dir. Volume (veh/h)	Adj. Dir. Volume (veh/h)	Dir. Pct. Trucks	Opp. Volume (veh/h)	Opp. Pct. Trucks	% Left Turns	% Right Turns
1	1	Maple St-Oak St	Multilane Highway	Edit	NA	2	55	5280	1.0000	2.0	Level	NA	1100	1100	0.0	NA	NA		
2	2	-	Multilane Highway	Edit	NA	2	55	5280	1.0000	1.0	Level	NA	1100	1100	5.0	NA	NA		
3	3	Main	Signalized Inters...	Edit	NA	2	35	1750	0.3314	0.0	NA	NA	1060	1060	0.0	NA	NA	9.43	7.55
4	4	Third St-Fourth St	Two-Lane High...	Edit	Passing Constrained	1	55	3960	0.7500	NA	NA	2	700	700	3.0	400	2.5		
5	5	-	Two-Lane High...	Edit	Passing Lane	2	55	5280	1.0000	NA	NA	2	700	700	3.0	400	2.5		
6	6	-	Two-Lane High...	Edit	Passing Constrained	1	55	6600	1.2500	NA	NA	1	700	700	0.0	400	0.0		
7	7	-	Two-Lane High...	Edit	Passing Zone	1	55	7920	1.5000	NA	NA	1	700	700	0.0	400	0.0		
8	8	Broadway	Signalized Inters...	Edit	NA	2	40	2000	0.3788	0.0	NA	NA	780	780	2.0	NA	NA	5.13	5.13
9	9	-	Multilane Highway	Edit	NA	2	55	10560	2.0000	2.0	Level	NA	1040	1040	0.0	NA	NA		
10	10	-	Multilane Highway	Edit	NA	2	55	15840	3.0000	0.0	Level	NA	1040	1040	5.0	NA	NA		
11	11	Oak St	Signalized Inters...	Edit	NA	2	35	1000	0.1894	0.0	NA	NA	1040	1040	5.0	NA	NA	16.83	13.94
12	12	-	Two-Lane High...	Edit	Passing Constrained	1	55	5280	1.0000	NA	NA	1	720	720	5.0	400	0.0		
13	13	First Ave	Roundabout Int...	Edit	NA	1	35	1000	0.1894	0.0	NA	NA	720	720	5.0	475	5.0	9.72	6.94
14	14	-	Two-Lane High...	Edit	Passing Zone	1	55	10560	2.0000	NA	NA	1	600	600	5.0	450	0.0		
15	15	Second Ave	AWSC Intersecti...	Edit	NA	1	35	1000	0.1894	0.0	NA	NA	600	600	3.0	385	NA	5.26	7.02
16	16	-	Two-Lane High...	Edit	Passing Constrained	1	55	7920	1.5000	NA	NA	1	650	650	5.0	550	0.0		

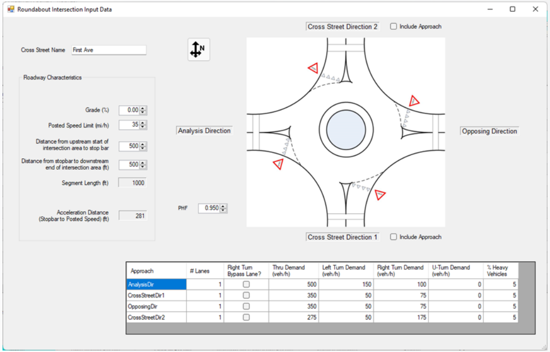
Computational Engine



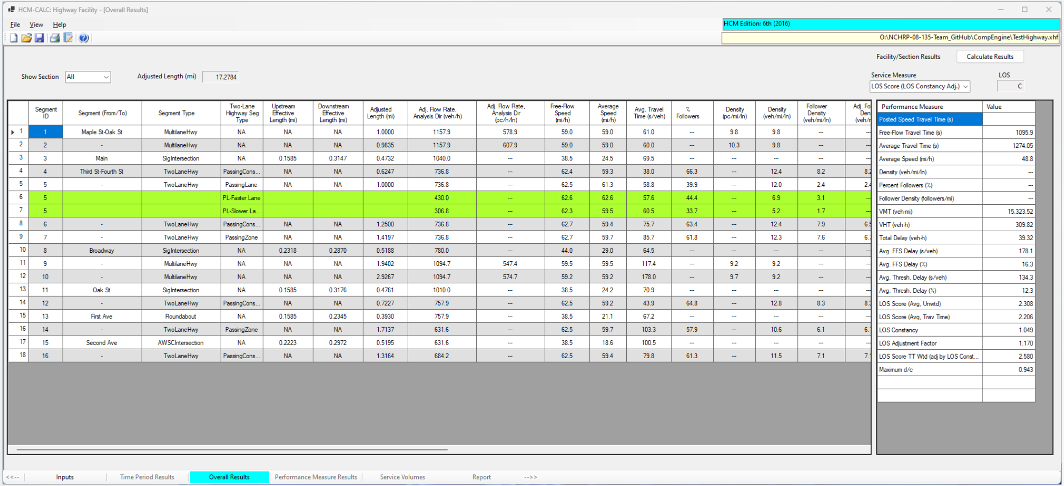


Computational Engine





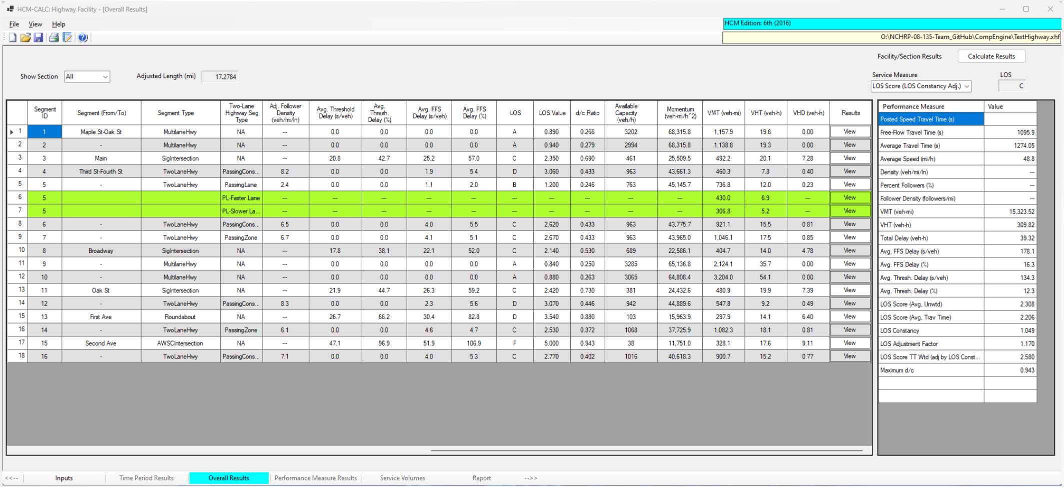
Computational Engine



	Segment ID	Segment (From/To)	Segment Type	Two-Lane Highway Seg Type	Upstream Effective Length (mi)	Downstream Effective Length (mi)	Adjusted Length (mi)	Adj. Flow Rate, Analysis Dir (veh/h)	Adj. Flow Rate, Analysis Dir (pc/h/ln)	Free-Flow Speed (mi/h)	Average Speed (mi/h)	Avg. Travel Time (s/veh)	% Followers	Density (pc/mi/ln)	Density (veh/mi/ln)	Follower Density (veh/mi/ln)	Adj. Fo Den (veh/
1	1	Maple St-Oak St	MultilaneHwy	NA	NA	NA	1.0000	1157.9	578.9	59.0	59.0	61.0	---	9.8	9.8	---	---
2	2	-	MultilaneHwy	NA	NA	NA	0.9835	1157.9	607.9	59.0	59.0	60.0	---	10.3	9.8	---	---
3	3	Main	SigIntersection	NA	0.1585	0.3147	0.4732	1040.0	---	38.5	24.5	69.5	---	---	---	---	---
4	4	Third St-Fourth St	TwoLaneHwy	PassingCons...	NA	NA	0.6247	736.8	---	62.4	59.3	38.0	66.3	---	12.4	8.2	8.2
5	5	-	TwoLaneHwy	PassingLane	NA	NA	1.0000	736.8	---	62.5	61.3	58.8	39.9	---	12.0	2.4	2.4
6	5			PL-Faster Lane				430.0	---	62.6	62.6	57.6	44.4	---	6.9	3.1	---
7	5			PL-Slower La...				306.8	---	62.3	59.5	60.5	33.7	---	5.2	1.7	---
8	6	-	TwoLaneHwy	PassingCons...	NA	NA	1.2500	736.8	---	62.7	59.4	75.7	63.4	---	12.4	7.9	6.5
9	7	-	TwoLaneHwy	PassingZone	NA	NA	1.4197	736.8	---	62.7	59.7	85.7	61.8	---	12.3	7.6	6.7
10	8	Broadway	SigIntersection	NA	0.2318	0.2870	0.5188	780.0	---	44.0	29.0	64.5	---	---	---	---	---
11	9	-	MultilaneHwy	NA	NA	NA	1.9402	1094.7	547.4	59.5	59.5	117.4	---	9.2	9.2	---	---
12	10	-	MultilaneHwy	NA	NA	NA	2.9267	1094.7	574.7	59.2	59.2	178.0	---	9.7	9.2	---	---
13	11	Oak St	SigIntersection	NA	0.1585	0.3176	0.4761	1010.0	---	38.5	24.2	70.9	---	---	---	---	---
14	12	-	TwoLaneHwy	PassingCons...	NA	NA	0.7227	757.9	---	62.5	59.2	43.9	64.8	---	12.8	8.3	8.3
15	13	First Ave	Roundabout	NA	0.1585	0.2345	0.3930	757.9	---	38.5	21.1	67.2	---	---	---	---	---
16	14	-	TwoLaneHwy	PassingZone	NA	NA	1.7137	631.6	---	62.5	59.7	103.3	57.9	---	10.6	6.1	6.1
17	15	Second Ave	AWSCIntersection	NA	0.2223	0.2972	0.5195	631.6	---	38.5	18.6	100.5	---	---	---	---	---
18	16	-	TwoLaneHwy	PassingCons...	NA	NA	1.3164	684.2	---	62.5	59.4	79.8	61.3	---	11.5	7.1	7.1

Performance Measure	Value
Posted Speed Travel Time (s)	
Free-Flow Travel Time (s)	1095.9
Average Travel Time (s)	1274.05
Average Speed (mi/h)	48.8
Density (veh/mi/ln)	---
Percent Followers (%)	---
Follower Density (followers/mi)	---
VMT (veh-mi)	15,323.52
VHT (veh-h)	309.82
Total Delay (veh-h)	39.32
Avg. FFS Delay (s/veh)	178.1
Avg. FFS Delay (%)	16.3
Avg. Thresh. Delay (s/veh)	134.3
Avg. Thresh. Delay (%)	12.3
LOS Score (Avg. Unwtd)	2.308
LOS Score (Avg. Trav Time)	2.206
LOS Constancy	1.049
LOS Adjustment Factor	1.170
LOS Score TT Wtd (adj by LOS Const...	2.580
Maximum d/c	0.943

Computational Engine



	Segment ID	Segment (From/To)	Segment Type	Two-Lane Highway Seg Type	Adj. Follower Density (veh/mi/ln)	Avg. Threshold Delay (s/veh)	Avg. Thresh. Delay (%)	Avg. FFS Delay (s/veh)	Avg. FFS Delay (%)	LOS	LOS Value	d/c Ratio	Available Capacity (veh/h)	Momentum (veh-mi/h^2)	VMT (veh-mi)	VHT (veh-h)	VHD (veh-h)	Results
1	1	Maple St-Oak St	MultilaneHwy	NA	---	0.0	0.0	0.0	0.0	A	0.890	0.266	3202	68,315.8	1,157.9	19.6	0.00	View
2	2	-	MultilaneHwy	NA	---	0.0	0.0	0.0	0.0	A	0.940	0.279	2994	68,315.8	1,138.8	19.3	0.00	View
3	3	Main	SigIntersection	NA	---	20.8	42.7	25.2	57.0	C	2.350	0.690	461	25,509.5	492.2	20.1	7.28	View
4	4	Third St-Fourth St	TwoLaneHwy	PassingCons...	8.2	0.0	0.0	1.9	5.4	D	3.060	0.433	963	43,661.3	460.3	7.8	0.40	View
5	5	-	TwoLaneHwy	PassingLane	2.4	0.0	0.0	1.1	2.0	B	1.200	0.246	763	45,145.7	736.8	12.0	0.23	View
6	5			PL-Faster Lane	---	---	---	---	---	---	---	---	---	---	430.0	6.9	---	View
7	5			PL-Slower La...	---	---	---	---	---	---	---	---	---	---	306.8	5.2	---	View
8	6	-	TwoLaneHwy	PassingCons...	6.5	0.0	0.0	4.0	5.5	C	2.620	0.433	963	43,775.7	921.1	15.5	0.81	View
9	7	-	TwoLaneHwy	PassingZone	6.7	0.0	0.0	4.1	5.1	C	2.670	0.433	963	43,965.0	1,046.1	17.5	0.85	View
10	8	Broadway	SigIntersection	NA	---	17.8	38.1	22.1	52.0	C	2.140	0.530	689	22,586.1	404.7	14.0	4.78	View
11	9	-	MultilaneHwy	NA	---	0.0	0.0	0.0	0.0	A	0.840	0.250	3285	65,136.8	2,124.1	35.7	0.00	View
12	10	-	MultilaneHwy	NA	---	0.0	0.0	0.0	0.0	A	0.880	0.263	3065	64,808.4	3,204.0	54.1	0.00	View
13	11	Oak St	SigIntersection	NA	---	21.9	44.7	26.3	59.2	C	2.420	0.730	381	24,432.6	480.9	19.9	7.39	View
14	12	-	TwoLaneHwy	PassingCons...	8.3	0.0	0.0	2.3	5.6	D	3.070	0.446	942	44,889.6	547.8	9.2	0.49	View
15	13	First Ave	Roundabout	NA	---	26.7	66.2	30.4	82.8	D	3.540	0.880	103	15,963.9	297.9	14.1	6.40	View
16	14	-	TwoLaneHwy	PassingZone	6.1	0.0	0.0	4.6	4.7	C	2.530	0.372	1068	37,725.9	1,082.3	18.1	0.81	View
17	15	Second Ave	AWSCIntersection	NA	---	47.1	96.9	51.9	106.9	F	5.000	0.943	38	11,751.0	328.1	17.6	9.11	View
18	16	-	TwoLaneHwy	PassingCons...	7.1	0.0	0.0	4.0	5.3	C	2.770	0.402	1016	40,618.3	900.7	15.2	0.77	View

Performance Measure	Value
Posted Speed Travel Time (s)	
Free-Flow Travel Time (s)	1095.9
Average Travel Time (s)	1274.05
Average Speed (mi/h)	48.8
Density (veh/mi/ln)	---
Percent Followers (%)	---
Follower Density (followers/mi)	---
VMT (veh-mi)	15,323.52
VHT (veh-h)	309.82
Total Delay (veh-h)	39.32
Avg. FFS Delay (s/veh)	178.1
Avg. FFS Delay (%)	16.3
Avg. Thresh. Delay (s/veh)	134.3
Avg. Thresh. Delay (%)	12.3
LOS Score (Avg. Unwtd)	2.308
LOS Score (Avg. Trav Time)	2.206
LOS Constancy	1.049
LOS Adjustment Factor	1.170
LOS Score TT Wtd (adj by LOS Const...	2.580
Maximum d/c	0.943

The End

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https://github.com/NCHRP-08-135