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Phase 2 of Transportation Pooled Fund Study #TPF-5(361): SHRP2 Naturalistic Driving Study Pooled Fund: Advancing Implementable Solutions

Verification and Calibration of Microscopic Traffic Simulation Using Driver Behavior and Car-Following Metrics for Freeway Segments

User Guideline for Naturalistic Assessments of Car-following Trajectories

December 2022

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AADT	annual average daily traffic
CDF	cumulative distribution function
CSV	comma-separated values
CVM	Cramer-Von Mises
DKW	Dvoretzky–Kiefer–Wolfowitz Inequality
DOT	Department of Transportation
kph	kilometers per hour
K-S	Kolmogorov–Smirnov
mph	miles per hour
NACT	The Naturalistic Assessments of Car-following Trajectories
NDS	naturalistic driving study
SHRP2	Second Strategic Highway Research Program
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION AND BACKGROUND

This guideline presents a first attempt at developing targets for microscopic calibration derived from a large driving sample extracted from over 1,700 unique drivers. In particular, the research team used datasets from the Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study (NDS) (Virginia Tech Transportation Institute, 2013) to assess naturalistic car-following behavior. This guideline was developed as part of a larger research project conducted by the authors, which included a comprehensive report as a primary product (*Verification and Calibration of Microscopic Traffic Simulation Using Driver Behavior and Car-Following Metrics for Freeway Segments Research Report*).

NDS targets were developed for freeway segments where passenger vehicles are traversing mainlines in good weather conditions. Driver behavior targets are presented in terms of distributions of spacing and accelerations while following a leading vehicle at different speed ranges. These targets were incorporated into an open-source application called the Naturalistic Assessment of Car-following Trajectories (NACT) tool, where a user can upload vehicle traversal data for comparisons with the expected NDS targets to support calibration efforts.

The proposed calibration process is expected to complement traditional calibration of microscopic traffic simulation, which is typically conducted to reproduce overall system performance measures, such as travel time, delay, and queues (Dowling et al., 2004; Ge and Menendez, 2012; Gomes et al., 2004; Park and Qi, 2006; Lownes and Machemehl, 2006). State department of transportation (DOT) guidelines typically recommendations on the type of parameters to be adjusted and a range of typical values, all of which are also at the macroscopic level. Examples include calibration documents from the DOTs in Florida (FL) (Florida DOT, 2021), Oregon (Oregon DOT, 2011), Virginia (Virginia DOT, 2020), and Wisconsin (Wisconsin DOT, 2019), where the guidance is intended to cover targets for macroscopic metrics, without mention of microscopic-level calibration.

Therefore, the intent of microscopic calibration of driver behavior is not to replace current calibration practices, but to enhance calibration by comparing trajectory data from simulation and naturalistic car-following metrics.

This guideline is organized into seven chapters, followed by three appendices:

- Chapter 2 defines the scope of work.
- Chapter 3 provides details of the NDS targets developed in terms of vehicle spacing, acceleration, and acceleration change rates (jerk).
- Chapter 4 explains the NACT tool and gives a step-by-step guide in how to use it.
- Chapter 5 describes the outcomes from the tool and provides guidance on the interpretation of results.
- Chapter 6 describes an example of calibration using the NACT tool in Vissim.
- Chapter 7 summarizes key notes, recommendations, and limitations.
- Appendix A provides additional details on calculations of traffic estimations using NDS.
- Appendix B lists the percentiles for the vehicle spacing targets.
- Appendix C describes the results from an analysis on the effects of site characteristics on the NDS targets.

CHAPTER 2. SCOPE OF GUIDELINES

This guideline presents a method to characterize car-following behavior from passenger vehicles traveling on urban and suburban freeway segments. Car-following is described in terms of spacing, acceleration, and acceleration change rate (jerk) distributions for a wide range of speed levels from very, low-speed (0-20 mph) to high-speed (65-80 mph) conditions.

The main objectives of this guideline are two-fold. First, this guideline documents naturalistic car-following behavior on freeway segments from a large sample of drivers using spacing and acceleration distributions in detail not previously available, serving as general targets (i.e. NDS targets) to conduct calibration; and, second, to incorporate such targets into a calibration process where they are compared to trajectory data extracted from simulation. To this end, the research team developed a computer application to read and analyze trajectories, produce distributions of car-following behavior from simulation, and perform comparisons with the targets. This document provides detailed guidance on the use of the tool, along with examples to illustrate applications.

While the NACT tool analyzes input data to generate comparisons with the NDS targets, it does not aim to guide the selection of specific car-following parameters to perform calibration. This is because the tool is model agnostic and compares generic vehicle trajectory data without knowledge of the underlying simulation package. Nonetheless, the guideline document provides examples using a specific package to illustrate the use of the tool through different iterations of simulation runs and the effects of specific parameters on vehicle spacing and acceleration.

CHAPTER 3. NDS DRIVER BEHAVIOR TARGETS

The research team used VTTI-provided data for the development of targets for microscopic calibration, with a focus on car-following behavior on freeway segments, specifically when vehicles are traveling through mainline lanes. This is, excluding the behavior of drivers on entry or exit ramps, or using acceleration or deceleration segments as they leave or enter ramps, or in the process of changing lanes.

Data requested from VTTI included time series that indicated vehicle trajectory (i.e., vehicle coordinates), vehicle speed as measured from the vehicle speedometer, and processed radar data identifying objects detected by the front-facing radar, their longitudinal and lateral range, and traveling lane with respect to the instrumented vehicle. Additional details related to data collection and time series data can be found in the full report for the project associated with the guidance development, Transportation Pooled Fund Study #TPF-5(361).

The research team selected traversals from 104 urban and suburban freeway sites located in three States (North Carolina, Washington, and Florida) for the extraction of driver behavior. Site selection considered multiple criteria to cover a variety of location characteristics, including speed limits, number of lanes, and traffic conditions. Table 1 shows summary statistics for site characteristics.

Table 1. Summary statistics of selected sites for data analysis.

	Number of Sites	Average	Maximum	Minimum
Directional AADT	104	56,440	101,333	15,833
Speed Limit (mph)	104	62.1	70	55
Number of Lanes	104	3.4	5	2
Presence Auxiliary Lane	104	0.34	1	0
Site Length (miles)	104	1.62	4.21	0.35

The research team also identified sites to cover a large number of traversals made by drivers with diverse demographics, maintaining similar distributions of driver age groups as in the NDS complete datasets. Table 2 illustrates the driver age groups. This distribution does not follow the same age breakdown as the average U.S. driving population, so the research team also developed characterizations of driver behavior that more closely represent national averages. Outcomes from updated distributions that reflect U.S. driving population breakdowns can be found in the main project document mentioned above.

Table 2. Driver age distribution in final NDS dataset.

Driver Age	Proportion
16-24	36%
25-34	16%
35-44	7%
45-54	9%
55-65	10%
65-74	11%
75+	11%

The research team then post-processed data for the selected traversals to limit time series data to the geographical location of the selected analysis sections within the NDS sites. For this process, the research team re-projected the original vehicle trajectory data to local coordinates, bounded to only include data within the sites, and smoothed to obtain time series of vehicle position, speed, and acceleration of the instrumented vehicle.

The research team further analyzed the radar data in combination with the instrumented vehicle trajectory to develop leader-follower time series. This new time series included vehicle spacing between the instrumented vehicle, acting as a follower, and a downstream vehicle in the same lane acting as a leader.

After analysis of the datasets, time series with a 0.1-second resolution were available for the instrumented vehicle position, speed, and acceleration, describing the vehicle kinetics in the longitudinal direction and the car-following behavior from a microscopic standpoint in terms of vehicle spacing. The research team used simple linear interpolation to estimate values for variables at timestamps between observations as long as the data gap was at most 2 seconds, with larger gaps in data resulting in the time series not being further considered in the analysis.

The research team, to further analyze car-following behavior, also further filtered the data to include only instances where the following behavior for the same leader-follower pair was observed for at least 10 seconds. This filter was aimed at targeting only car-following instances where the follower had established a following behavior, removing instances of short leader-follower interactions. Setting a minimum time for leader-follower analyses is consistent with previous NDS', where minimum thresholds have been used to characterize following behavior (Zhu et al., 2018; LeBlanc et al., 2013; Chong et al., 2013; Fernandez, 2011).

Figure 1 shows a depiction of the car following behavior in terms of the empirical cumulative distribution of spacing for all drivers and all sites, and table 3 includes key percentiles. However, additional contextualization is needed to specify behavior under different traffic conditions, so spacing distributions can be further refined.

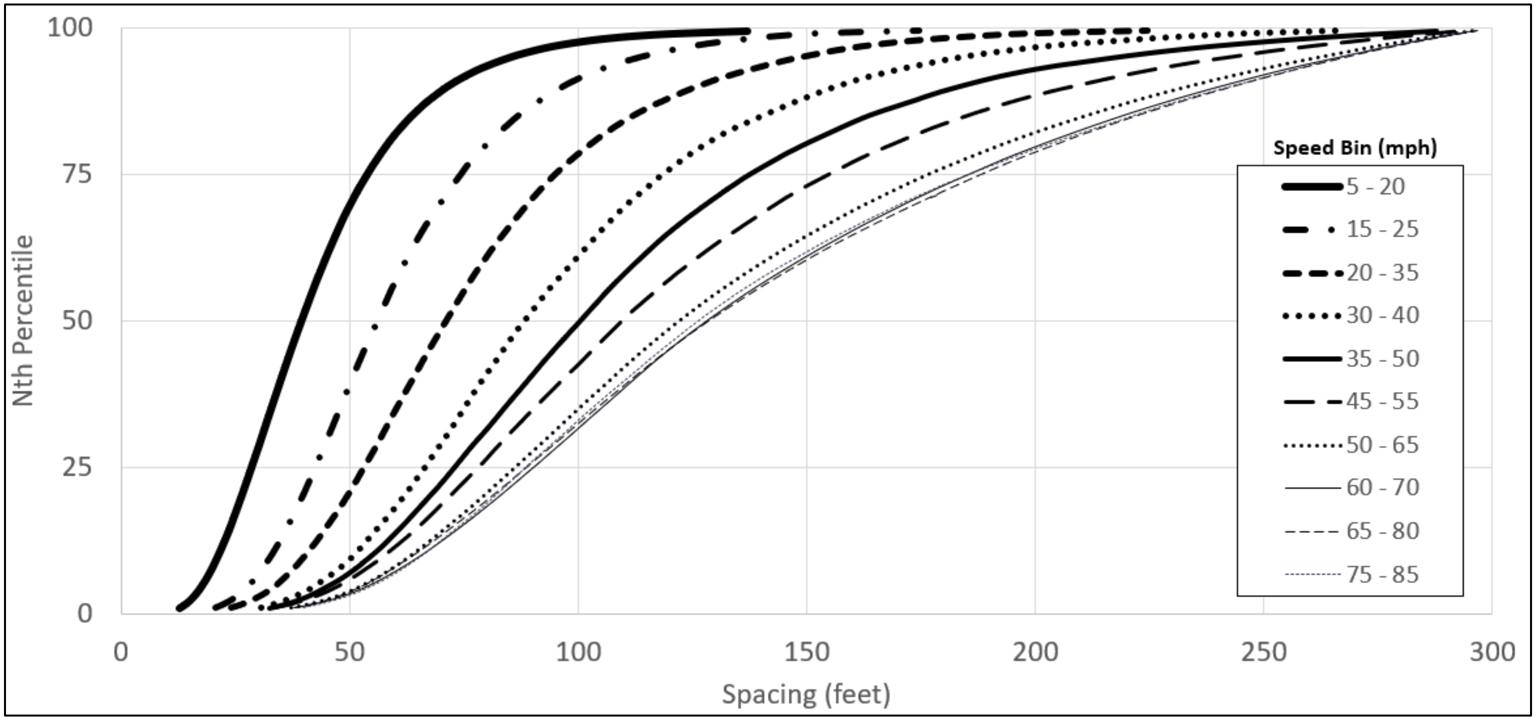
NDS datasets do not provide an estimation of traffic condition, so additional analysis was conducted to validate speed as a surrogate measure for traffic conditions. Outcomes from this analysis showed that speed was a reasonable indicator of traffic density, supporting the use of speed as a surrogate for traffic conditions. Appendix A includes details of the speed-density analysis.

Spacing Distributions by Speed Groups

After establishing speed as a surrogate for traffic, the research team expanded the data analysis to obtain target spacings at different speed levels. Overlapping speed groups were defined to cover the complete typical spectrum of freeway-level speeds, ranging from conditions near standstill to speeds up to 85 miles per hour (mph). The selected traversals provided sufficient data to extract behavior at individual speed-group levels while ensuring similar driver distributions by age, reducing possible bias due to dissimilar participant composition.

In summary, over 1,600 hours of car-following behavior from passenger cars on freeway segments under good weather and daytime conditions remained in the final datasets. A total of 1,738 unique drivers are included in the final datasets, and each of the specified speed groups contained at least 15 hours and up 400 hours of driving. The groups with the largest driving times were those with speeds 50 mph and over, and the lowest for the speed groups between 15 mph and 40 mph.

Figure 1 shows an illustration of the cumulative spacing distributions for 10 different groups that serve as targets for simulation outcomes. Appendix B includes additional details including the density functions and percentiles for each speed groups.



Source: FHWA

Figure 1. Graphic. Vehicle spacing distributions from NDS datasets - by speed group.

Table 3. Key percentiles vehicle spacing (ft) distributions from NDS datasets - by speed group.

Nth Percentile	Speed Bin (mph)									
	5 - 20	15 - 25	20 - 35	30 - 40	35 - 50	45 - 55	50 - 65	60 - 70	65 - 80	75 - 85
1	12.9	20.6	24.2	30.8	32.6	33.5	37.2	38.1	37.8	39.9
5	17.9	28.2	34.3	43.0	45.9	48.3	53.2	54.9	53.6	55.7
10	21.3	32.9	40.4	51.0	54.9	57.8	63.5	65.9	64.0	66.1
25	28.6	42.4	53.2	66.6	73.0	78.2	86.3	90.4	88.7	88.7
50	39.5	56.1	71.2	88.3	100.5	109.6	122.1	128.2	128.6	126.4
75	53.8	74.3	95.0	118.6	137.4	154.9	176.6	185.5	188.1	185.5
90	71.3	96.7	126.1	156.5	183.0	208.2	233.5	240.4	243.1	242.7
95	84.9	113.5	148.7	183.7	217.1	242.4	262.1	266.6	267.7	267.1
99	118.6	151.1	197.4	244.6	273.9	286.1	291.2	292.4	292.6	291.8

From figure 1, it is observed that spacing generally increases with an increase in speed, as expected, with practically no spacing differences for groups above 60 mph. Greater spacing differences are noted between lower speed groups at lower percentiles, with differences becoming gradually smaller as speeds reach higher levels. For example, the 25^{th} percentile spacing for the speed groups 5-20 mph and 15-25 mph are 28.6 ft and 42.4 ft, and the same percentiles for speed groups 45-55 mph and 50-65 mph are 78.2 ft and 86.3 ft, respectively.

The research team also explored the effects of roadway geometric characteristics on leader-follower spacing to determine if further targets were needed for different site configurations. Outcomes from this exploration indicated that for the same speed groups, there were no consistent systematic changes in spacing distributions, particularly for larger group sizes (e.g., 50-65 mph, or 60-70 mph), and for sites with different number of lanes (2, 3, 4, or 5 lanes). The research team also obtained similar results when sites were analyzed for different speed limits (55, 60, 65, or 70 mph) and even when analyzed based on the State the data was collected (FL, NC, or WA). Outcomes from these evaluations are included in appendix C.

Acceleration Distributions by Speed Groups

In terms of vehicle kinematics, acceleration was the next natural microscopic variable after analyzing vehicle location (i.e. spacing) by speed groups. Empirical cumulative distributions from NDS were produced based on the speed rate change using a time window of 0.5 seconds. Therefore, the research team observed acceleration at a lower resolution than speed. This decision was in part as a result of typical human driving, where conservative estimates would still exceed 0.5 seconds of perception-reaction times, and therefore the ability to adjust acceleration more than once. Higher frequency of acceleration changes would also incorporate larger effects from speed measurement errors.

Figure 2 and figure 3 show the cumulative distribution functions for positive acceleration and negative acceleration (deceleration), respectively. Similar to the spacing data, the acceleration distributions display organized and consistent patterns. Larger accelerations are more common at lower speeds (lower than 50 mph), with a 50^{th} percentile of about 1 ft/s^2 compared to about 0.3 ft/s^2 for the 50-65 mph group. These acceleration values are relatively small compared to maximum accelerations a driver can typically apply, but they are well within typical ranges specified for oscillation acceleration parameters. It is important to recognize that accelerations obtained from NDS correspond to car-following observations, excluding overtaking or lane-changing maneuvers or free-flowing conditions.

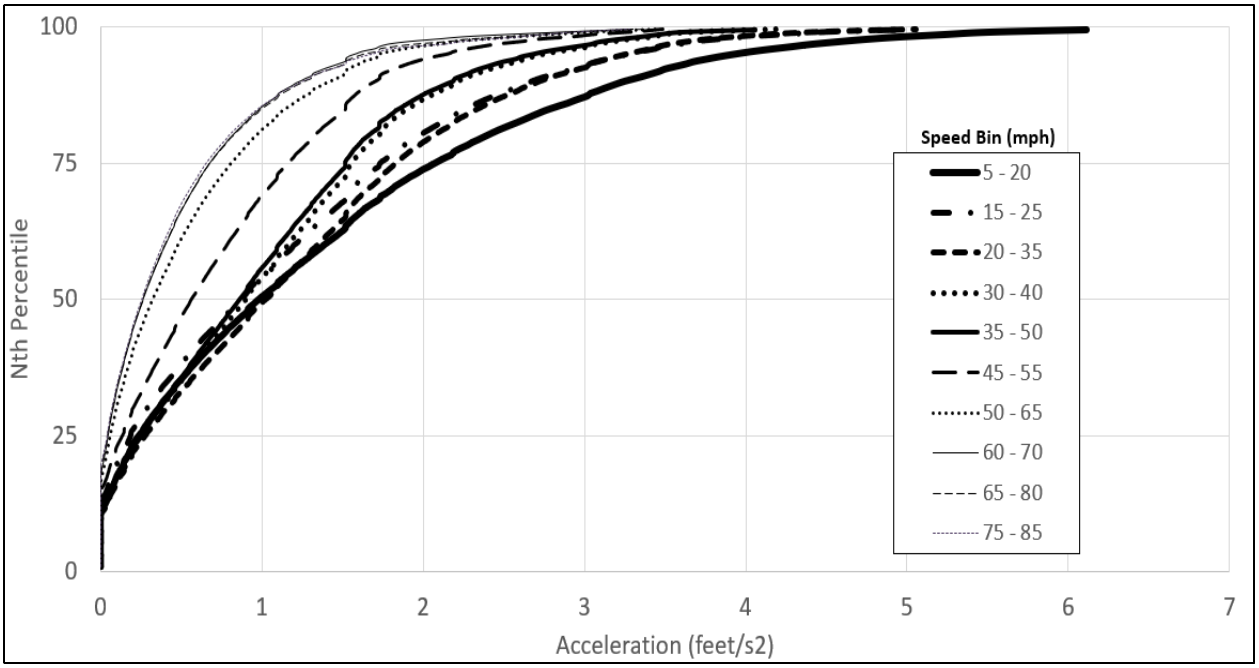


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Figure 2. Graphic. Empirical cumulative distribution plot of acceleration for all speed groups.

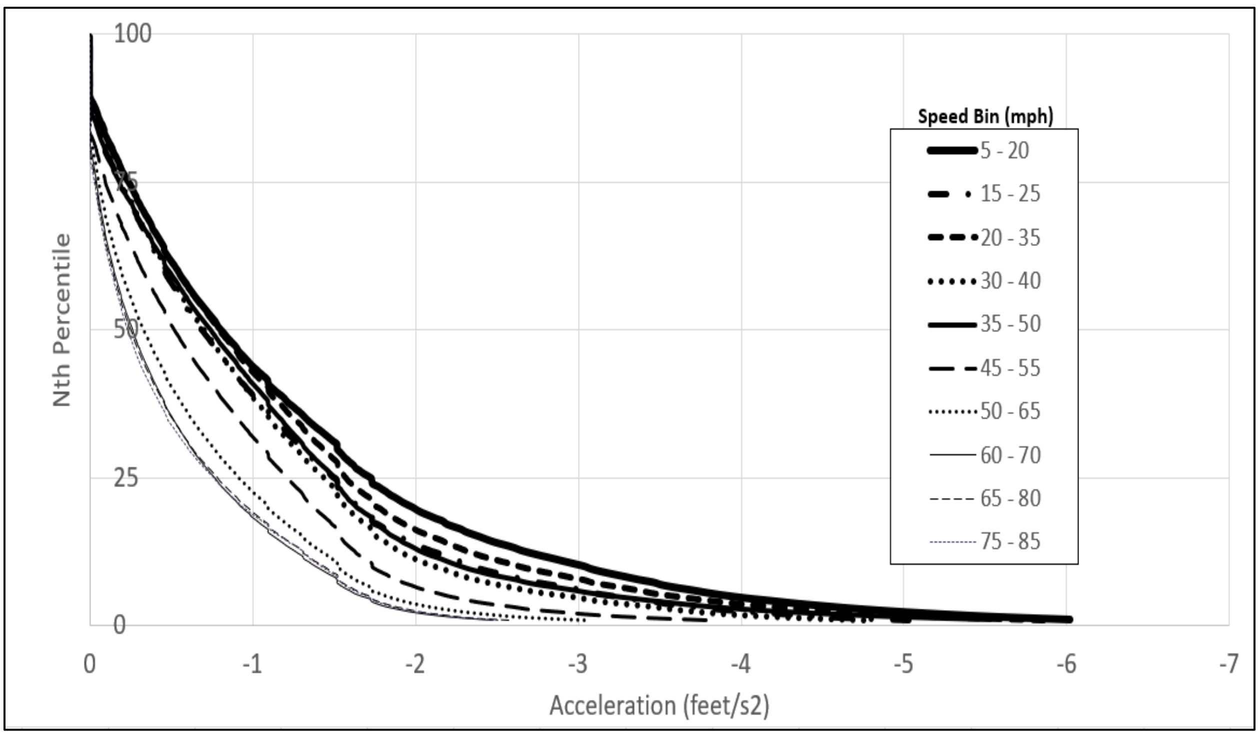

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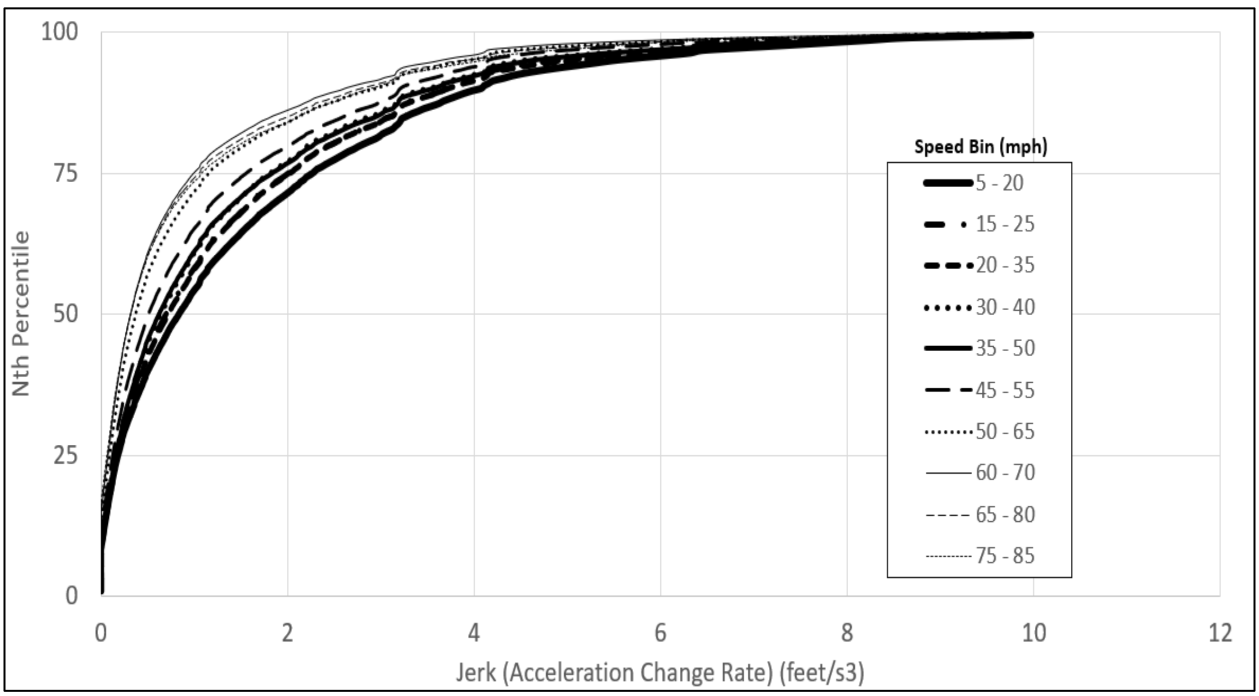
Figure 3. Graphic. Empirical cumulative distribution plot of negative acceleration (deceleration) of all speed groups.

Lastly, it is also noted that both positive and negative acceleration distributions from instrumented vehicles closely mirror each other, indicating an oscillatory behavior of a follower with respect to the leader, typically expected from car-following conditions.

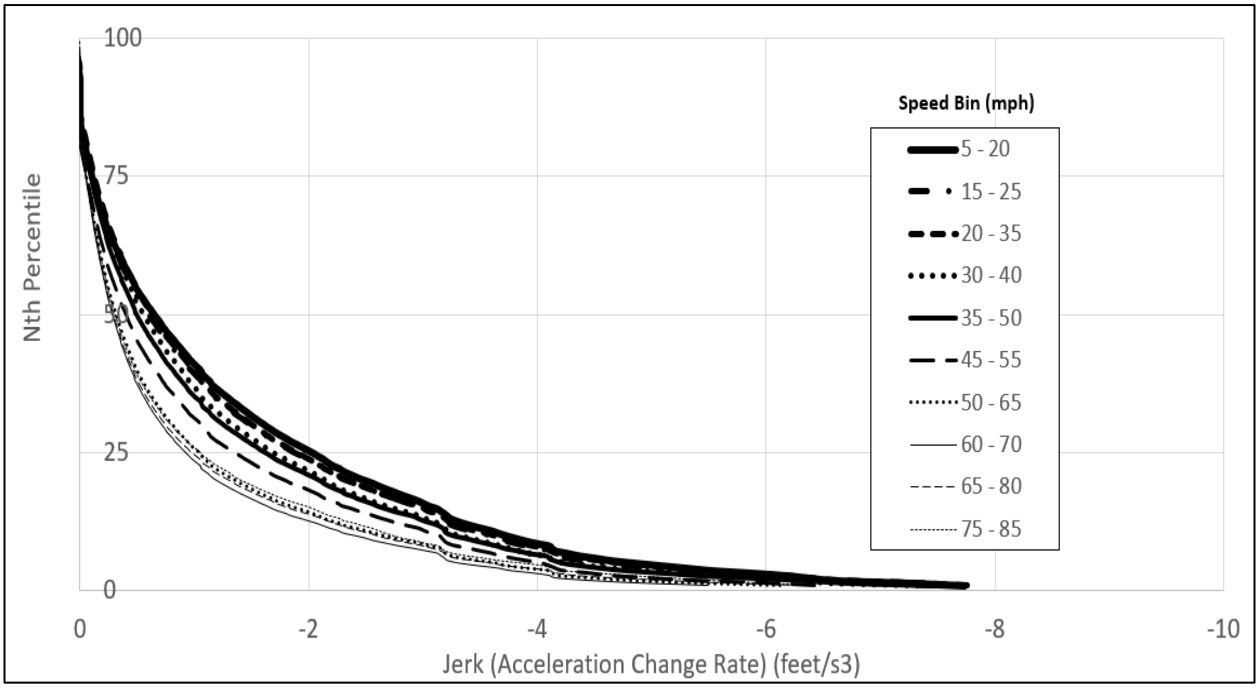
Acceleration Rate Change (Jerk) Distributions by Speed Groups

As an alternative to acceleration data, the research team also analyzed the rate of acceleration change (i.e., jerk) to establish potential NDS targets for simulation. Even though acceleration metrics did not result in enhanced targets compared to spacing, the research team also developed jerk distributions to identify potential targets that could be beneficial for calibration at a microscopic level. The calculations for jerk values used two consecutive acceleration values. Therefore, since acceleration values were estimated every 0.5 seconds, jerk values reflect variations in the acceleration between such values. Figure 4 and figure 5 show the empirical distribution of the jerk values for both acceleration and deceleration, respectively. As expected from the acceleration distributions, larger jerk values are associated with lower speeds. Sudden maneuvers at lower speeds can produce larger longitudinal changes in acceleration compared to vehicles already traveling at freeway speeds. Also, data are consistent and indicate gradual decreases of jerk values with speed, however as a differentiating metric between speed group, jerk values carry less power compared to acceleration, which in turn carries less power than spacing.



Source: FHWA

Figure 4. Graphic. Empirical cumulative distribution plot of jerk (for acceleration) for all speed groups.



Source: FHWA

Figure 5. Graphic. Empirical cumulative distribution plot of jerk (for deceleration) for all speed groups.

Standstill Distance

The research team also used additional outcomes from highly congested traffic conditions to develop an empirical cumulative distribution to illustrate field-based standstill distance as an additional reference to calibrate this element within the simulation car-following models. The 50th percentile of the distribution is equivalent to 9.3 ft, and the boundaries of the interquartile range at located between 8 ft and 11.5 ft, as shown in figure 6.

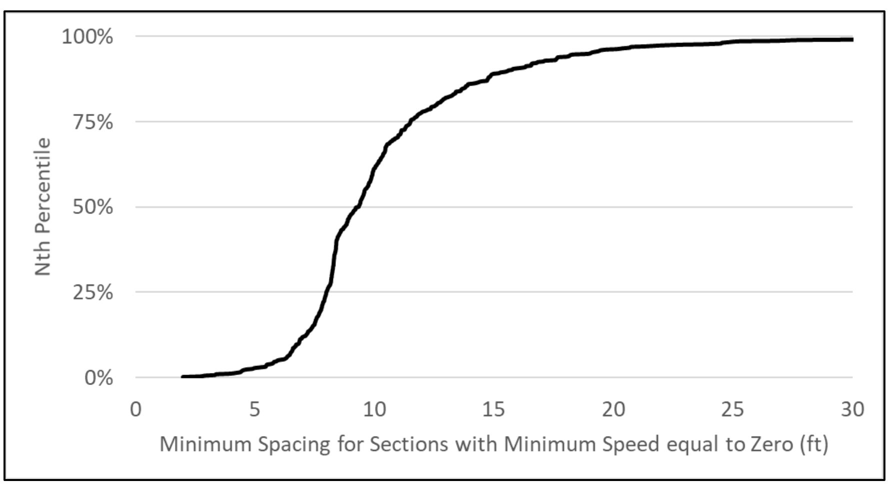


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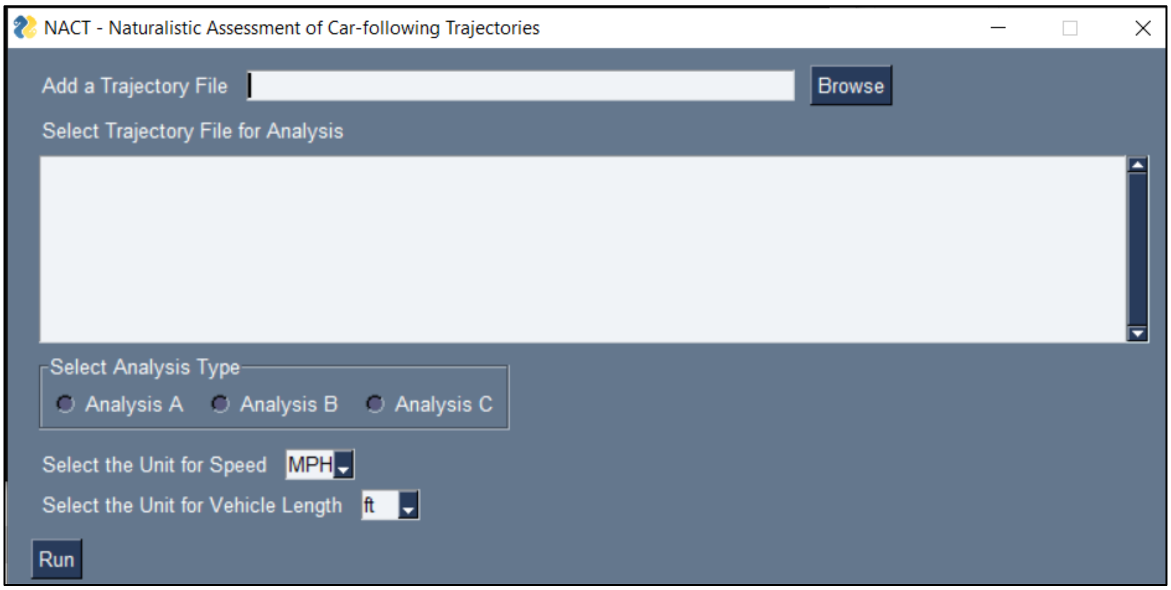
Figure 6. Graphic. Cumulative distribution plot of standstill distance.

CHAPTER 4. NATURALISTIC ASSESSMENTS OF CAR-FOLLOWING TRAJECTORIES (NACT) TOOL

The research team developed a custom stand-alone tool built on Python v3.10.6 (Python Language Foundation, 2022), called *Naturalistic Assessments of Car-following Trajectories* (NACT), to analyze trajectory data in relation to naturalistic behavior extracted from NDS datasets. The NACT tool processes input trajectories to produce leader-follower datasets, characterize car-following behavior in the simulated scenario, and then performs comparisons with the NDS targets.

The tool is presented as a compiled application in the form of an executable file that contains all required dependencies to run on Windows-based machines. Upon opening, the application will display the user interface as shown in figure 7.



Source: FHWA

Figure 7. Screenshot. NACT Tool's main user interface screen.

The tool is intended to be used as part of a comprehensive calibration process, as shown in the schematic representation in figure 8. Trajectories are processed such that leader-follower pairs are identified and the spacing distributions for corresponding traffic conditions are compared to the target benchmark from NDS. Goodness-of-fit testing quantifies whether simulation trajectories produce similar spacing and accelerations as those in real-world conditions. If comparisons result in significant differences, then the process loops back for further modification of car following parameters. Otherwise, the simulation can be considered calibrated from a microscopic standpoint.

The start of the microscopic calibration process (i.e. use of the NACT tool) is tied to standard calibration at the macroscopic level, specifically at the point where macroscopic calibration is complete so that a verification of the trajectories at the microscopic level can be conducted as a second calibration stage. The integration of calibration at the microscopic level can be viewed as a bi-level analysis scenario, where the first level deals with calibration of macroscopic metrics and the second level deals with microscopic metrics. Analogous to findings in previous studies, where calibration at different levels can affect each other (Hale et al., 2021), it is important to conduct a final verification of the validity of the initial macroscopic calibration after the microscopic stages are complete. This is illustrated in figure 8 by the last decision point before the calibration is considered complete.

Thus, the proposed microscopic comparisons of spacing are aimed not only at improving initial simulation parameter choice, but mostly as a verification of the driving behavior after typical macroscopic calibration steps. Previous naturalistic studies also used vehicle spacing as the preferred metric to analyze car-following behavior (Zhu et al., 2018; Sangster et al., 2013; Punzo and Montanino, 2016).

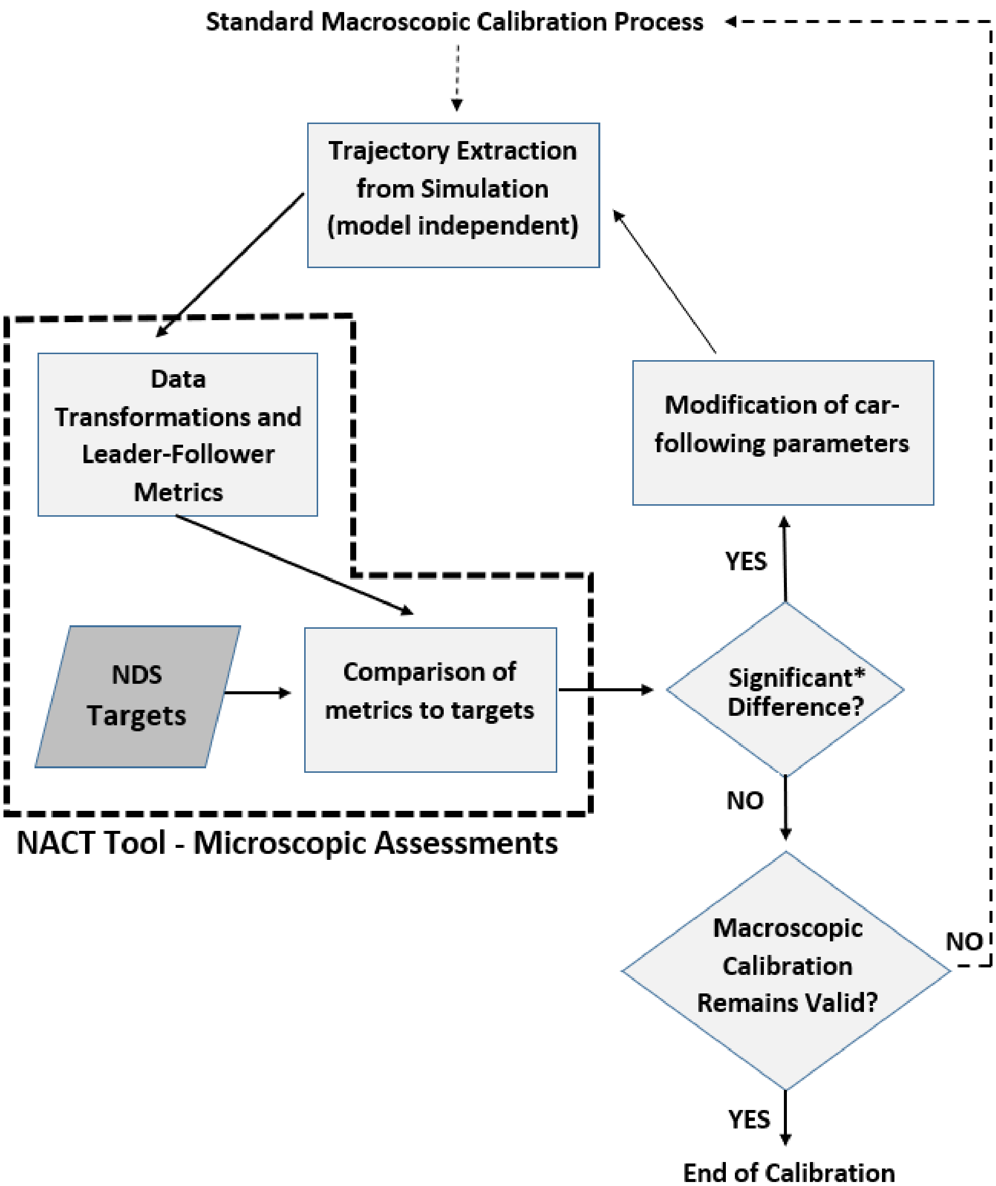


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Figure 8. Graphic. Proposed use of microscopic calibration to complement standard calibration.

The following sections provide step-by-step descriptions to use the NACT tool, including tips, and recommendations to enhance the usability of the tool.

Step-By-Step NACT Usage

1. ***Add a Trajectory File***

   The first step requires the user to select and upload an input trajectory file for analysis. This file must conform to the upload specification described below:

   - File type: Comma-separated Values (csv)
   - Required Column Names – Description, Type:
     - SimSec – Simulation second, Numerical.
     - VehicleNO – Unique Vehicle ID, Integer.
     - LinkNO – Unique Link Number, Integer.
     - LaneNO – Unique Lane Number, Integer.
     - PosX – X vehicle position from the origin in the simulation reference system, Numerical.
     - PosY – Y vehicle position from the origin in the simulation reference system, Numerical.
     - Speed – Vehicle speed, Numerical.
     - Length – Vehicle length, Numerical.

   The "Browse" button will open a file manager window for the user to select one or more files to analyze in the following steps.

   Notes:

   - Values in columns PosX and PosY are required to be in meters.
   - Speed can reflect values in mph or kilometers per hour (kph). The user will specify units prior to running the analysis.

   Portions of a sample input file following the upload specification are shown in figure 9 for illustration purposes.

SimSec	VehicleNO	LinkNO	LaneNO	PosX	PosY	Speed	Length
1.5	2	1	2	9718.497	-2931	60.8	13.82
1.6	1	1	1	9700.136	-2901.44	72.6	13.16
1.6	2	1	2	9716.828	-2928.86	60.8	13.82
1.6	3	1	3	9717.172	-2935.25	67.45	13.82
1.6	4	1	4	9715.022	-2938.45	60.29	13.82
1.7	1	1	1	9698.143	-2898.88	72.6	13.16
1.7	2	1	2	9715.159	-2926.71	60.8	13.82
1.7	3	1	3	9715.32	-2932.87	67.45	13.82
1.7	4	1	4	9713.367	-2936.32	60.29	13.82
1.8	1	1	1	9696.15	-2896.32	72.6	13.16
1.8	2	1	2	9713.49	-2924.56	60.8	13.82
1.8	3	1	3	9713.469	-2930.49	67.45	13.82
1.8	4	1	4	9711.712	-2934.19	60.29	13.82

Source: FHWA

Figure 9. Graphic. Sample input file following the upload specification.

2. Select a Trajectory File for Analysis

Files added in the previous step can be selected for analysis. The tool allows for adding multiple files, but active selections are limited to a single file. Thus, the tool will only analyze one file at a time.

3. Select Analysis Type

The tool has three types of analysis:

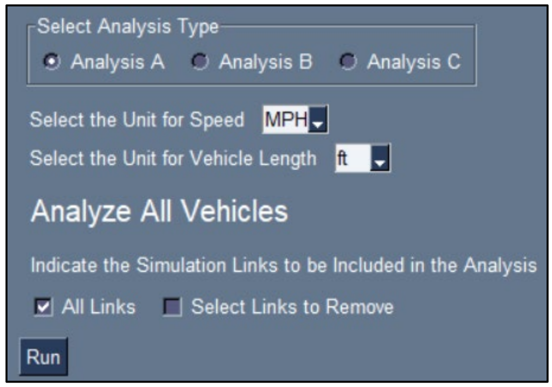
- Analysis A: Analyze All Vehicles.
- Analysis B: Sample Vehicles.
- Analysis C: Re-run Sampling from Existing Analysis.

The analysis selection is dependent on the number of vehicles and the driving times in the input file. Smaller files with fewer vehicles allow for fast processing of all data at once (Analysis A), whereas larger files may require vehicle sampling to prevent longer running times in the application (Analysis B). A third option is also provided (Analysis C) to reuse outputs from previous analysis to explore different sampling sizes and iterations.

In addition, options for analysis A and B provide the ability to remove specific simulation links from the analysis, as shown in figure 10. For example, the user could exclude link IDs of ramp segments, so they are not part of the analysis. Lastly, options B and C require the user to specify the number of vehicles to be sampled from the input file, reducing running time and also allowing for different outcomes from the same simulation run when the tool is run multiple times.

4. Run NACT Tool

The last step, as expected, is to submit the analysis to be run by the tool. This triggers a number of processes to analyze the input file and generate outputs, as described next.



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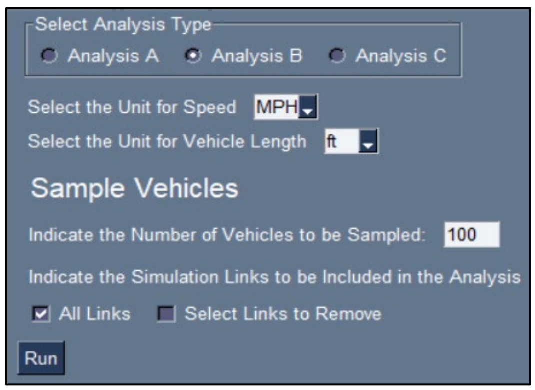
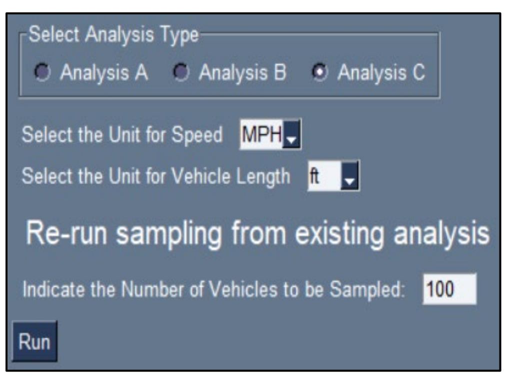
A. Subfigure example of Analysis A options.



Source: FHWA

B. Subfigure example of Analysis B options.



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C. Subfigure example of Analysis C options.

Figure 10. Screenshots. User options for the three types of analysis in the NACT Tool.

Analysis of Input Trajectory Data

As the tool begins to run, and after the input file is verified to follow the data specification, the 5-step procedure to analyze the data is shown in figure 11 and described below.

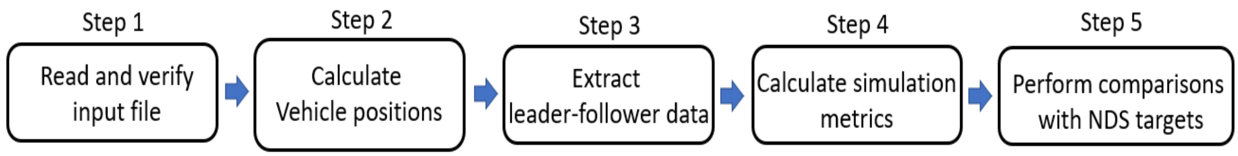


Figure 11. Graphic. The NACT Tool's data processing.

With the input file already loaded in memory (Step 1), in Step 2 the tool first calculates the position of all vehicles along the simulation links using the columns 'PosX' and 'PosY' columns. This is represented by the distance D, calculated in figure 12.

$$D(t_n) = \sqrt{\left(PosX_{t_{n+1}} - PosX_{t_n}\right)^2 - \left(PosY_{t_{n+1}} - PosY_{t_n}\right)^2}$$

Figure 12. Equation. Calculation of Vehicle Position (Distance) within a link.

Where t_n is the simulation second at time n, and $n \varepsilon \mathbb{Z}$.

Next, in Step 3 the tool identifies and extracts leader-follower pairs. A leader-follower pair is identified if a vehicle is in front of the follower vehicle, and both are on the same lane, the same link, and at the same simulation time. The leader-follower extraction is performed utilizing multiprocessing with *n – 1* available cores of the user's computer.

The leader-follower process iterates through each vehicle in the simulation, hereinafter referred to as the subject vehicle. For each subject vehicle, a search boundary is defined beginning and ending with the first and last timestamp of the subject vehicle. Then, all vehicles in the simulation are filtered using the search boundary, and the resulting data are merged with the timeseries from the subject vehicle. Additional filters are applied to preserve only data from vehicles in the same link ID and lane number at a given timestamp, selecting only vehicles that are in front or behind of the subject vehicle. Then, the leader of the subject vehicle (if it exists) is found as the closest vehicle in the positive direction (direction of travel) using the position information calculated in the previous step.

Leader-follower pairs are extracted as a CSV file named 'leader_follower' and saved in the same directory as the trajectory file. The file contains the following information:

- SimSec.
- Follower_ID.
- Speed – Follower speed.
- Leader_ID.
- Leader_Speed.
- Spacing.

In Step 4, calculations of sustained following times are performed for each leader-follower pair, so they can be classified in one of the following overlapping speed bins for target matching.

- 5 – 20 mph.
- 15 – 25 mph.
- 20 – 35 mph.
- 30 – 40 mph.
- 35 – 50 mph.
- 45 – 55 mph.
- 50 – 65 mph.
- 60 – 70 mph.
- 65 – 80 mph.
- 75 – 85 mph.

Then, the process iterates through each vehicle in the leader-follower pair file to filter for portions of the trajectory within the bins. Note that since a vehicle speed might fluctuate, and its speed might be outside of the speed bin, the same leader-follower pair can be selected for multiple speed bins at different times within the simulation. As described above, leader-follower pairs are selected in the analysis only if their duration is 10 seconds or greater, so the data in each speed bin are further filtered considering such criterion.

The output of this procedure is extracted as a CSV file named 'sustained_speed_durations' and saved in the same directory as the trajectory file. The file contains the following information:

- Follower_ID.
- Cond - refers to the speed bins above.
- begin_time – refers to the SimSec when the sustained following started.
- end_time – refers to the SimSec when the sustained following ended.
- duration - refers to the duration of the following.

For each speed bin, a total of 220 spacing percentile points are calculated and carried over onto Step 5 for comparisons with the NDS targets. Spacings greater than 300 ft are filtered from the data to prevent radar readings outside of the radar range, which could capture behavior beyond car-following that perhaps belongs to free-flowing conditions.

Finally, Step 5 performs statistical comparisons, and graphical representations of the NDS and the simulation distributions are generated. The Kolmogorov–Smirnov (K-S) test and the Cramer-Von Mises (CVM) test are applied to the data, where the two distributions being compared are those from the NDS target and the simulation data. Comparisons are made for each of the speed groups and summarized in an output file called "Analysis Results".

In addition, K-S and CVM statistics and their p-value are reported on a figure generated by the application along with the cumulative distribution function (CDF) plots of the spacing distribution. Each figure is then named according to the speed bin naming scheme and saved in the same directory as the trajectory file.

CHAPTER 5. OUTPUTS AND INTERPRETATION OF RESULTS

The NACT tool produces a series of outputs as a result of comparisons between extracted driving behavior from simulation and the NDS targets on vehicle spacing. There are mainly two sets of outcomes from this analysis, described below.

Summary of Results

This file contains a summary of the tests performed between distributions from the simulation and the NDS targets, including the K-S test and the CVM test for each of the speed groups. The columns in this output file are shown below:

- Condition – Identifies the traffic condition by indicating the speed group.
- KS_Stat – Kolmogorov-Smirnov statistic from a two-sample test.
- KS_p-value – Corresponding p-value for the K-S statistic.
- CVM_Stat – Cramer-Von Mises statistic from a two-sample test.
- CVM_p_value – Corresponding p-value for the CVM statistic.
- Sample_size – Number of observations from the simulation sample in the speed group.

The null hypothesis for the two tests performed on each speed group is that the two distributions sampled come from the same (unspecified) distribution. So, a resulting p-value lower than the desired significant level would reject the null hypothesis and indicate significant differences between the NDS targets and the simulation trajectories for that speed group. By default, the NACT tool indicates significant differences at the 95-percent significance level, but the p-value is provided so that the user could also make assessments at different levels.

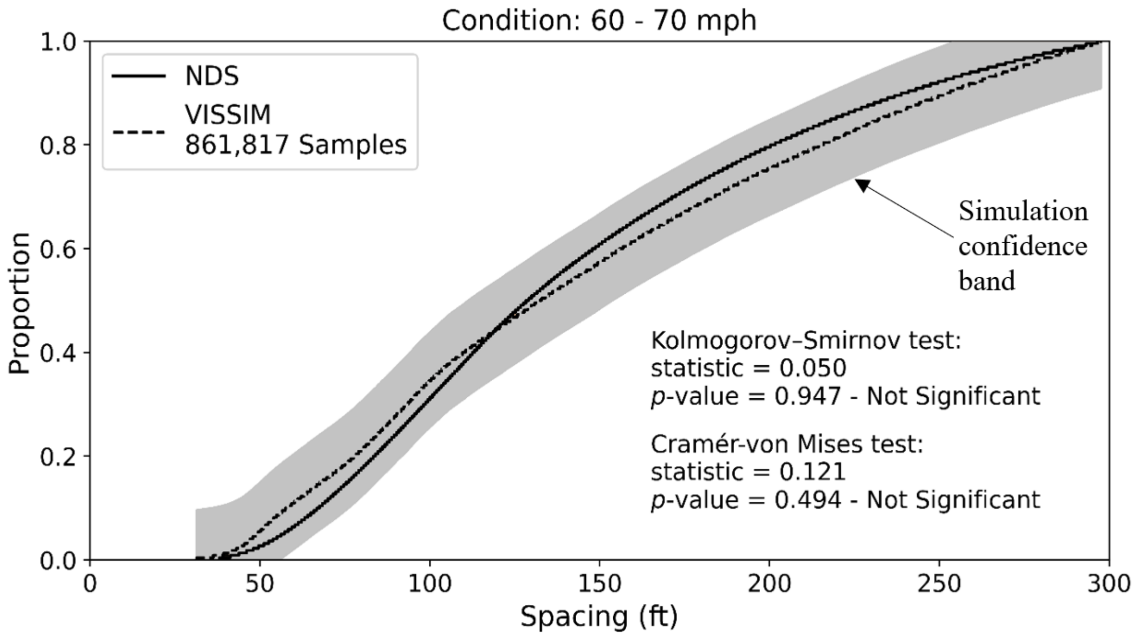
An important element to note in the comparisons is the sample size of each speed group. Given that the research team generated the percentile distribution so that it is represented by 220 points, the new sample size for comparisons of rankings and percentiles is also reduced to 220. This is important because the variability of K-S and CVM results is related to the initial sample size the 220 percentiles are drawn from. Analysis of the data indicate that at least 50,000 points are needed for reliable K-S values, with CVM statistics variating more widely.

It follows that test results for individual speed groups that are based on fewer than 50,000 sample points, as indicated in the “sample_size” column, should be interpreted with caution. In cases where specific speed groups are of high interest, but the speed group has a low sample size, additional simulation time or a different set of demand volume that is more likely to generate such group speeds is recommended. When using “Analysis B”, re-sampling is also an alternative to increase the number of K-S and CVM tests performed for the user to compile statistics and p-values from such tests and draw conclusions on the comparisons with NDS targets. Note that “Analysis A” includes all vehicles in the input file, so rerunning this option with all vehicles will result in the same output files as initially produced.

Distribution Plots

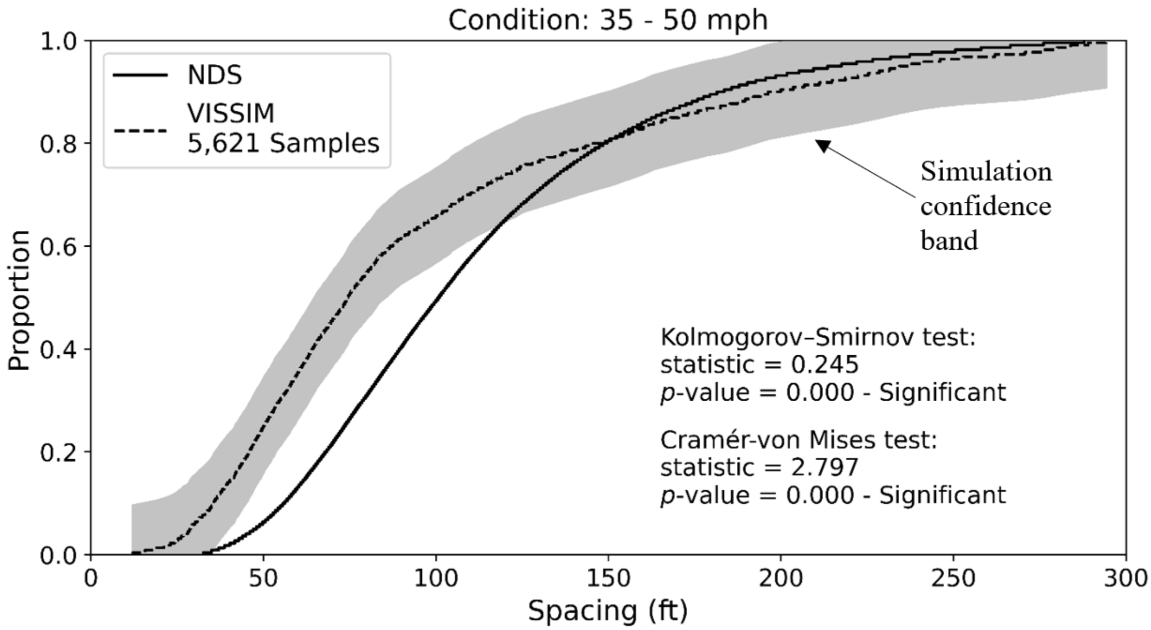
A second set of outcomes produced by the NACT tool is a series of figures with the cumulative distribution plots of both the simulation trajectories and the NDS targets, and a set of confidence bands around the simulation-based distribution. The confidence bands are based on the Dvoretzky–Kiefer–Wolfowitz (DKW) inequality with a 95-percent confidence level, and indicate sections of the distribution where the K-S value is more likely to differ from the NDS targets.

Figure 13 and figure 14 show sample figures produced by the NACT tool, where figure 13 displays a simulation-based distribution that is not significantly different than the NDS targets for the behavior at speeds between 60 and 70 mph. A contrasting scenario is in figure 14, where the simulation distribution is significantly different than the NDS targets, as indicated by the two statistical tests and also the segments from the NDS target distributions outside the confidence bands.



Source: FHWA

Figure 13. Graphic. Sample NACT Tool output – Similar simulation and NDS spacing distributions.



Source: FHWA

Figure 14. Graphic. Sample NACT Tool output – Significantly different simulation and NDS spacing distributions.

Figure 13 and figure 14 serve as a visual aid to identify locations along the distributions where larger discrepancies may exist between simulation and target spacing distributions. They also help track the effects of modifying car-following parameters when two or more figures using different inputs are compared for the same speed groups.

It is important to mention that not all speed groups must match the NDS targets for the calibration process to be successful. First, not all scenarios will produce enough observations in all speed groups for comparisons to be reliable, indicating that comparisons for some speed levels should not be the focus of calibration; and second, even if one or more relevant speed groups are indicating significant differences, the user should identify tradeoffs not only between groups in the microscopic calibration, but also outcomes from the macroscopic calibration.

CHAPTER 6. EXAMPLE CALIBRATION OF CAR-FOLLOWING PARAMETERS USING VISSIM AND THE NACT TOOL

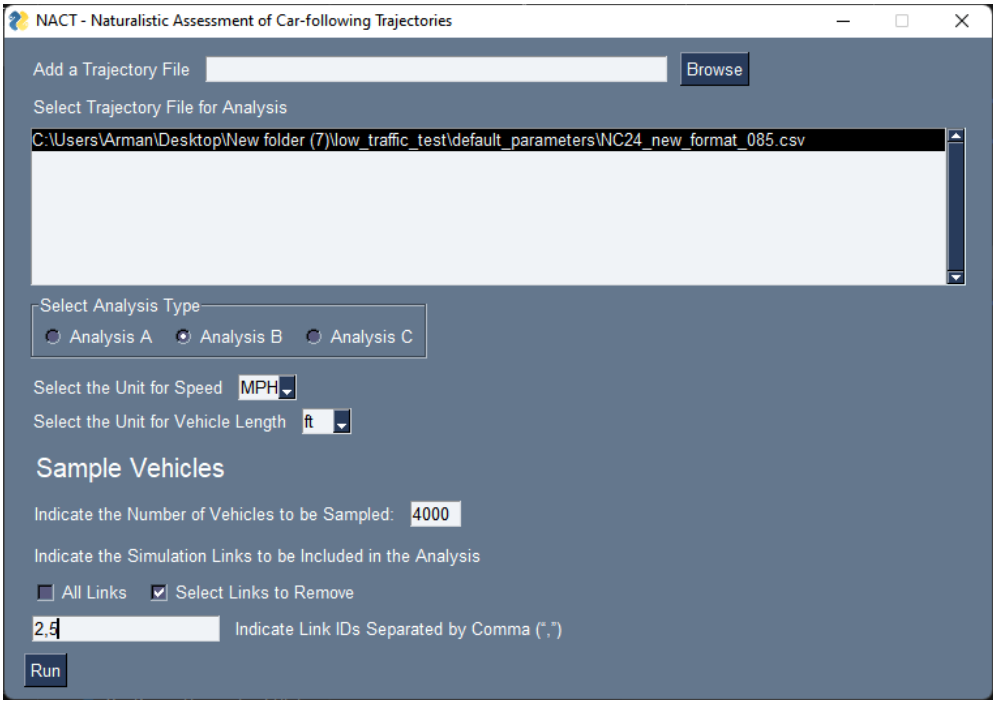
This example illustrates the calibration process using the NACT tool. The research team used modified trajectory files exported from Vissim (PTV, 2022) and ensured their fit and uploaded them to the NACT tool. In this example, Analysis B is demonstrated, where the user specified the number of vehicles to be sampled. Trajectories extracted from a simulation package will require minimum updates to conform to column name and units in the upload specification, thus is expected to be a straightforward process.

The simulation scenario shown in figure 15 was initially set to use default car-following parameters. The simulation time was defined as one hour with traffic demands set to generate 6,000 vehicles per hour, representing low traffic conditions.

© PTV, HERE

Figure 15. Graphic. Sample site modeled in Vissim including link IDs.

Sampling in this example was set to 4,000 vehicles without considering vehicles using the entry and exit ramps, which corresponded to link IDs 2 and 5. Figure 16 illustrates the setup of this scenario in the NACT tool just before it is set to run the analysis.



Source: FHWA

Figure 16. Graphic. Initial setup of NACT parameters to run the simulation example.

Results from the NACT tool were read from the "Analysis Results" file generated after the tool completed running. Table 4 shows the results from this analysis for all speed bins, where the K-S and the CVM test outcomes are shown in terms of the resulting statistics and the p-values.

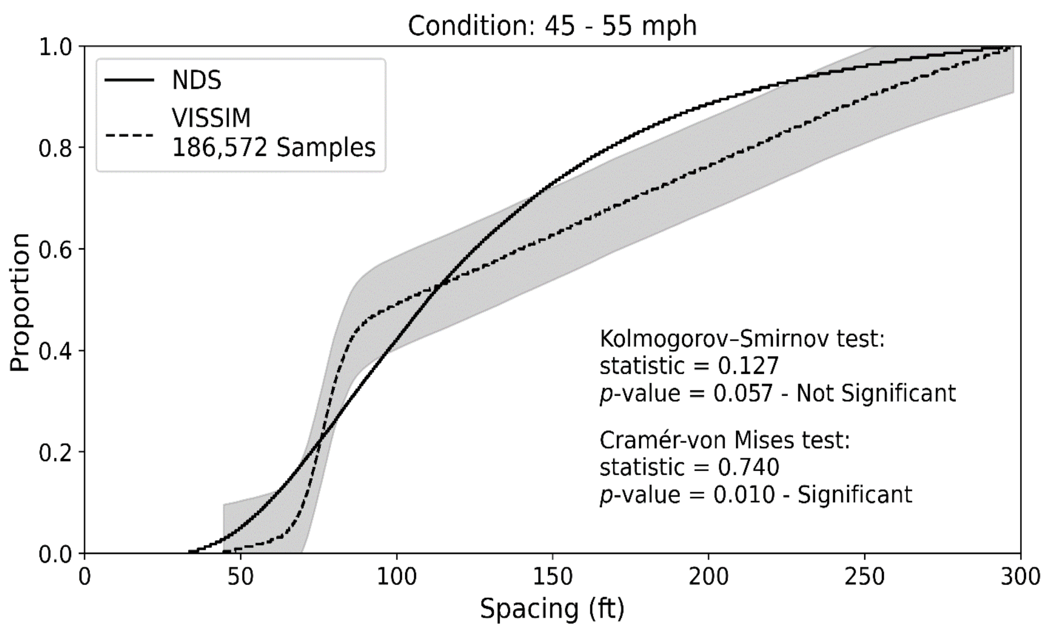
The sample size of each speed group from the simulation distribution before scaling is shown in the last column. These values are helpful to identify potential groups without enough observations to produce reliable results. From the guidelines, recommended sample sizes should generally be about 50,000 observations, otherwise producing results that are more likely to generate fluctuating test outcomes.

Table 4. Statistical test results from NACT Tool using default simulation parameters.

Condition	KS_Stat	KS_p-value	CVM_Stat	CVM_p_value	Sample_size
20 – 35	0.400	0.000	6.076	0.000	132
30 – 40	0.323	0.000	3.139	0.000	455
35 – 50	0.286	0.000	2.573	0.000	7108
45 – 55	0.132	0.044	0.743	0.010	187667
50 – 65	0.105	0.181	0.317	0.121	1142180
60 – 70	0.136	0.033	0.318	0.120	881153
65 – 80	0.200	0.000	1.534	0.000	453091
75 – 85	0.364	0.000	7.375	0.000	21197

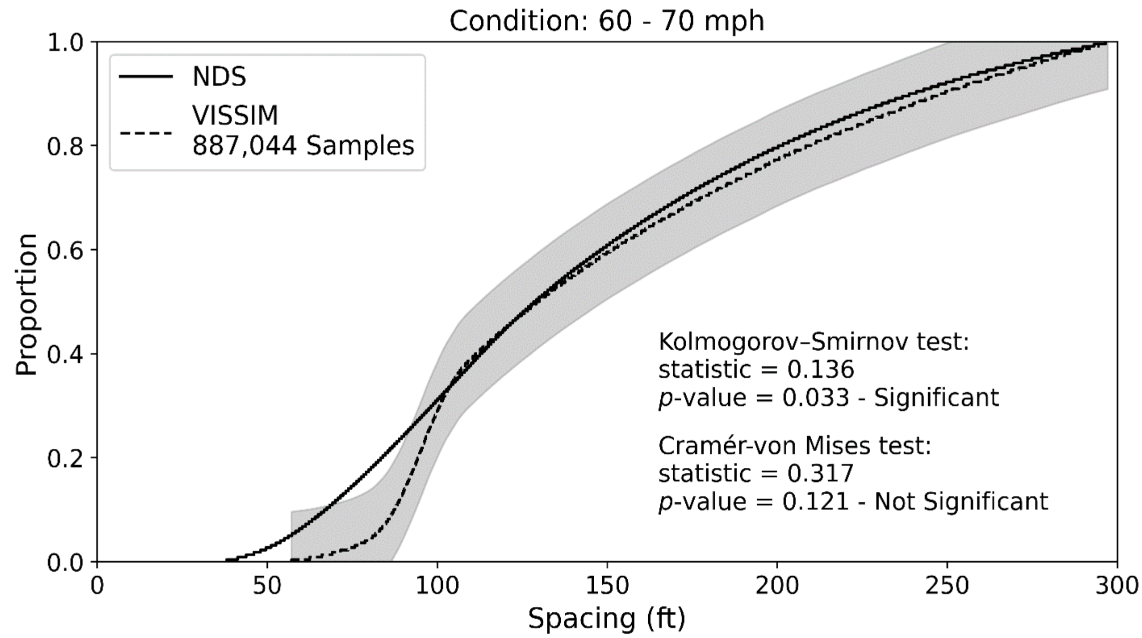
Focus was given to speed bins between 45 mph and 80 mph, all of which had over 100,000 observations each. From table 4, the spacing distribution of the speed group 50 – 65 mph indicated a match with the NDS targets, as indicated by the non-significance of the tests according to their p-value. This is a positive outcome as this speed group represents the largest group in the simulation. However, improvement on the remaining groups will be pursued in the next steps.

Results for the speed groups with significant differences with the NDS targets are shown in figure 17, figure 18, and figure 19, which correspond to speed groups 45-55 mph, 60-70 mph, and 65-80 mph, respectively. The visual representations of the distributions are helpful to identify the areas generating significant differences. For example, from figure 17, a large portion of the spacing distribution is concentrated near 75 ft, generating a double inflexion that results in significant differences in both the K-S and the CVM tests. Figure 18 indicates differences are due to a single inflexion point at the low end of spacing, where fewer-than-expected observations were found in the simulation. It is noticed that the vertical difference between the two distributions is significant at that point (also near 75 ft), but the CVM test is not significant, pointing to the simulation distribution as a whole not being significantly different than the NDS target. Lastly, figure 19 also shows lack of variation capable of generating lower spacing at speeds 65-80 mph, hence the K-S test significance, and in addition a shift along the rest of the distribution that resulted in the CVM test being also significant.



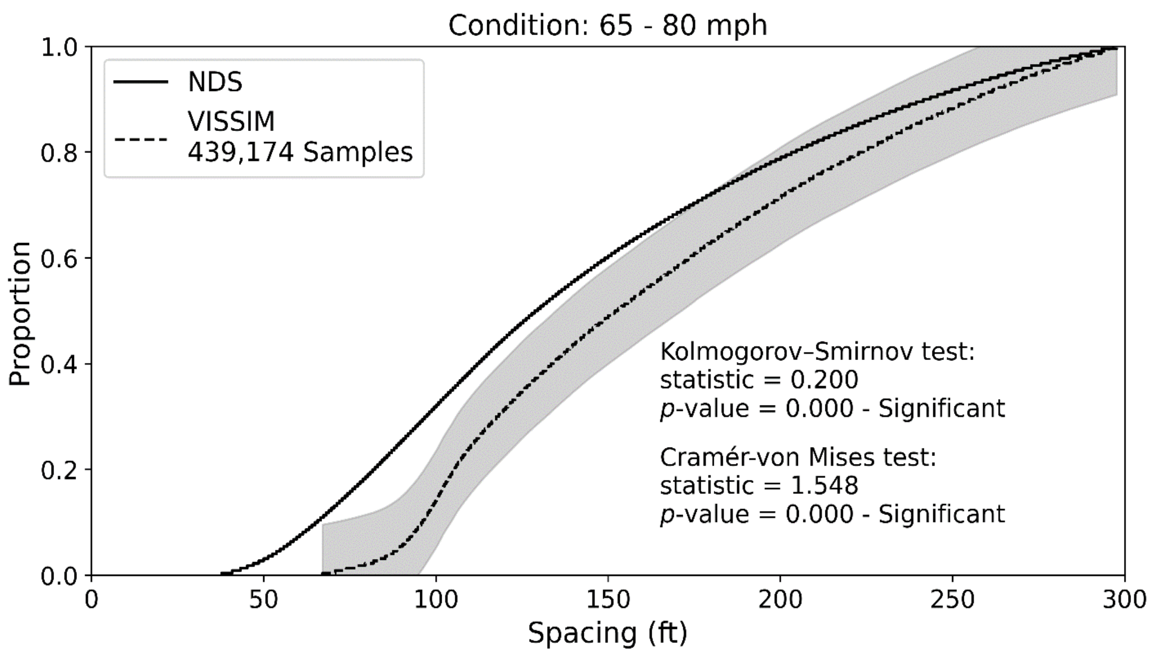
Source: FHWA

Figure 17. Graphic. NACT Tool distributions for speed group 45-55 mph – default Vissim parameters.



Source: FHWA

Figure 18. Graphic. NACT Tool distributions for speed group 60-70 mph – default Vissim parameters.



Source: FHWA

Figure 19. Graphic. NACT Tool distributions for speed group 65-80 mph – default Vissim parameters.

After running the default parameters in the first set of simulation runs, the research team attempted a second trial using a set of parameters they had obtained previously from an empirical calibration. Parameter changes in this second run were extensive and are summarized in table 5.

Table 5. Default and modified Vissim car-following parameters for initial and first modified run.

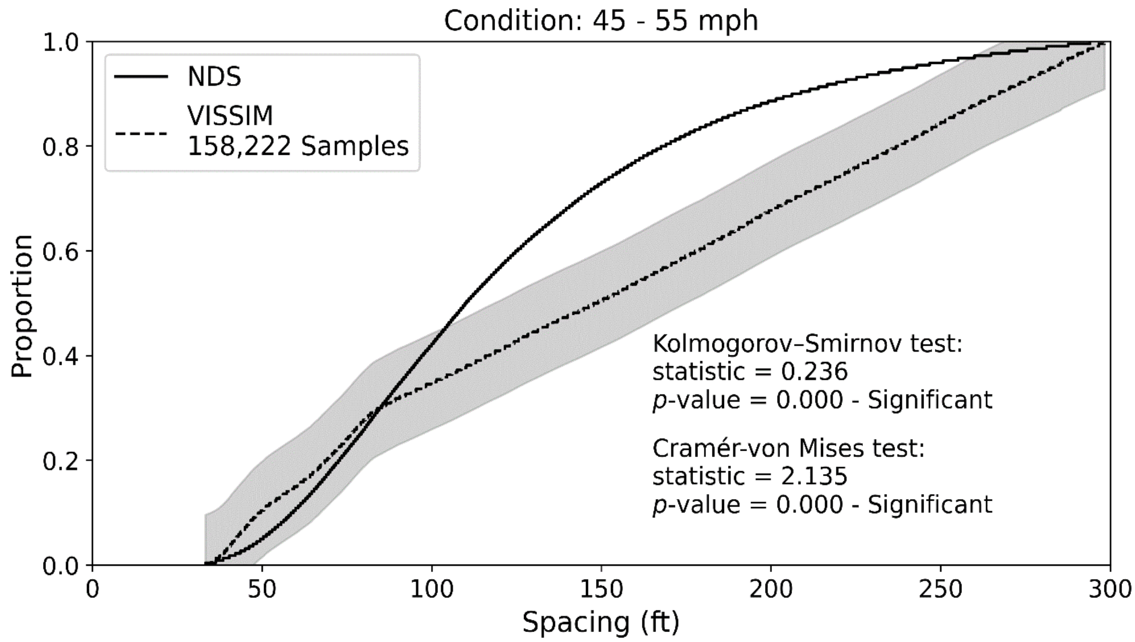
Parameter (units)	Default Parameters	Modifications Round 1
CC0 - Standstill distance (m)	1.5	1.5
CC1 - Headway time (s)	0.9	0.95
CC2 - Following variation (m)	4	4.92
CC3 - Threshold for entering following (s)	-8	-7.52
CC4 - Negative following threshold (m/s)	-0.35	-0.83
CC5 - Positive following threshold (m/s)	0.35	0.75
CC6 - Speed dependency of oscillation	11.44	11.44
CC7 - Oscillation acceleration (m/s2)	0.25	0.007
CC8 - Standstill acceleration (m/s2)	3.5	3.5
CC9 - Acceleration with 50 mph (m/s2)	1.5	0.92

The research team extracted new trajectory files from Vissim again and ran them through the NACT tool, resulting in the summary shown in table 6.

Table 6. Statistical test results from NACT Tool using first modification simulation parameters.

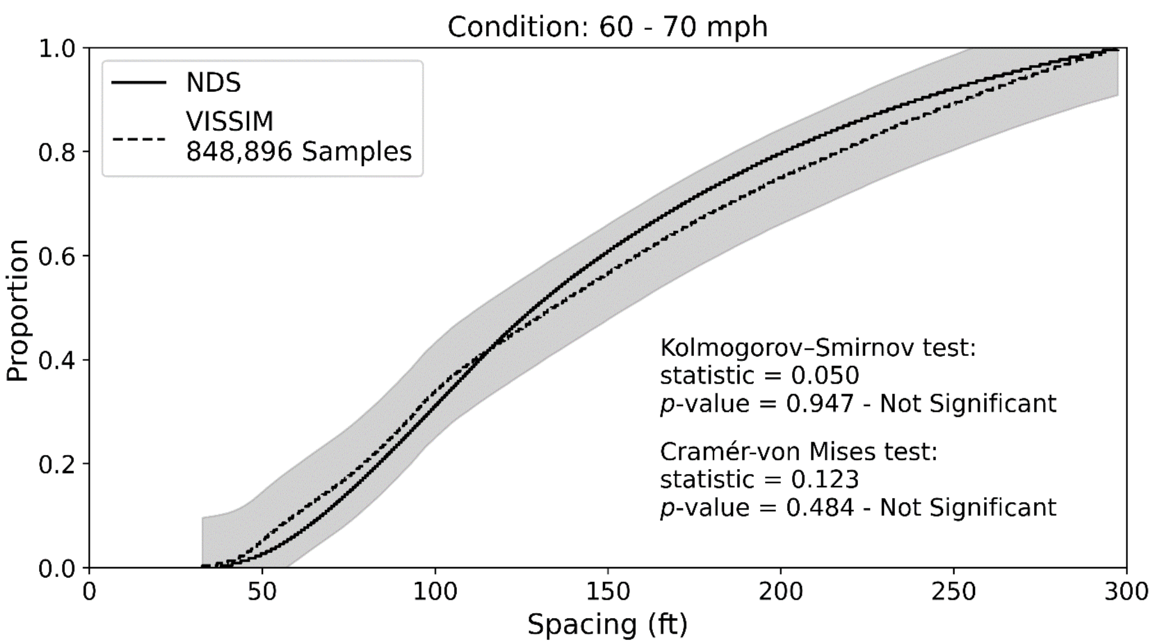
Condition (mph)	KS_Stat	KS_p-value	CVM_Stat	CVM_p_value	Sample_size
45 – 55	0.236	0.000	2.135	0.000	158,222
50 – 65	0.082	0.454	0.383	0.080	974,438
60 – 70	0.050	0.947	0.123	0.484	848,896
65 – 80	0.032	1.000	0.036	0.957	555,547

This second scenario brought improvements on two additional speed groups, only leaving the group for speeds between 45 to 55 mph with significant differences with respect to the NDS targets. The distribution plots for the same groups investigated in the previous iteration are shown in figure 20, figure 21, and figure 22 to illustrate the effects of the car-following parameter changes for speed groups 45-55 mph, 60-70 mph, and 65-80 mph, respectively. Improvements in the simulation distributions for the larger, higher-speed groups above 60 mph are noticed both visually and in terms of the statistical comparisons. Confidence bands are helpful to have an approximate boundary to gauge locations where differences are more likely to be significant. On the other hand, the lower speed distribution (45 to 55 mph) still exhibits significant differences, this time almost eliminating one of the inflection points and deviating by having larger proportions of higher vehicle spacing. However, compared to the previous simulation run, the distribution fit did not improve based on both a visual inspection and the test statistics.



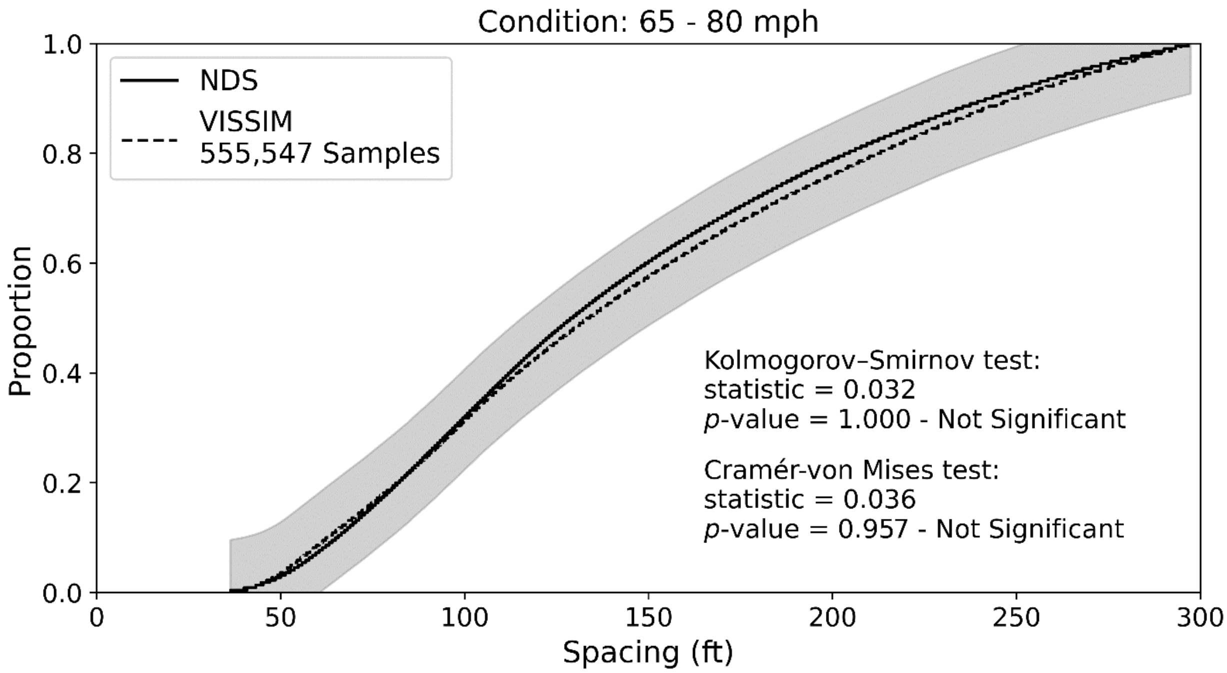
Source: FHWA

Figure 20. Graphic. NACT Tool distributions for speed group 45-55 mph – First modification of Vissim parameters.



Source: FHWA

Figure 21. Graphic. NACT Tool distributions for speed group 60-70 mph – First modification of Vissim parameters.



Source: FHWA

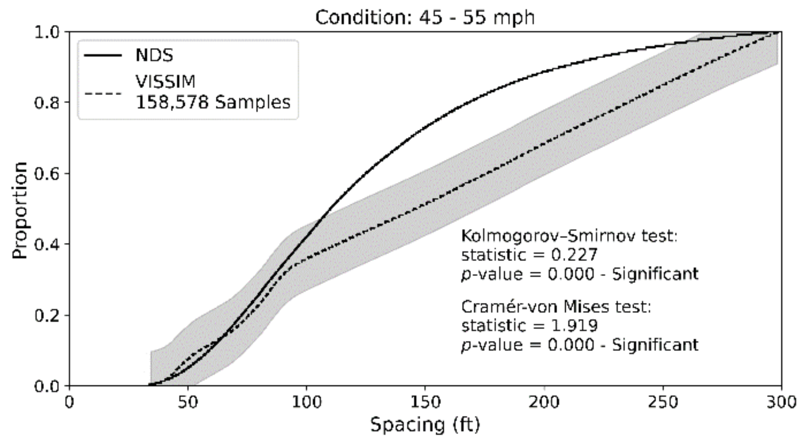
Figure 22. Graphic. NACT Tool distributions for speed group 65-80 mph – First modification of Vissim parameters.

Additional calibration rounds were focused on parameters CC1 (Time headway) and CC2 (Following variation), the most common parameters calibrated in Vissim, resulting in marginal changes to the overall target matching evaluation. Table 7 shows examples of four of the additional parameter changes and their results. Significant differences at the 95-percent confidence level are noted with an asterisk (*) and were only observed for the same speed group (45 to 55 mph) with the exception of the last iteration for the speed group 65 to 80 mph (with CC1=1.25, CC2=24), indicating that the parameter values had negatively affected this group without significant improvements elsewhere. Additional modifications to parameters CC3 (Threshold for entering "following") and CC4 (Negative "following" threshold) were also evaluated without significant improvement in the fit of the 45 to 55 mph speed group.

Table 7. Statistical test results from NACT Tool using four additional modifications of simulation parameters.

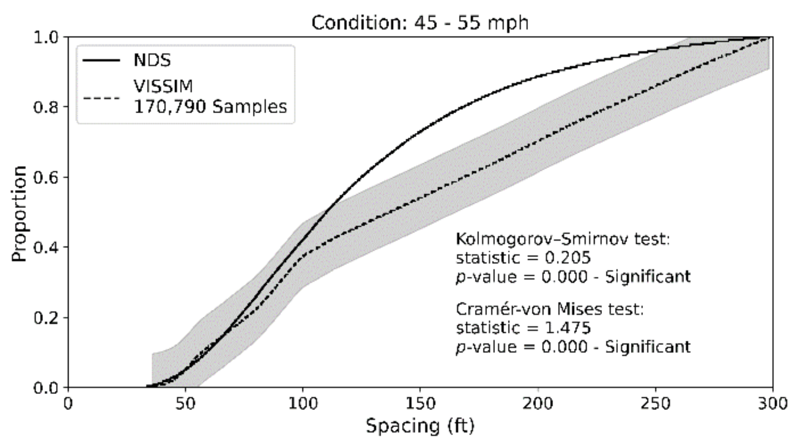
Iteration	Parameter CC1	Parameter CC2	Speeds (mph)	KS_Stat	KS p-value	CVM_Stat	CVM p-value	Sample Size
Modification Round 2	0.99	17	45 – 55	0.227	0 *	1.919	0 *	158,578
			50 – 65	0.082	0.454	0.229	0.218	987,523
			60 – 70	0.055	0.900	0.097	0.600	856,348
			65 – 80	0.041	0.993	0.109	0.543	543,836
Modification Round 3	1.1	17	45 – 55	0.205	0 *	1.475	0 *	170,790
			50 – 65	0.064	0.766	0.112	0.531	1,024,628
			60 – 70	0.050	0.947	0.094	0.616	832,249
			65 – 80	0.073	0.607	0.237	0.206	514,286
Modification Round 4	0.98	26	45 – 55	0.191	0.001*	1.239	0.001*	152,681
			50 – 65	0.064	0.766	0.127	0.469	986,330
			60 – 70	0.050	0.947	0.094	0.617	847,012
			65 – 80	0.068	0.687	0.219	0.235	523,439
Modification Round 5	1.25	24	45 – 55	0.164	0.005	1.083	0.002	173,040
			50 – 65	0.064	0.766	0.171	0.331	1,026,815
			60 – 70	0.100	0.222	0.385	0.079	800,907
			65 – 80	0.141	0.025	0.927	0.004	460,338

Figure 23 illustrate results of the four additional modification rounds for speed bin 45-55 mph from table 8. From the figure, even though parameters for CC1 and CC2 changed significantly within a wide reasonable range, there is no clear improvement from modification rounds 2 through 5 as the p-values remain small and the distributions still show significant differences.



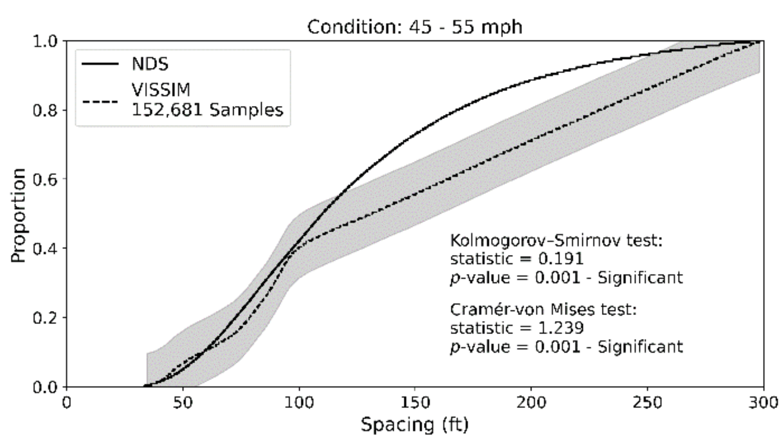
Source: FHWA

A. Subfigure example of modification round 2.



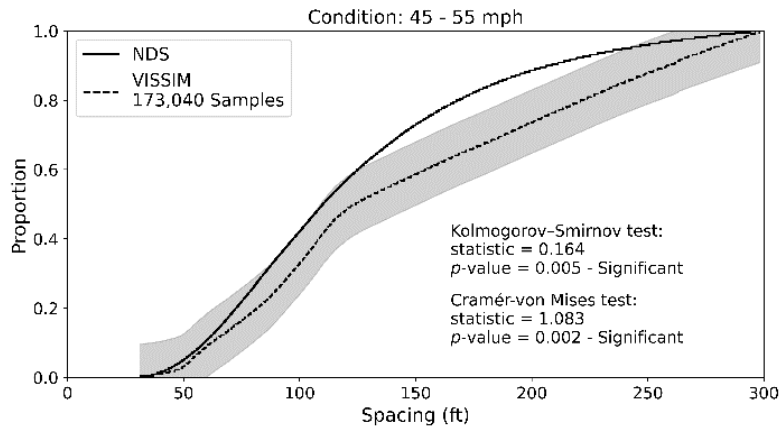
Source: FHWA

B. Subfigure example of modification round 3.



Source: FHWA

C. Subfigure example of modification round 4.



Source: FHWA

D. Subfigure example of modification round 5.

Figure 23. Graphics. NACT Tool distributions for speed group 45-55 mph – Four additional modifications of Vissim parameters.

It is noted that there is no guarantee for all speed groups to conform simultaneously to NDS distributions under a single set of car following parameters. However, outputs from the NACT tool can guide this process and identify if differences can be reduced using reasonable parameter values, or if some differences are to remain even at the end of the calibration process. It is always recommended to prioritize the use of reasonable parameter values instead of modifying them beyond recommended ranges for the sake of improving fit to NDS, as this may have unintended consequences in alternative scenarios.

Tradeoffs are expected in the calibration process and the user should carefully evaluate alternatives to obtain the best overall set of outcomes. In this particular example, given that the sample size of the group with speeds 45 to 55 mph is the lowest of those suitable for comparison, goodness of fit values from other groups are recommended to be prioritized.

It is also possible that multiple parameters can achieve the objective to fit simulation distributions to those from NDS, leaving the final decision at the microscopic scale open, but the analyst is encouraged to then focus on those that also produce the best results from a macroscopic calibration standpoint.

CHAPTER 7. SUMMARY AND LIMITATIONS

This guideline provides user-level information to use the model-independent NACT tool in the context of a proposed calibration process from microscopic level metrics. The analysis presented here is based on vehicle spacing target distributions for different speed levels developed from naturalistic driving extracted from the SHRP2 NDS.

The NACT tool is developed as an open-source tool in Python in the form of a portable executable file, so that all dependencies to run the tool are embedded.

The proposed calibration process for microscopic metrics of vehicle spacing is part of an iterative set of steps that include standard calibration to match macroscopic targets such as travel time, delay, and queues. In essence, the NACT tool is complementary to current calibration practices. The additional calibration steps for microscopic targets are intended to ensure that vehicle-to-vehicle interactions produced by the simulation reflect a naturalistic behavior. Verification of vehicle-to-vehicle interactions is a particularly important task, as simulation parameters may often provide reasonable default car-following settings, but such behavior could be modified during the macroscopic-based calibration, generating substantially different (and unintended) behavior.

The guideline also illustrates examples on the use of the NACT tool outputs to investigate differences between simulation trajectory data and NDS. Items discussed included the effects of modifications in the car following parameters across speed groups, prioritization of speed groups given their relative size, and tradeoffs when modifying car following parameters. There is no guarantee that comparisons from all groups will fit the NDS distributions, so prioritization and fit of the most significant groups is recommended, even if it results in smaller groups having significant differences. The tool provides both p-values and graphical indications to point to the areas that need improvements, so the user can take advantage of these when performing calibration. For example, if the cumulative distribution from simulation lacks observations on the lower end of the spacing scale (i.e., the simulation distribution is significantly below the NDS), then car following parameters that produce a larger variance and/or a smaller mean headway in the simulation could help minimizing discrepancies.

In addition, and as a general rule while conducting calibration, modification of car following parameters can typically be limited to parameters with a known physical meaning. For example, it is recommended to adjust parameters such as time headways (CC1 in Vissim) over parameters that are not clearly defined or that are difficult to interpret in the physical world, such as the speed dependency of oscillation (CC6 in Vissim).

The NDS targets were developed based on driving behavior from urban and suburban freeway segments, under good weather conditions during daytime, and without temporary construction zones. Data from NDS was collected from instrumented passenger cars, acting as followers in leader-follower conditions, and the effect of having a larger or smaller vehicle as the leader vehicle was not evaluated.

Lastly, data from NDS was collected in the U.S., and driving behavior in other countries may differ from those represented in the developed targets.

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APPENDIX A. TRAFFIC ESTIMATION AND SPEED-DENSITY ANALYSIS

Given the dependency of car-following behavior on existing traffic conditions, the extraction of data from NDS and the development of target metrics required contextualization of driving conditions. However, since the NDS datasets do not provide such estimations, the research team conducted an exploration to identify potential metrics for this purpose.

From the fundamental traffic diagram, speed, flow, and density were candidate metrics to describe the traffic conditions experienced by the NDS drivers along the traversals. From those three metrics, only speed was readily available, requiring additional analysis to develop estimates for flow and density.

The research team borrowed a method to obtain these estimates from ideas commonly applied to probe vehicle data (Seo et al., 2015), where, in this case, the instrumented vehicle and radar objects act as probe vehicles. The methodology is based on definitions of speed and density using an area within the time-space diagram as shown in figure 24.

$$\widehat{q_A} = \frac{\sum_{n \in N(A)} d_n(A)}{\sum_{n \in N(A)} a_n(A)} \qquad \widehat{k_A} = \frac{\sum_{n \in N(A)} t_n(A)}{\sum_{n \in N(A)} a_n(A)} \qquad \widehat{v_A} = \frac{\sum_{n \in N(A)} d_n(A)}{\sum_{n \in N(A)} t_n(A)}$$

Figure 24. Equation. Flow, density and speed for traffic state estimations.

Where:

$\widehat{q_A}$ = estimated flow.
$\widehat{k_A}$ = estimated density.
$\widehat{v_A}$ = estimated speed.
$d_n(A)$ = distance traveled.
$t_n(A)$ = time spent by a known vehicle *n* in segment *A*.
$a_n(A)$ is the time-space region in *A* observed by combinations of known vehicles.

The summation terms in these equations are applied over all known vehicles *N* observed in each segment *A*. Known vehicles include both instrumented vehicles and radar objects.

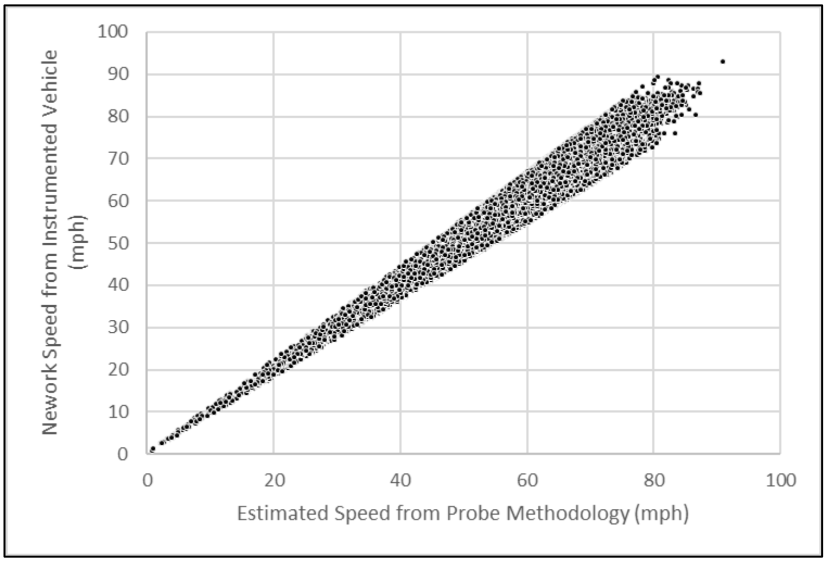
For the purpose of exploring the relationships between the three fundamental metrics, the research team divided traversals into speed groups using the speed of the instrumented vehicle to generate general classifications of traffic characterized as: 1) low traffic (speeds higher than 60 mph), 2) medium traffic (speeds between 40-60 mph), and 3) high traffic (speeds lower than 40 mph).

The research team partitioned traversals based on their sustained speed, similar to the process applied to identify the period of sustained following from the leader-follower pairs. Thus, each partition is considered to provide a representation of the traffic conditions at the time of the traversal.

The research team applied the methodology to estimate flow, density, and speed to each partition. Over 50,000 partitions were obtained from this exercise, representing 780 hours of driving in low traffic (637 hours), medium traffic (115 hours), and high traffic (28 hours) altogether.

Results provided consistent trends, with the speed estimations being the most reliable among the three of them, followed by the density, and last by the flow estimates. This is expected, as the flow is expected to amplify poor observations since is the one metric that uses two estimated values (i.e., distance traveled and area in the space-time diagram), whereas speed and density use direct measurements of time.

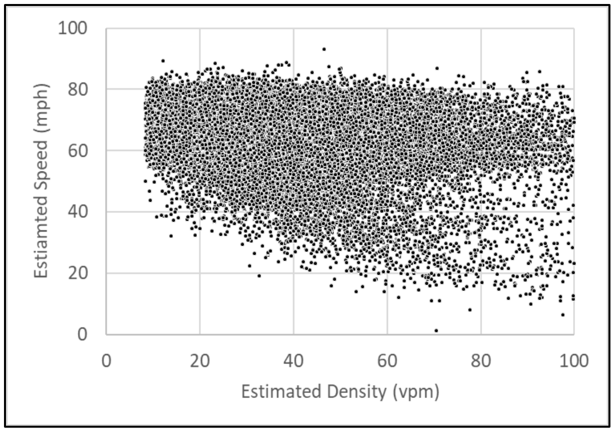
Verification of the speed estimates confirm the consistency of the calculations, as shown in figure 25, where the speeds from the methodology above are compared to the network speeds from NDS.



Source: FHWA

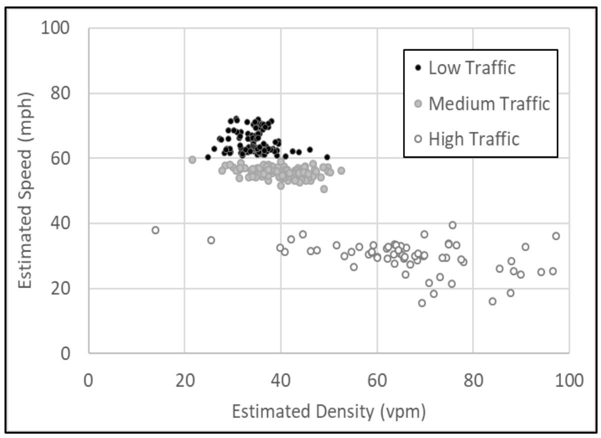
Figure 25. Graphic. Comparison of calculated speeds from probe methodology and NDS speeds.

Similarly, the research team analyzed estimated densities to identify trends in relation to the speed data. A priori expectation was to observe a decrease of speed with an increase of density, with the data confirming this trend, particularly when aggregated at the site level. Figure 26A and figure 26B show individual density-speed pairs and the density-speed aggregates by site, respectively.



Source: FHWA

A. Subfigure example of observations from individual partitions/traversals.



Source: FHWA

B. Subfigure example of observations at site-level.

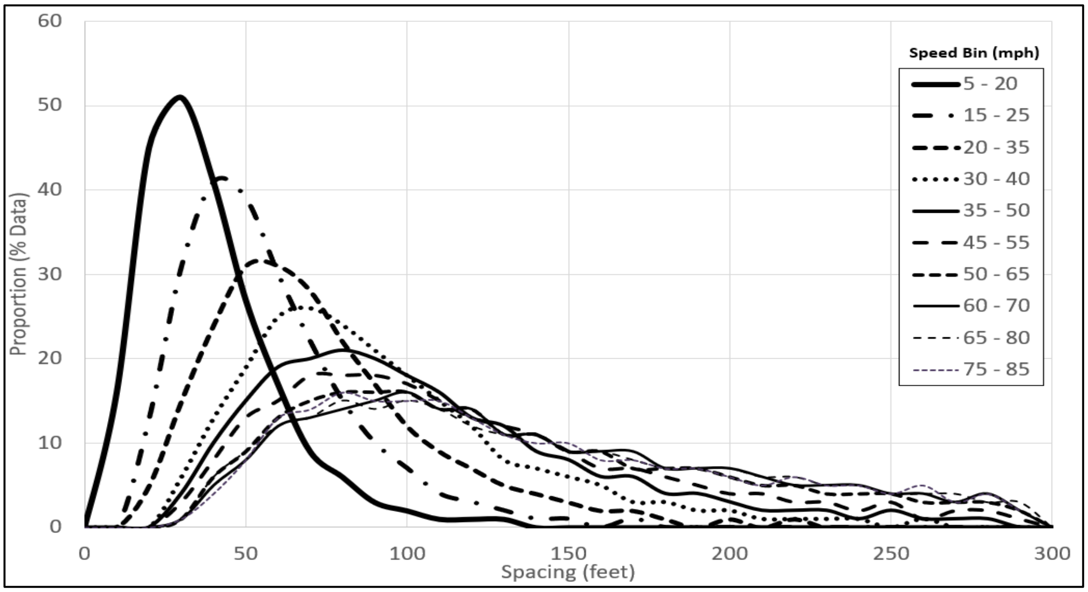
Figure 26. Graphics. Speed-density plots from NDS data.

Speeds lower than 8 mph are not observed, even though a large number of individual speed values at specific timestamps were below this value and even zero. This is because each point represents the average sustained speed within the selected speed bins, potentially including averages along the complete traversal. In addition, aggregation of traffic condition categories based on speeds resulted in more stratified speed levels compared to the density estimates in figure 26B. Additional subcategorization of conditions by speed will likely provide smoother transitions from highest to lowest speeds, but in turn will affect the accuracy of the density estimations, as the area in the denominator of figure 24 will become increasingly smaller, becoming more susceptible to noise or lack of observations.

This analysis provided empirical evidence of consistent decrease of speed levels a valid basis to represent traffic conditions when characterizing driving behavior.

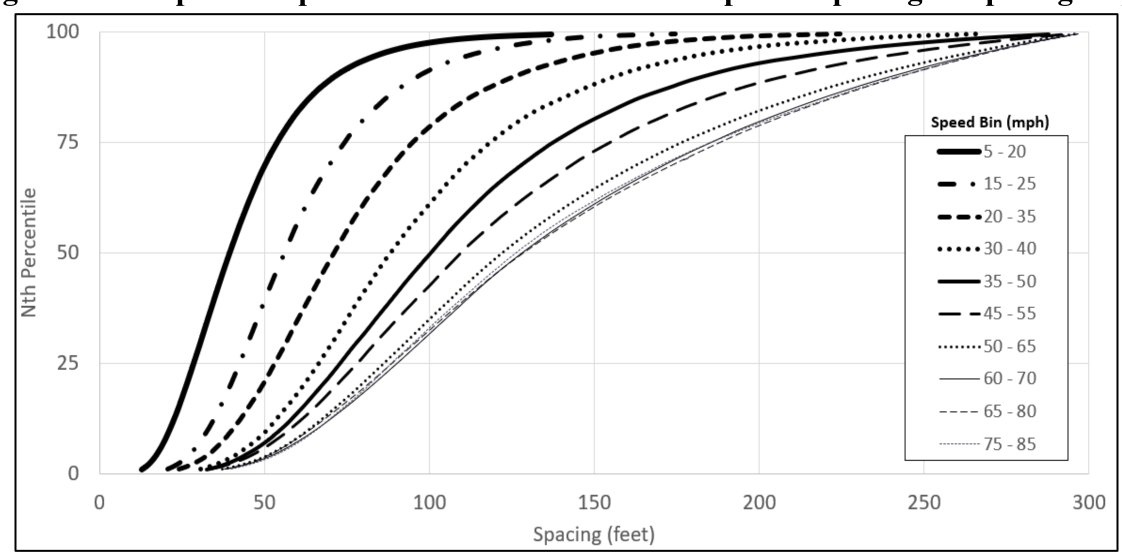
APPENDIX B. TARGET SPACING DISTRIBUTIONS AND PERCENTILES BY SPEED GROUP

This appendix details the speed distributions the research team obtained directly from NDS and transformed into percentiles for each of the 10 defined speed groups. After careful site selection and data processing, outcomes from NDS datasets provided remarkably consistent results. Spacing distributions followed expected trends from low to higher speeds and both a shorter and longer spacing values, as shown in figure 27 and figure 28. Detailed percentiles can be found in table 8.



Source: FHWA

Figure 27. Graphic. Empirical cumulative distribution plot of spacing all speed groups.



Source: FHWA

Figure 28. Graphic. Empirical cumulative distribution plot of spacing all speed groups.

Table 8. Percentile points (220) of spacing cumulative distribution for statistical comparisons.

Nth Percentile	Speed Group (mph)									
	5 - 20	15 - 25	20 - 35	30 - 40	35 - 50	45 - 55	50 - 65	60 - 70	65 - 80	75 - 85
1	12.89	20.59	24.16	30.75	32.57	33.54	37.20	38.15	37.82	39.94
1.45	13.80	21.97	26.04	32.82	34.97	36.34	40.14	41.30	40.82	42.70
1.9	14.59	23.10	27.60	34.80	37.05	38.47	42.63	43.82	43.20	45.15
2.35	15.22	24.10	28.87	36.28	38.76	40.31	44.73	46.05	45.21	47.10
2.8	15.78	24.95	29.99	37.62	40.32	42.06	46.58	47.97	46.96	48.93
3.25	16.30	25.74	31.04	38.97	41.64	43.61	48.26	49.61	48.56	50.60
3.7	16.76	26.45	32.01	40.21	42.80	44.97	49.74	51.12	49.98	52.08
4.15	17.20	27.10	32.89	41.31	43.89	46.18	51.03	52.55	51.29	53.42
4.6	17.59	27.69	33.64	42.16	44.92	47.34	52.24	53.84	52.56	54.68
5.05	17.96	28.23	34.33	43.09	46.03	48.36	53.37	55.04	53.69	55.87
5.5	18.34	28.71	34.96	43.94	47.05	49.38	54.50	56.19	54.77	57.05
5.95	18.70	29.20	35.58	44.73	48.00	50.30	55.58	57.28	55.79	58.14
6.4	19.03	29.64	36.20	45.59	48.90	51.25	56.59	58.31	56.80	59.10
6.85	19.34	30.09	36.79	46.45	49.72	52.13	57.55	59.32	57.74	60.09
7.3	19.66	30.52	37.37	47.22	50.54	52.97	58.47	60.33	58.65	61.07
7.75	19.97	30.93	37.92	47.89	51.34	53.80	59.35	61.31	59.56	61.93
8.2	20.26	31.32	38.47	48.62	52.12	54.67	60.24	62.24	60.46	62.79
8.65	20.53	31.74	38.96	49.27	52.80	55.51	61.11	63.16	61.36	63.63
9.1	20.80	32.13	39.44	49.91	53.48	56.32	61.93	64.07	62.23	64.47
9.55	21.07	32.49	39.95	50.50	54.21	57.07	62.73	64.97	63.13	65.31
10	21.33	32.88	40.45	51.03	54.88	57.78	63.53	65.85	64.01	66.11
10.45	21.60	33.24	40.94	51.59	55.59	58.46	64.30	66.71	64.86	66.90
10.9	21.87	33.59	41.40	52.15	56.23	59.19	65.07	67.53	65.69	67.65
11.35	22.12	33.92	41.84	52.64	56.88	59.89	65.82	68.36	66.52	68.38
11.8	22.37	34.26	42.28	53.14	57.50	60.63	66.56	69.17	67.32	69.09
12.25	22.60	34.58	42.73	53.63	58.08	61.31	67.29	69.97	68.11	69.80
12.7	22.85	34.88	43.15	54.13	58.64	62.01	68.01	70.77	68.89	70.51
13.15	23.10	35.19	43.59	54.63	59.19	62.69	68.73	71.55	69.67	71.24
13.6	23.34	35.51	43.99	55.10	59.79	63.34	69.43	72.33	70.44	71.94
14.05	23.57	35.82	44.39	55.61	60.34	64.02	70.13	73.11	71.22	72.64
14.5	23.81	36.12	44.79	56.12	60.91	64.65	70.84	73.88	71.98	73.38
14.95	24.02	36.43	45.19	56.64	61.49	65.27	71.54	74.64	72.75	74.13
15.4	24.24	36.73	45.60	57.14	62.04	65.89	72.23	75.41	73.51	74.86
15.85	24.45	37.03	46.01	57.66	62.59	66.51	72.93	76.16	74.26	75.61
16.3	24.65	37.33	46.41	58.18	63.12	67.11	73.64	76.90	75.01	76.34
16.75	24.87	37.63	46.82	58.62	63.63	67.72	74.34	77.63	75.76	77.05
17.2	25.08	37.92	47.22	59.07	64.15	68.31	75.03	78.35	76.53	77.75
17.65	25.29	38.21	47.59	59.56	64.68	68.89	75.73	79.07	77.28	78.44
18.1	25.50	38.50	47.96	60.05	65.22	69.45	76.40	79.79	78.01	79.10

Nth Percentile	Speed Group (mph)									
	5 - 20	**15 - 25**	**20 - 35**	**30 - 40**	**35 - 50**	**45 - 55**	**50 - 65**	**60 - 70**	**65 - 80**	**75 - 85**
18.55	25.71	38.79	48.34	60.52	65.74	70.00	77.08	80.50	78.75	79.75
19	25.91	39.06	48.71	60.96	66.27	70.58	77.73	81.22	79.47	80.40
19.45	26.12	39.31	49.06	61.38	66.78	71.18	78.38	81.92	80.19	81.04
19.9	26.34	39.58	49.42	61.81	67.29	71.76	79.03	82.63	80.90	81.66
20.35	26.54	39.86	49.78	62.26	67.82	72.36	79.67	83.33	81.60	82.29
20.8	26.74	40.11	50.14	62.68	68.36	72.92	80.31	84.01	82.30	82.95
21.25	26.94	40.37	50.49	63.12	68.89	73.48	80.95	84.70	83.01	83.60
21.7	27.15	40.62	50.84	63.53	69.41	74.05	81.58	85.39	83.71	84.20
22.15	27.34	40.88	51.17	63.94	69.90	74.63	82.21	86.07	84.39	84.80
22.6	27.55	41.13	51.50	64.36	70.39	75.19	82.85	86.75	85.08	85.40
23.05	27.75	41.37	51.82	64.78	70.88	75.76	83.50	87.43	85.77	86.02
23.5	27.95	41.62	52.15	65.21	71.37	76.33	84.13	88.09	86.46	86.65
23.95	28.14	41.85	52.47	65.62	71.83	76.92	84.77	88.78	87.15	87.25
24.4	28.34	42.10	52.80	66.04	72.32	77.49	85.41	89.46	87.83	87.87
24.85	28.53	42.36	53.13	66.46	72.80	78.06	86.05	90.15	88.51	88.49
25.3	28.73	42.61	53.47	66.85	73.27	78.63	86.68	90.82	89.18	89.09
25.75	28.93	42.85	53.81	67.23	73.73	79.19	87.31	91.50	89.87	89.72
26.2	29.13	43.10	54.15	67.60	74.20	79.71	87.92	92.17	90.55	90.34
26.65	29.32	43.35	54.48	67.98	74.68	80.24	88.56	92.82	91.23	90.98
27.1	29.52	43.60	54.81	68.39	75.13	80.74	89.19	93.49	91.92	91.65
27.55	29.71	43.85	55.14	68.77	75.60	81.25	89.83	94.15	92.61	92.33
28	29.91	44.10	55.47	69.16	76.08	81.77	90.47	94.81	93.29	93.00
28.45	30.11	44.34	55.79	69.57	76.55	82.31	91.10	95.47	93.98	93.64
28.9	30.31	44.58	56.12	69.98	77.05	82.85	91.73	96.13	94.66	94.29
29.35	30.50	44.81	56.44	70.39	77.56	83.37	92.36	96.79	95.34	94.95
29.8	30.69	45.05	56.76	70.79	78.05	83.92	92.98	97.46	96.04	95.62
30.25	30.88	45.30	57.06	71.18	78.57	84.45	93.60	98.12	96.72	96.29
30.7	31.07	45.54	57.35	71.55	79.09	85.00	94.22	98.77	97.39	96.97
31.15	31.25	45.79	57.65	71.94	79.62	85.53	94.83	99.43	98.06	97.57
31.6	31.45	46.04	57.95	72.32	80.12	86.10	95.44	100.08	98.73	98.17
32.05	31.64	46.29	58.25	72.68	80.60	86.67	96.05	100.73	99.43	98.80
32.5	31.82	46.52	58.56	73.06	81.09	87.22	96.68	101.38	100.10	99.45
32.95	32.01	46.75	58.86	73.43	81.56	87.79	97.30	102.02	100.77	100.08
33.4	32.20	46.99	59.17	73.78	82.04	88.33	97.92	102.68	101.44	100.71
33.85	32.40	47.23	59.48	74.14	82.52	88.87	98.54	103.34	102.12	101.36
34.3	32.58	47.46	59.79	74.50	82.99	89.43	99.15	104.01	102.81	102.01
34.75	32.77	47.68	60.11	74.88	83.45	90.01	99.77	104.66	103.49	102.66
35.2	32.96	47.92	60.42	75.24	83.93	90.59	100.40	105.32	104.19	103.33
35.65	33.16	48.16	60.74	75.59	84.41	91.15	101.02	105.98	104.88	103.99
36.1	33.35	48.40	61.07	75.95	84.91	91.73	101.63	106.66	105.59	104.64
36.55	33.54	48.63	61.39	76.31	85.39	92.28	102.25	107.31	106.29	105.33

Nth Percentile	Speed Group (mph)									
	5 - 20	**15 - 25**	**20 - 35**	**30 - 40**	**35 - 50**	**45 - 55**	**50 - 65**	**60 - 70**	**65 - 80**	**75 - 85**
37	33.74	48.87	61.71	76.66	85.87	92.86	102.89	107.96	106.98	106.01
37.45	33.93	49.10	62.03	77.03	86.37	93.44	103.53	108.62	107.68	106.66
37.9	34.12	49.34	62.34	77.40	86.87	94.03	104.17	109.26	108.39	107.33
38.35	34.32	49.58	62.67	77.78	87.37	94.60	104.82	109.91	109.09	108.03
38.8	34.51	49.84	63.00	78.17	87.85	95.18	105.46	110.57	109.78	108.76
39.25	34.70	50.09	63.32	78.56	88.34	95.75	106.10	111.21	110.47	109.44
39.7	34.89	50.33	63.65	78.94	88.83	96.31	106.75	111.86	111.16	110.14
40.15	35.09	50.57	63.97	79.33	89.30	96.88	107.36	112.51	111.85	110.83
40.6	35.28	50.81	64.29	79.74	89.79	97.48	107.98	113.18	112.55	111.53
41.05	35.48	51.03	64.60	80.13	90.28	98.08	108.60	113.84	113.25	112.22
41.5	35.68	51.25	64.91	80.53	90.77	98.69	109.23	114.51	113.97	112.91
41.95	35.87	51.49	65.22	80.96	91.24	99.30	109.87	115.18	114.71	113.58
42.4	36.07	51.72	65.54	81.38	91.72	99.90	110.52	115.84	115.42	114.26
42.85	36.26	51.97	65.85	81.81	92.21	100.48	111.17	116.52	116.13	114.95
43.3	36.46	52.23	66.19	82.20	92.69	101.04	111.81	117.20	116.85	115.60
43.75	36.66	52.47	66.51	82.59	93.20	101.62	112.46	117.90	117.58	116.30
44.2	36.85	52.72	66.85	82.96	93.72	102.18	113.12	118.61	118.31	117.02
44.65	37.05	52.97	67.18	83.35	94.22	102.75	113.78	119.31	119.08	117.70
45.1	37.24	53.23	67.51	83.73	94.71	103.33	114.46	120.01	119.83	118.39
45.55	37.45	53.49	67.84	84.14	95.23	103.91	115.14	120.73	120.60	119.12
46	37.65	53.75	68.18	84.53	95.76	104.48	115.83	121.46	121.36	119.86
46.45	37.86	54.02	68.52	84.93	96.29	105.05	116.52	122.21	122.14	120.61
46.9	38.06	54.28	68.86	85.32	96.81	105.62	117.22	122.95	122.92	121.34
47.35	38.27	54.53	69.19	85.70	97.36	106.21	117.93	123.70	123.71	122.05
47.8	38.48	54.80	69.53	86.10	97.86	106.80	118.63	124.46	124.51	122.77
48.25	38.68	55.06	69.88	86.53	98.36	107.38	119.34	125.22	125.32	123.48
48.7	38.89	55.34	70.22	86.98	98.91	107.97	120.04	126.01	126.15	124.20
49.15	39.10	55.60	70.55	87.45	99.45	108.54	120.75	126.79	126.98	124.95
49.6	39.32	55.87	70.89	87.93	99.98	109.12	121.48	127.56	127.82	125.74
50.05	39.52	56.13	71.24	88.39	100.51	109.71	122.22	128.33	128.66	126.53
50.5	39.74	56.37	71.58	88.81	101.03	110.28	122.96	129.13	129.52	127.26
50.95	39.95	56.62	71.92	89.26	101.54	110.88	123.71	129.94	130.37	128.03
51.4	40.16	56.87	72.27	89.72	102.05	111.51	124.47	130.76	131.23	128.83
51.85	40.37	57.12	72.60	90.15	102.57	112.16	125.23	131.58	132.09	129.66
52.3	40.59	57.37	72.95	90.61	103.11	112.82	126.01	132.41	132.97	130.50
52.75	40.81	57.64	73.30	91.08	103.62	113.51	126.79	133.25	133.86	131.32
53.2	41.03	57.89	73.64	91.52	104.16	114.17	127.58	134.09	134.74	132.15
53.65	41.23	58.16	73.99	91.94	104.67	114.84	128.35	134.94	135.63	132.98
54.1	41.45	58.41	74.33	92.37	105.19	115.52	129.13	135.78	136.52	133.75
54.55	41.67	58.66	74.69	92.82	105.69	116.20	129.95	136.64	137.44	134.58
55	41.88	58.91	75.03	93.28	106.23	116.87	130.77	137.52	138.36	135.47

Nth Percentile	Speed Group (mph)									
	5 - 20	**15 - 25**	**20 - 35**	**30 - 40**	**35 - 50**	**45 - 55**	**50 - 65**	**60 - 70**	**65 - 80**	**75 - 85**
55.45	42.10	59.17	75.38	93.75	106.78	117.56	131.61	138.41	139.28	136.37
55.9	42.32	59.46	75.73	94.23	107.33	118.22	132.43	139.30	140.21	137.30
56.35	42.54	59.73	76.09	94.74	107.88	118.90	133.28	140.21	141.16	138.23
56.8	42.77	60.02	76.46	95.25	108.45	119.59	134.13	141.14	142.12	139.12
57.25	43.00	60.31	76.83	95.78	109.03	120.31	134.99	142.08	143.08	140.01
57.7	43.24	60.61	77.19	96.28	109.61	120.99	135.85	143.01	144.02	140.96
58.15	43.47	60.90	77.57	96.80	110.20	121.69	136.73	143.94	145.00	141.91
58.6	43.71	61.20	77.96	97.34	110.79	122.45	137.63	144.90	145.97	142.87
59.05	43.94	61.49	78.36	97.83	111.37	123.20	138.52	145.86	146.95	143.82
59.5	44.18	61.79	78.77	98.32	111.96	123.94	139.42	146.81	147.95	144.86
59.95	44.41	62.07	79.18	98.83	112.56	124.66	140.32	147.77	148.96	145.90
60.4	44.64	62.37	79.59	99.36	113.20	125.43	141.25	148.74	149.97	146.97
60.85	44.89	62.69	79.99	99.88	113.80	126.22	142.17	149.72	150.96	148.00
61.3	45.12	63.01	80.38	100.39	114.41	126.99	143.09	150.70	151.96	149.04
61.75	45.36	63.31	80.77	100.91	115.04	127.76	144.03	151.69	152.99	150.07
62.2	45.61	63.62	81.19	101.42	115.68	128.54	144.98	152.69	154.06	151.08
62.65	45.86	63.93	81.61	101.95	116.29	129.34	145.94	153.72	155.12	152.10
63.1	46.12	64.25	82.05	102.47	116.91	130.14	146.91	154.75	156.18	153.14
63.55	46.37	64.57	82.49	102.97	117.54	130.94	147.90	155.80	157.26	154.18
64	46.62	64.90	82.93	103.48	118.19	131.78	148.89	156.85	158.36	155.31
64.45	46.87	65.22	83.38	104.01	118.85	132.64	149.90	157.90	159.48	156.45
64.9	47.13	65.56	83.83	104.51	119.53	133.54	150.91	158.96	160.60	157.55
65.35	47.38	65.90	84.28	105.00	120.23	134.42	151.93	160.02	161.74	158.68
65.8	47.63	66.25	84.74	105.53	120.94	135.28	152.95	161.10	162.89	159.78
66.25	47.89	66.60	85.20	106.08	121.64	136.10	154.00	162.19	164.05	160.93
66.7	48.15	66.98	85.64	106.63	122.38	136.99	155.06	163.28	165.19	162.05
67.15	48.41	67.36	86.10	107.20	123.13	137.86	156.13	164.42	166.36	163.18
67.6	48.68	67.73	86.57	107.73	123.85	138.74	157.21	165.54	167.56	164.36
68.05	48.96	68.12	87.05	108.29	124.62	139.62	158.28	166.68	168.74	165.58
68.5	49.24	68.49	87.52	108.87	125.42	140.51	159.36	167.83	169.93	166.83
68.95	49.53	68.86	87.98	109.44	126.23	141.38	160.45	168.98	171.12	167.97
69.4	49.83	69.24	88.44	110.03	126.97	142.26	161.57	170.11	172.32	169.09
69.85	50.13	69.64	88.93	110.68	127.80	143.16	162.70	171.25	173.55	170.28
70.3	50.43	70.04	89.42	111.30	128.58	144.04	163.89	172.40	174.77	171.51
70.75	50.74	70.42	89.91	111.97	129.38	144.97	165.06	173.60	176.01	172.81
71.2	51.04	70.78	90.41	112.67	130.21	145.90	166.23	174.78	177.25	174.10
71.65	51.35	71.18	90.93	113.38	131.03	146.92	167.39	176.02	178.52	175.38
72.1	51.66	71.57	91.46	114.05	131.83	147.95	168.59	177.24	179.77	176.70
72.55	51.99	71.99	91.98	114.79	132.64	148.95	169.79	178.47	181.04	178.00
73	52.32	72.43	92.52	115.49	133.51	149.98	170.98	179.74	182.30	179.30
73.45	52.66	72.86	93.07	116.12	134.39	151.05	172.20	181.02	183.61	180.66

Nth Percentile	Speed Group (mph)									
	5 - 20	**15 - 25**	**20 - 35**	**30 - 40**	**35 - 50**	**45 - 55**	**50 - 65**	**60 - 70**	**65 - 80**	**75 - 85**
73.9	53.00	73.28	93.63	116.76	135.23	152.17	173.46	182.32	184.90	182.07
74.35	53.35	73.71	94.17	117.44	136.06	153.26	174.71	183.63	186.19	183.48
74.8	53.69	74.13	94.75	118.22	136.98	154.38	175.99	184.93	187.51	184.92
75.25	54.04	74.56	95.35	118.97	137.96	155.47	177.33	186.26	188.84	186.33
75.7	54.39	74.96	95.96	119.75	138.93	156.61	178.67	187.60	190.16	187.82
76.15	54.75	75.36	96.58	120.49	139.93	157.75	180.05	188.93	191.48	189.32
76.6	55.11	75.82	97.21	121.24	140.94	158.86	181.46	190.24	192.84	190.81
77.05	55.50	76.29	97.86	122.02	141.95	159.95	182.89	191.56	194.22	192.36
77.5	55.89	76.78	98.56	122.81	142.99	161.13	184.31	192.91	195.66	193.80
77.95	56.28	77.27	99.25	123.61	144.01	162.33	185.73	194.29	197.11	195.29
78.4	56.66	77.79	99.94	124.42	145.02	163.60	187.17	195.74	198.59	196.80
78.85	57.06	78.36	100.67	125.26	146.08	164.93	188.64	197.22	200.10	198.31
79.3	57.47	78.95	101.36	126.19	147.26	166.24	190.07	198.70	201.59	199.83
79.75	57.88	79.54	102.05	127.06	148.40	167.57	191.55	200.22	203.14	201.46
80.2	58.30	80.11	102.84	128.00	149.57	169.01	193.05	201.73	204.66	203.19
80.65	58.71	80.62	103.59	128.94	150.77	170.37	194.57	203.28	206.18	204.79
81.1	59.14	81.19	104.36	129.92	152.04	171.72	196.17	204.84	207.70	206.44
81.55	59.60	81.80	105.16	130.91	153.28	173.12	197.78	206.44	209.26	208.20
82	60.06	82.44	105.99	131.95	154.55	174.59	199.41	208.02	210.84	209.88
82.45	60.55	83.07	106.84	133.05	155.79	175.98	201.10	209.63	212.48	211.59
82.9	61.06	83.76	107.66	134.26	157.05	177.43	202.77	211.22	214.15	213.35
83.35	61.57	84.43	108.50	135.56	158.32	179.01	204.50	212.88	215.81	215.09
83.8	62.10	85.09	109.44	136.83	159.60	180.67	206.27	214.56	217.51	216.82
84.25	62.62	85.72	110.39	138.13	160.92	182.30	208.06	216.25	219.19	218.59
84.7	63.16	86.38	111.37	139.45	162.29	183.95	209.84	217.97	220.88	220.25
85.15	63.73	87.12	112.41	140.78	163.73	185.63	211.64	219.68	222.63	221.95
85.6	64.33	87.87	113.45	142.09	165.36	187.35	213.52	221.45	224.41	223.77
86.05	64.94	88.65	114.59	143.48	167.04	189.23	215.35	223.28	226.21	225.50
86.5	65.55	89.50	115.74	144.79	168.85	191.04	217.21	225.12	227.97	227.16
86.95	66.16	90.35	116.90	146.13	170.61	192.95	219.10	227.00	229.80	228.99
87.4	66.84	91.23	118.22	147.53	172.41	194.93	221.02	228.88	231.63	230.98
87.85	67.57	92.13	119.53	149.00	174.20	196.94	223.03	230.75	233.51	232.83
88.3	68.32	93.07	120.84	150.49	175.80	199.10	225.13	232.71	235.42	234.76
88.75	69.08	93.99	122.16	151.92	177.57	201.38	227.27	234.69	237.39	236.79
89.2	69.84	95.00	123.54	153.55	179.39	203.63	229.41	236.74	239.41	238.89
89.65	70.63	95.97	124.93	155.09	181.43	206.12	231.68	238.79	241.49	241.04
90.1	71.47	96.92	126.48	156.89	183.51	208.74	233.97	240.92	243.52	243.14
90.55	72.39	97.96	128.01	158.67	185.68	211.35	236.26	243.08	245.60	245.43
91	73.32	99.16	129.58	160.46	187.89	213.93	238.55	245.21	247.65	247.54
91.45	74.35	100.36	131.34	162.39	190.25	216.52	240.96	247.38	249.76	249.58
91.9	75.39	101.61	133.24	164.80	192.71	219.29	243.46	249.58	251.98	251.77

Nth Percentile	Speed Group (mph)									
	5 - 20	**15 - 25**	**20 - 35**	**30 - 40**	**35 - 50**	**45 - 55**	**50 - 65**	**60 - 70**	**65 - 80**	**75 - 85**
92.35	76.52	103.00	135.19	167.17	195.52	222.15	246.01	251.88	254.16	253.99
92.8	77.66	104.45	137.27	169.55	198.42	225.15	248.52	254.17	256.35	256.07
93.25	78.94	106.03	139.42	172.08	201.71	228.32	251.15	256.54	258.57	258.18
93.7	80.38	107.68	141.55	174.97	205.18	231.59	253.84	259.04	260.86	260.37
94.15	81.83	109.52	143.91	177.82	209.41	235.01	256.57	261.59	263.20	262.62
94.6	83.40	111.68	146.26	180.67	213.45	238.74	259.50	264.27	265.62	264.98
95.05	85.08	113.73	149.03	184.10	217.53	242.90	262.47	266.88	268.01	267.36
95.5	86.89	116.10	151.93	187.79	221.94	246.71	265.45	269.50	270.40	269.60
95.95	88.99	118.82	154.79	192.12	226.60	250.67	268.51	272.11	272.92	272.03
96.4	91.29	121.65	158.19	196.80	231.74	255.10	271.37	274.90	275.59	274.60
96.85	93.88	124.76	162.06	201.83	237.31	259.93	274.47	277.71	278.32	277.26
97.3	97.02	128.22	166.73	208.50	243.68	264.78	277.68	280.60	281.13	280.15
97.75	100.77	132.61	172.23	216.85	250.50	270.17	281.01	283.50	283.98	283.10
98.2	105.32	138.00	179.28	225.24	258.00	275.48	284.52	286.64	286.99	286.01
98.65	111.44	144.06	188.10	234.67	266.43	281.15	288.20	289.86	290.14	289.31
99.1	120.67	153.10	200.05	247.41	276.07	287.56	292.00	293.15	293.30	292.58
99.55	137.00	174.69	224.61	266.12	287.84	293.92	295.92	296.48	296.60	296.22

APPENDIX C. EFFECTS OF SITE CHARACTERISTICS ON SPACING

The effects of specific site characteristics of interest were analyzed by developing separate distributions for groups of sites with common features. These features include: 1) number of mainline through lanes, 2) posted speed limit, and 3) geographical location (State).

Results of the K-S comparisons for the three evaluations and their p-values for each speed group are shown in table 9, table 10, and table 11. Significant differences at the 95-percent confidence level are noted with a shaded cell and an asterisk (*).

Table 9. Comparisons of spacing distributions by number of lanes.

Speed Bin (mph)	Test	Number of Lanes					
		2vs3	2vs4	2vs5	3vs4	3vs5	4vs5
0 - 20	KS Statistic	0.177	0.145	0.064	0.036	0.141	0.117
	p-value	0.002*	0.019*	0.766	0.999	0.025*	0.117
15 - 25	KS Statistic	0.245	0.218	0.123	0.036	0.123	0.222
	p-value	0.000*	0.000*	0.073	0.999	0.073	0.222
20 - 35	KS Statistic	0.155	0.164	0.055	0.014	0.114	0.073
	p-value	0.010*	0.005*	0.900	1.000	0.117	0.073
30 - 40	KS Statistic	0.200	0.205	0.159	0.032	0.109	0.269
	p-value	0.000*	0.000*	0.008*	1.000	0.146	0.269
35 - 50	KS Statistic	0.145	0.155	0.086	0.014	0.086	0.222
	p-value	0.019*	0.010*	0.385	1.000	0.385	0.222
45 - 55	KS Statistic	0.091	0.114	0.041	0.032	0.105	0.057
	p-value	0.324	0.117	0.993	1.000	0.181	0.057
50 - 65	KS Statistic	0.077	0.082	0.045	0.027	0.041	0.993
	p-value	0.528	0.454	0.977	1.000	0.993	0.993
60 - 70	KS Statistic	0.059	0.041	0.041	0.036	0.027	1.000
	p-value	0.838	0.993	0.993	0.999	1.000	1.000
65 - 80	KS Statistic	0.082	0.032	0.045	0.059	0.041	1.000
	p-value	0.454	1.000	0.977	0.838	0.993	1.000
75 - 85	KS Statistic	0.277	0.259	0.295	0.032	0.045	0.687
	p-value	0.000*	0.000*	0.000*	1.000	0.977	0.687

Table 10. Comparisons of spacing distributions by speed limits.

Speed Bin (mph)	Test	Speed Limit (mph)					
		55vs60	55vs65	55vs70	60vs65	60vs70	65vs70
0 - 20	KS Statistic	0.077	0.205	0.123	0.145	0.077	0.057
	p-value	0.528	0.000*	0.073	0.019*	0.528	0.057
15 - 25	KS Statistic	0.259	0.186	0.173	0.127	0.145	0.838
	p-value	0.000*	0.001*	0.003*	0.057	0.019*	0.838
20 - 35	KS Statistic	0.082	0.223	0.173	0.164	0.118	0.607
	p-value	0.454	0.000*	0.003*	0.005*	0.093	0.607
30 - 40	KS Statistic	0.195	0.395	0.236	0.273	0.055	0.000
	p-value	0.000*	0.000*	0.000*	0.000*	0.900	0.000*
35 - 50	KS Statistic	0.136	0.286	0.132	0.159	0.023	0.003
	p-value	0.033*	0.000*	0.044*	0.008*	1.000	0.003*
45 - 55	KS Statistic	0.114	0.127	0.041	0.109	0.082	0.269
	p-value	0.117	0.057	0.993	0.146	0.454	0.269
50 - 65	KS Statistic	0.059	0.059	0.045	0.064	0.018	0.977
	p-value	0.838	0.838	0.977	0.766	1.000	0.977
60 - 70	KS Statistic	0.055	0.032	0.059	0.064	0.009	0.687
	p-value	0.900	1.000	0.838	0.766	1.000	0.687
65 - 80	KS Statistic	0.123	0.064	0.123	0.077	0.014	0.687
	p-value	0.073	0.766	0.073	0.528	1.000	0.687
75 - 85	KS Statistic	0.445	0.364	0.445	0.127	0.018	0.117
	p-value	0.000*	0.000*	0.000*	0.057	1.000	0.117

Table 11. Comparisons of spacing distributions by geographical location (State).

Speed Bin (mph)	Test	State		
		NCvsFL	NCvsWA	FLvsWA
0 - 20	KS Statistic	0.059	0.114	0.141
	p-value	0.838	0.117	0.025*
15 - 25	KS Statistic	0.050	0.164	0.177
	p-value	0.947	0.005*	0.002*
20 - 35	KS Statistic	0.059	0.109	0.145
	p-value	0.838	0.146	0.019*
30 - 40	KS Statistic	0.086	0.123	0.091
	p-value	0.385	0.073	0.324
35 - 50	KS Statistic	0.073	0.041	0.045
	p-value	0.607	0.993	0.977
45 - 55	KS Statistic	0.100	0.091	0.036
	p-value	0.222	0.324	0.999
50 - 65	KS Statistic	0.059	0.050	0.027
	p-value	0.838	0.947	1.000
60 - 70	KS Statistic	0.068	0.059	0.023
	p-value	0.687	0.838	1.000
65 - 80	KS Statistic	0.082	0.068	0.036
	p-value	0.454	0.687	0.999
75 - 85	KS Statistic	0.114	0.141	0.073
	p-value	0.117	0.025*	0.607