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Assessment of Level-Of-Service for Freeway Segments Using HCM and Microsimulation Methods

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Abstract

The HCM2010 freeway facilities methodology offers a supplemental computational engine FREEVAL, which is a macroscopic/mesoscopic tool. It enables users to implement HCM-based freeway analysis quickly. Vissim is a microscopic simulation tool that enables users to model real-world conditions with high level of accuracy. One of the commonly used performance measures for freeway assessment is the Level-of-Service (LOS). The HCM freeway facility methodology uses density to estimate LOS. However, density is calculated differently in FREEVAL and Vissim, and comparing the estimated LOSs between the two may lead to invalid conclusions. The aim of this paper is to address a gap in the literature by comparing and contrasting the methodologies behind the two tools and by offering explanation and discussion of their outputs in terms of density and LOS. The study covers three major HCM freeway segment types (basic, on-ramp, and weaving) in under-saturated conditions. The assessment reveals that both tools are capable of replicating the field conditions after the calibration process. Finding show that LOS differs by maximum one grade between these tools. Segment density obtained from HCM methods is generally higher than the segment density from Vissim microsimulation.

Keywords: HCM, Level-of-Service, Vissim, Microsimulaton, FREEVAL, freeway analysis

1 Introduction

Level-Of-Service (LOS) is widely used performance measure to assess the freeway operations. In the Highway Capacity Manual (HCM) method, it is based on the vehicular density of the specific facility segment. Freeway facility methodology for LOS calculation consists of minimum five and maximum eight steps involving multiple analytical equations (Transportation Research Board, 2010).

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The number of steps depends on the segment type which can be basic, weave, merge, or diverge. The variation of methodology in different segment types makes the analysis time consuming, especially if the assessment has to cover several freeway segments.

To make the calculation process more convenient, HCM 2010 freeway facilities methodology is accompanied with a supplemental computational engine FREEVAL, which is a macroscopic/mesoscopic tool that enables users to implement HCM-based freeway analysis methodology quickly. FREEVAL has been associated with the HCM freeway facility chapter since the last decade. Original FREEVAL engine was developed in Microsoft Excel powered by Visual Basic for Applications (Rouphail, Schroeder, & Eads, 2011). The latest version is offered in Java environment with enhanced features, such as managed lanes and travel time reliability (Zegeer, et al., 2014). The latter is used in research. In the under saturated conditions, FREEVAL exactly matches the computational methods in the segment chapters in HCM 2010. In fact, one does not need to use FREEVAL in those cases. The difference is that FREEVAL does provide segment-based densities in vehicles/mile/lane or passenger cars/mile/lane. Even though FREEVAL is based on HCM methods, it is easier for use comparing to equation based HCM methodology.

Another way to evaluate freeway facilities is to use microsimulation tools, as proposed by HCM in alternative tools subsection. Although there are several microsimulation tools on the market, Vissim is one that enables users to model real-world traffic conditions with high level of accuracy and comprehension. Thus, the two tools represent quite opposite sides in freeway modelling – Vissim as a representative of microsimulation tools, requires time-consuming preparation and calibration of the model, but it usually provides better granularity of results. FREEVAL requires less on input and calibration sides but its results may not be as comprehensive and accurate as Vissim.

Researchers and practitioners use both tools for freeway analysis and tend to compare the outputs directly. The HCM freeway facilities methodology uses density in passenger cars per mile per lane (pc/mi/ln) to estimate LOS. However, density is calculated differently in Vissim, and comparing the estimated LOSs between the two may not represent a proper comparison, and can lead to invalid conclusions. Further, HCM 2010 states that Vissim density outputs should not be converted to pc/mi/ln using HCM equations (Transportation Research Board, 2010). Microsimulation already accounts for sluggish behavior of heavy vehicles, and using HCM equations would be equivalent to adding the heavy vehicle factor twice in the output.

HCM 2010 states that simulation tools should produce similar answers to the HCM output (Transportation Research Board, 2010). Further, it says the exact numerical match should not be expected due to different nature of the methodologies. HCM (FREEVAL) is based on deterministic equations, while Vissim is stochastic in nature. Current literature does not provide much insight into how different outputs from FREEVAL and microsimulation compare. Some research (Milam, Stanek, & Chris, 2006) has been done in the past, but it was based on the HCM 2000 guidelines. HCM 2010 has brought many changes, including supplemental chapters on how to use microsimulation tools along with HCM methods. Evidently, there is a gap in the common knowledge on how differences between these tools should be handled, so that practitioners can have an insight of how consistent results are.

This paper aims to address such a gap by comparing and contrasting the methodologies behind the two tools and by offering explanation and discussion of their outputs in terms of segment density and LOS. The paper covers three major HCM freeway segment types (basic, on-ramp, weaving) for under-saturated conditions and utilizes the methodology for segment density analysis. Field data are acquired from Performance Measurement System (PeMS) online database in California, for I-880 freeway. FREEVAL and Vissim models are calibrated and validated using the acquired data. The outputs of both tools are evaluated against the field data.

2 Literature Review

Bloomberg's study used 6 microsimulation models to compare their outputs with HCM 2000 based methods (Bloomberg, Swenson, & Haldors, 2003). As test sites, the authors used signalized intersections and freeway section. The results showed that all the microsimulation tools are similar in terms of output produced. When HCM 2000 and microsimulation modes were compared, they found that there were differences in the range of LOS grade. Grades varied by one grade at most. The study suggests that the difference between these two methodologies depends on the congestion level.

In a case study, (Milam, Stanek, & Chris, 2006) the authors identified consistency problems when applying simulation models and comparing density and delay outputs with HCM 2000 measures. The paper examines several tools and points out the importance of reading outputs correctly. There are no conclusions on how to overcome inconsistencies.

Wu and Lemke derived a new model for freeway assessment based on joint volume-to-capacity ratio for all the freeway segments combined. The model considered all the segments as a whole object (Wu & Lemke, 2011). The authors proposed that LOS determination can be done for the total segment, without calculating it for separate segments. The advantage of this model is assessment of on/off ramp, major freeway segment and merge/diverge/weaving areas in one step.

Jolovic el al. compared Vissim and FREEVAL for oversaturated freeway conditions (Jolovic & Stevanovic, 2012). FREEVAL failed to replicate both speed and density from the field. Vissim was successfully calibrated to replicate speeds and density correctly, but only after speed reduction areas were installed, to simulate the effects downstream queue propagation, which occurred outside of the boundaries of the model.

Sajjadi et. al. enhanced the HCM freeway facilities module to enable travel time reliability analysis by introducing new parameters and modifying the existing traffic stream behavior models. The researchers added the Speed Adjustment Factor (SAF) to account for reduction in Free Flow Speed (FFS). They enhanced all the traffic stream behaviors models for all segment types to account for FFS reduction (Sajjadi, Schroeder, & Rouphail, 2013).

The main concern of the study conducted in Texas was the efficiency of auxiliary lanes (Qi, et al., 2014). Microsimulation was the primary method for evaluation of weaving segments with and without auxiliary lanes. The authors also compared real data, HCM weaving procedure and Vissim simulation, to check if Vissim is the appropriate tool to evaluate auxiliary lane impact. During the validation process, they found that Vissim outputs were strongly correlated with HCM weaving procedure in terms of speeds and density. However, this study did not focus on microsimulation and HCM comparative evaluation, but on the effects of adding auxiliary lanes at freeway segments.

The forthcoming German HCM manual (HBS) will have alternative methods chapters, similar to the US HCM 2010. A study conducted in Germany (Geistefeldt, et al., 2014), tested five different microsimulation models on diverge freeway segment with the two-lane off ramp, to give standard parameter sets for the simulation of German freeways; thereby allowing microsimulation LOS assessment with the analytical methods from the manual. After calibration, Vissim, Aimsun, Paramics, and BABSIM were capable of replicating the design capacity values recommended by the manual.

Hartmann et. al. (Hartmann, Vortisch, & Schroeder, 2015) tested FREEVAL engine for German conditions, but found that the model is suitable for US conditions only. The German methodology does not have the breakdown propagation method. So for LOS F of the facility, the analysis terminates. Also capacity definition varies from the US HCM methods. The authors proposed the German version of FREEVAL model, compared it to the US version, and tested the practical application of the model on German motorways. The developed model analyzes LOS based on the modified cell transmission model and allows 24-hour analysis of a freeway facility of any length. The authors concluded that the model produces results comparable to Vissim microsimulation and field data.

These studies show that in some cases microsimulation can successfully match the results obtained from HCM guidelines. Even then, the LOS can differ by one grade. However, the testing between Vissim and FREEVAL (German version) has been done only for German conditions and only for one freeway segment. Older US FREEVAL version coded in MS Excel has not had sufficient speed calibration parameters available. That affected the output, especially for the oversaturated conditions. New FREEVAL model with enhanced SAF should give more flexibility to the user and allow better calibration results. Currently, there are no available studies which tested how new FREVAL version performs. Additional research is needed to evaluate the differences between FREEVAL and microsimulation tools for the US based conditions and to test how improved FREEVAL engine performs.

3 Methodology

The overall methodology is shown in Figure 1. Collected data are used to calibrate and validate both Vissim and FREEVAL models. After the models are successfully calibrated and validated, the outputs are extracted and compared.

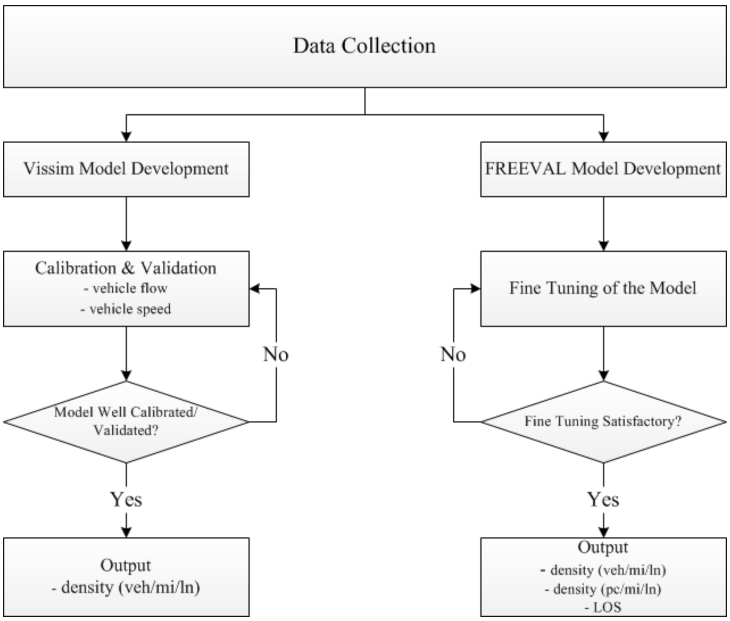


Figure 1 Overall Methodology

The test site is a part of I-880 Nimitz freeway facility, located between Stevenson Blvd and Mowry Ave in Freemont, California. The test bed consists of two basic, one on-ramp and one weaving segment, as shown in Figure 2. Weaving segment has an auxiliary lane between on-ramp and off-ramp. Field data were collected from California's PeMS online database for February 8th and February 10th, 2014. PeMS uses loop detectors to collect the traffic data. The authors retrieved field traffic volumes, speeds and occupancies in 5-min intervals for a 24-hour period.

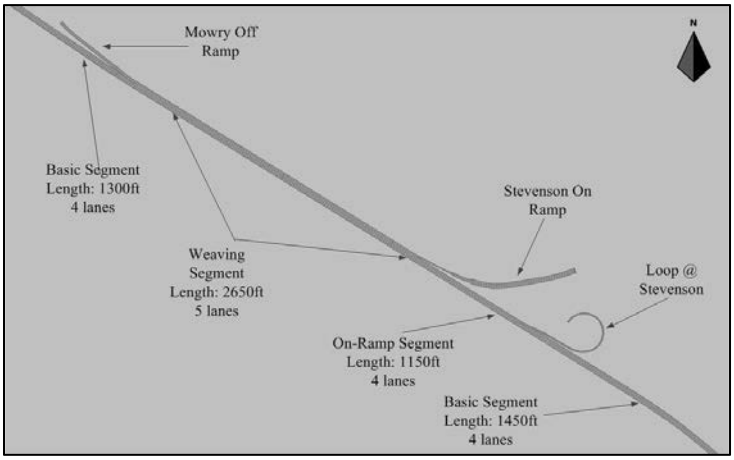
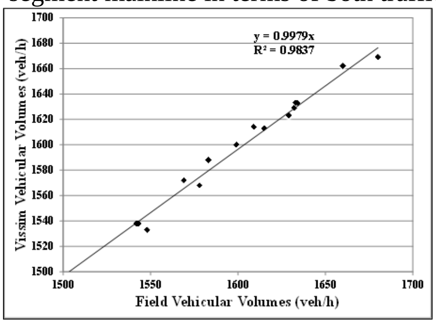
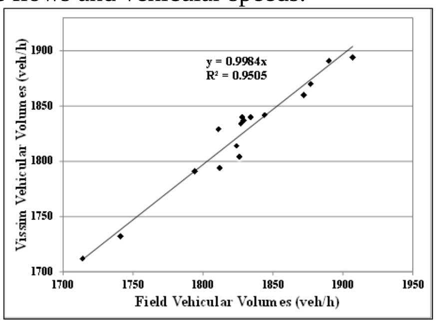


Figure 2 Study area of I-880 Nimitz freeway

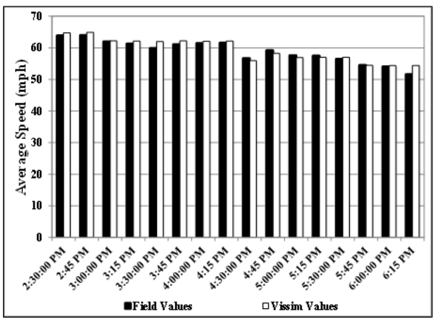
The Vissim model was developed, calibrated and validated for the 4-hour period, from 2:30PM-6:30PM, with the 15-min of warm up time. Vissim was chosen as a microsimulation modeling tool because of the availability (NMSU has a Vissim license), and its proven performance and popularity in the US market. The Vissim model is calibrated in terms of traffic volumes and speeds using February 8th, 2014 data. Validation is performed in terms of vehicle speeds using February 10th, 2014 data. Five simulation runs were averaged and compared to the field values to account for the stochastic nature of Vissim. Figure 3 and Figure 4 show the calibration results for Vissim. It can be seen that for on-ramp, off-ramp and for the loop freeway entrance field traffic flows closely match their simulation counterparts, which is documented with high coefficients of determination. High correlation is also achieved for segment mainline in terms of both traffic flows and vehicular speeds.



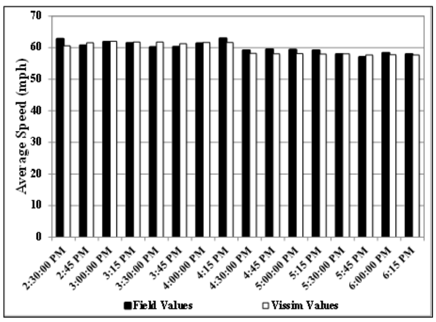
A) Volume calibration before Stevenson Blvd On-Ramp



B) Volume calibration for weaving area

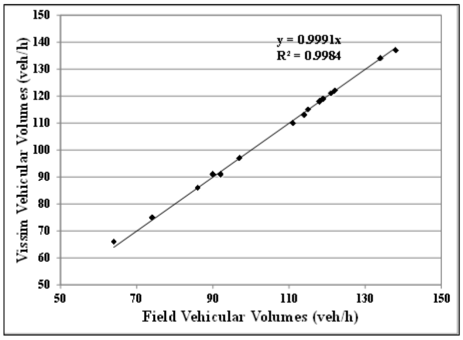


C) Speed calibration before Stevenson Blvd On-Ramp

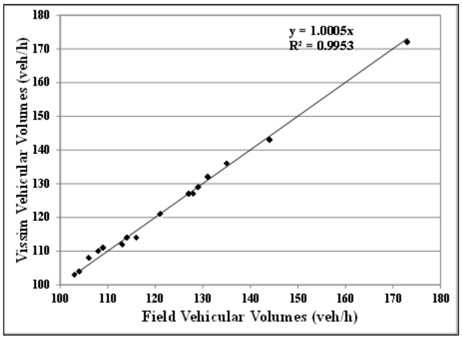


D) Speed calibration for weaving area

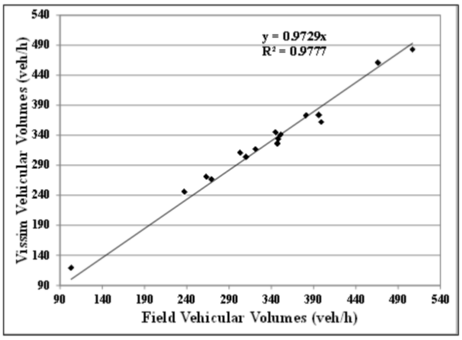
Figure 3 Calibration of Mainline I-880 freeway in terms of volumes and speeds



A) Volume calibration for Stevenson Blvd Loop



B) Volume calibration for Stevenson Blvd On-Ramp



C) Volume calibration for Mowry Off-Ramp

Figure 4 Loop, On-Ramp, and Off-Ramp calibration in terms of traffic volumes

Validation is a process of testing whether the model if capable of replicating a set of field data for the conditions different from those for which the calibration is done. Figure 5 presents validation results in terms of vehicle speeds for the same time frame (2:30-6:30PM) but for a different date. Figure 5 shows the model can be applied to a different day with high confidence for vehicular speeds.

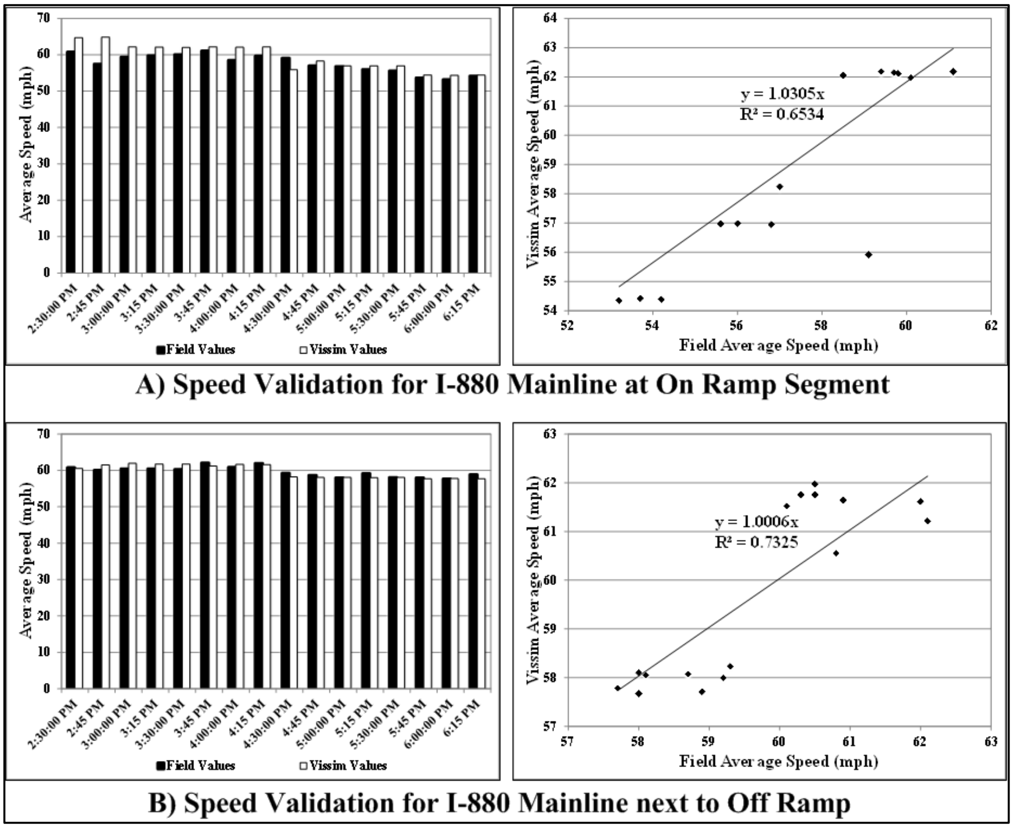


Figure 5 Speed validation

The FREEVAL model in this study consisted of four freeway segments: two basic segments, one on ramp segment and one weaving segment. Segment lengths are coded according the guidelines provided by the HCM supplemental methodology. In spatial terms, the authors developed 16 time intervals, each one 15-min long that corresponds to four hours of data analysis. Figure 6 shows an example of FREEVAL input for one 15-min interval. Highlighted cells are the minimum information required for FREEVAL input.

Segment	Seg. 1	Seg. 2	Seg. 3	Seg. 4
General Purpose Segment Data	*	*	*	*
General Purpose Segment Name	N/A	N/A	N/A	N/A
General Purpose Segment Type	Basic	On Ramp	Weaving	Basic
Segment Length (ft)	1,450	1,100	2,650	1,300
Terrain	Level	Level	Level	Level
Truck-PC Equivalent (ET)	2.00	2.00	2.00	2.00
# of Lanes: Mainline	4	4	5	4
Free Flow Speed (mph)	65	65	65	65
Mainline Dem. (vph)	6,532			
Mainline Single Unit Truck and B...	5.00			
Mainline Tractor Trailer (%)	1.00			
Seed Capacity Adj. Fac.	1.00	0.95	1.20	0.98
Seed Entering Dem. Adj. Fac.	1.00	1.00	1.00	1.00
Seed Exit Dem. Adj. Fac.	1.00	1.00	1.00	1.00
Seed Free Flow Speed Adj. Fac.	0.90	0.90	1.20	0.90
Seed Driver Pop. Capacity Adj. F...	1.00	1.00	1.00	1.00
Seed Driver Pop. Free Flow Spe...	1.00	1.00	1.00	1.00
Acc/Dec Lane Length (ft)		500		
ONR Side		Right	Right	
# Lanes: ONR		1	1	
ONR Queue Capacity (veh/ln)		50	50	
ONR Free Flow Speed (mph)		40	40	
ONR/Entering Dem. (vph)		256	524	
ONR Single Unit Truck and Bus (...		6.00	6.00	
ONR Tractor Trailer (%)		2.00	2.00	
ONR Metering Type		None	None	
ONR Metering Fixed Rate (vph)				
OFR Side			Right	
# Lanes: OFR			1	
OFR Free Flow Speed (mph)			40	
OFR/Exit Dem. (vph)			1,052	
OFR Single Unit Truck and Bus (...			5.00	
OFR Tractor Trailer (%)			2.00	
Weave Segment Ls (ft)			2,215	
Weave Segment LCRF			1	
Weave Segment LCFR			1	
Weave Segment LCRR			0	
Weave Segment NW			2	
Ramp to Ramp Dem. (vph)			1	

Figure 6 FREEVAL Input Window in Java Environment

FREEVAL has to be calibrated. In the first iteration, FREEVAL is coded with traffic input, free flow speed for mainline, on and off ramps, and heavy vehicles percentages. Speed output is compared to Vissim calibrated values for each 15-min time interval. The initial outputs showed that FREEVAL needed a speed adjustment in order to provide closer match with the field data. The speed was adjusted by varying the capacity adjustment factor (CAF) for each segment and the speed adjustment factor (SAF) for the weaving segment. According to the FREEVAL guidelines, SAF is a static factor of the location, and it should be used to model weather and/or geometric effects on free flow speed (Zegeer, et al., 2014).

Since the Vissim model is well calibrated for the field conditions in terms of both traffic flow and vehicle speeds, the FREEVAL speed output is compared with Vissim values. Figure 7 shows the results of this comparison, which show that macroscopic FREEVAL model can be calibrated to match microsimulation Vissim's outputs with high degree of confidence for all of the segments tested.

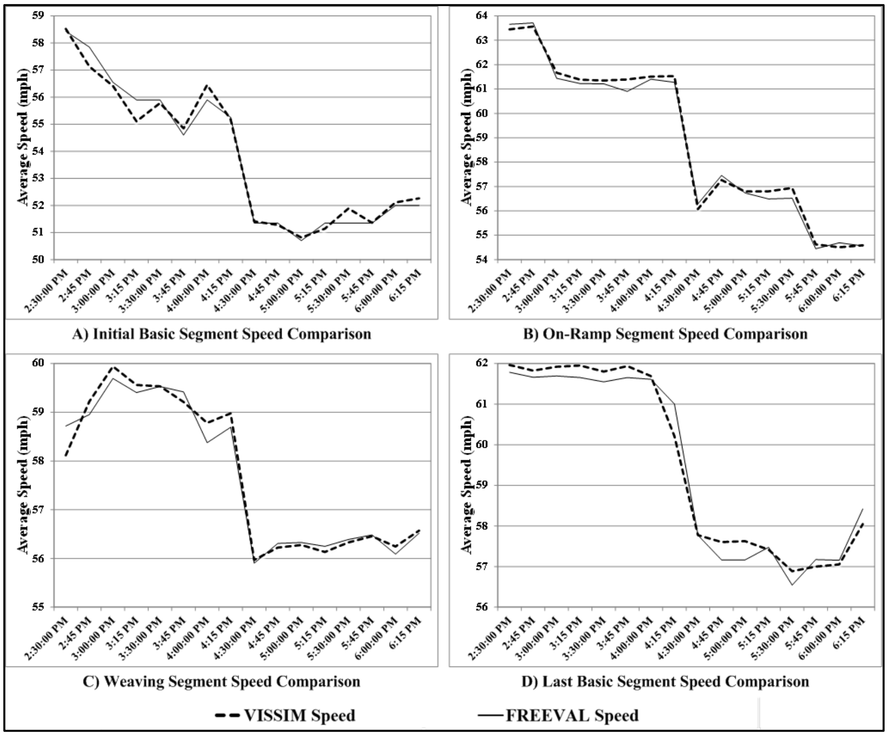


Figure 7 Calibration of FREEVAL speeds

Vehicle density is the amount of vehicles occupying one mile of the specific road segment, as expressed in veh/mi/ln. Density in Vissim can be obtained through the 'Link Evaluation' option or calculated from the 'Vehicle Records' output. The equation used in Vissim to calculate density in 'Link Evaluation' is as follows:

$$Density\left(\frac{veh}{mi}\right)=\frac{\frac{Total\,Time}{Time\,Interval\cdot 621.5}}{Segment\,Length}=\frac{Total\,Time}{Segment\,Length\cdot Time\,Interval\cdot 621.5} \quad [1]$$

where:

Total Time – the total time the vehicle spent on the link
Time Interval – the analysis time interval specified by the user
Segment Length – the length of the segment in miles

Note that the segment definitions in Vissim and FREEVAL are different. In Vissim, the segment length defines the evaluation cells which can be in per-lane or per-link format. In other words, a link in Vissim will be divided into smaller evaluation cells and the 'segment length' specifies the length of such cell. The total number of evaluation segments is equal to the Link Length divided by the Segment Length. Figure 8 illustrates the concept. If a vehicle passes over the evaluation cell, then the cell will be considered occupied. The *Total Time* is actually accumulation of the times when the evaluation cell is occupied. The *Time Interval* is a user input variable and the numerical value of *621.5* in the Equation [1] is used to convert veh/km to veh/mi.

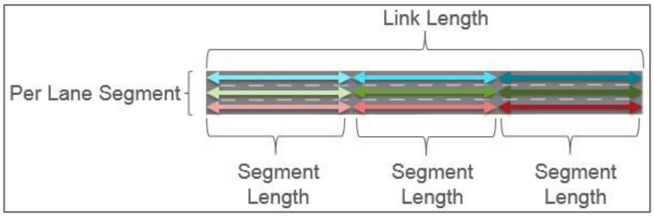


Figure 8 Segmentation of the links in Vissim for density-based calculations

Considering that the FREEVAL is coded by using specific lengths for each segment, extraction of density per segment in Vissim is done for exactly the same segment lengths coded in FREEVAL model. It should be noted that Vissim outputs density in veh/mi/ln, and that calculated LOS will be based on this value. Again, the intention of LOS calculation using microsimulation density is to evaluate the discrepancy between Vissim and HCM (FREEVAL) methodology.

Consequently, FREEVAL reports density in both veh/mi/ln and pc/mi/ln, also known as passenger car equivalent (PCE). However, only the PCE value is used to calculate the LOS. PCE accounts for the impact of the heavy vehicles and translates it into the passenger car impact. FREEVAL densities in both units are presented to better discuss the differences with Vissim density output. Considering that Vissim already accounts for the sluggish behavior of the heavy vehicles by assigning different speed distributions and limited maneuver abilities, it is expected that the HCM (FREEVAL) methodology will closely match the microsimulation results. There follow both values and a discussion of the differences between Vissim and FREEVAL segment density outputs.

4 Results and Discussion

Figure 9 shows density values for all of the segments evaluated. The charts present Vissim density obtained using the 'Link Evaluation' option; density from FREEVAL in both veh/mi/ln and FREEVAL PCE density in pc/mi/ln; and density from the field. The field density is calculated simply by dividing traffic flow with speed obtained from loop detectors (Qiu, Lu, Chow, & Shladover, 2010). In order to better visualize the findings, the ticker values (ranges) on both primary (veh/mi/ln) and secondary (pc/mi/ln) axes are kept the same to better present the findings.

For the initial basic segment shown in Figure 9A, field density closely matches with Vissim density output. FREEVAL overestimates the field density, regardless of whether the density is presented in veh/mi/ln or pc/mi/ln units. T-test conducted on field and Vissim densities with 95% confidence interval showed that there is no significant difference between two samples.

For the on-ramp segment, shown in Figure 9B, field density closely matches FREEVAL output in terms of veh/mi/ln. No significant difference has been found within 95% confidence interval between these two datasets. The same holds true for Vissim density output and the PCE density from FREEVAL.

The density expressed in PCE has the highest values for all the segments evaluated. For on-ramp segment (Figure 9B), it is little lower than density output from Vissim; still there is no significant difference between the two at the 95% confidence interval. In this study, the share of heavy vehicles in the total traffic flow was 6%. For higher heavy vehicle values, the difference between microsimulation density output and the PCE can be even higher. Higher density discrepancy will lead to higher LOS differences. This shows the importance of PCE in direct comparison of microsimulation tools and HCM outputs when estimating LOS.

The weaving segment results presented in Figure 9C reveal that PCE values are considerably higher than the Vissim density output. One should note that there are no field data for density for weaving segment. Detector in the field was placed just downstream of the weaving segment, so no accurate field density values could be derived.

Vissim and FREEVAL output in veh/mi/ln do not differ significantly at the 95% confidence level. Weaving segment also has the biggest discrepancy between PCE and the microsimulation density values. Weaving areas at freeways are very sensitive in terms of flow and speed stability, due to many merging/diverging vehicle maneuvers. Also, speed variations for this segment are the highest among the segments tested for consecutive 15-min intervals. All this can contribute to the obtained results.

For the last basic segment, shown in Figure 9D, Vissim density output closely matches density from FREEVAL expressed in veh/mi/ln, while PCE gives slightly higher values, as expected.

For both basic segments tested, Vissim outputs lower density values than FREEVAL. The difference is more obvious for the initial segment. Still, when assessing basic freeway segments with both tools, the users should be advised that Vissim density would be lower than the HCM based one.

These findings reveal that Vissim density outputs can match, in most of the cases the FREEVAL densities when these densities are expressed in veh/mi/ln. Even though Vissim incorporates the sluggish heavy vehicle behavior into the simulation, density from Vissim is generally lower than the one expressed in pc/mi/ln. Considering that the heavy vehicles adjustment factors from HCM 2010 are not recommended for use with the microsimulation outputs, a different approach needs to be developed to adjust Vissim outputs to be comparable with HCM analysis.

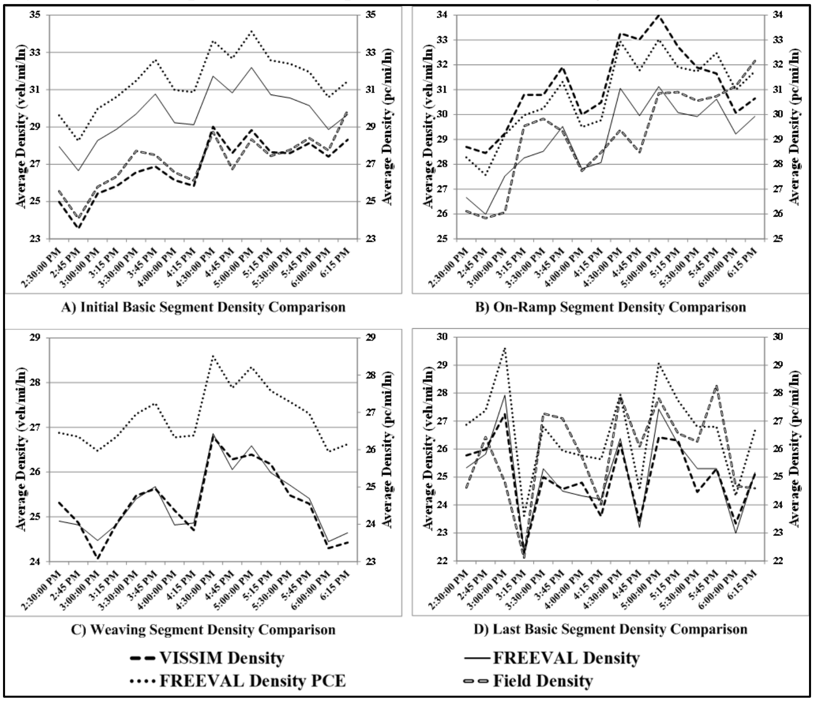


Figure 9 Density comparisons

The literature does not recommend direct LOSs comparison obtained from microsimulation and from HCM tools (Transportation Research Board, 2010). However, those recommendations do not state the magnitude of the discrepancy between the two methodologies. Understanding that government agencies and consultants use microsimulation and HCM tools extensively, it would be beneficial to reveal the discrepancies between these tools. Figure 10 show LOS comparisons between Vissim density output (in veh/mi/ln) and FREEVAL (in pc/mi/ln). One can observe that LOS calculated based on HCM versus Vissim analysis differ by one grade at most, and this is the case in 30 out of 64 time intervals for the four freeway segments. The general conclusion is that this result is heavily influenced by the large discrepancy in the case of on-ramp segment, where these two tools consistently report different LOS values.

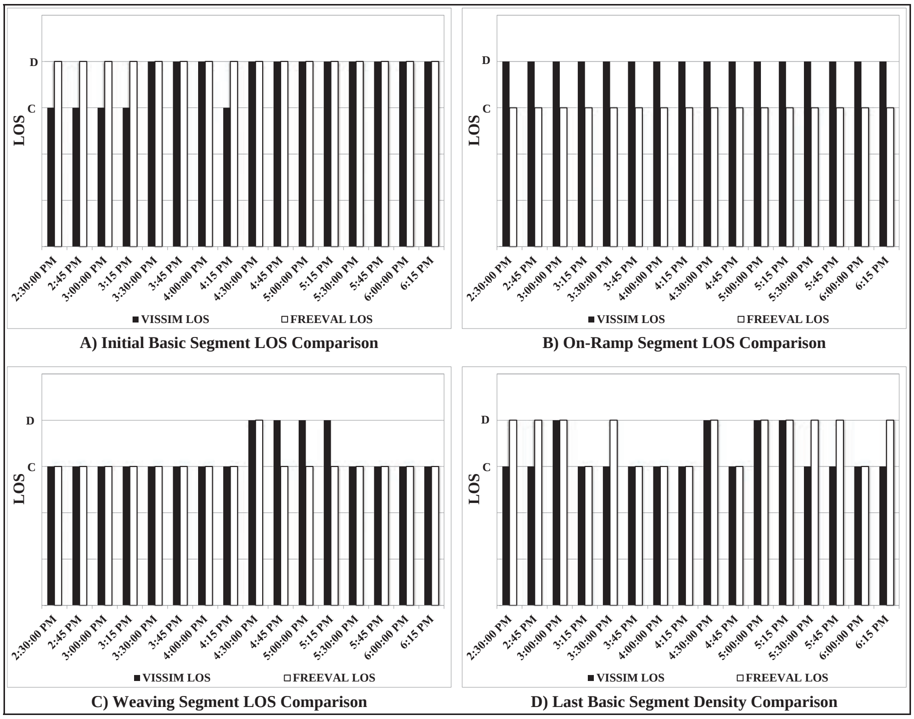


Figure 10 LOS Comparison

5 Conclusions and Limitations

Several conclusions can be reached in the analysis of FREEVAL and Vissim segment-based densities and LOS comparisons for undersaturated freeway segments:

1. FREEVAL requires careful calibration of vehicular speeds. Just inputting the required vehicle demand values, does not mean that the FREEVAL will replicate field conditions
2. Updated version of FREEVAL (coded in Java) improved significantly comparing to the previous one coded in MS Excel. Additional options allow quicker calibration, more user friendly interface, and faster execution of scenarios
3. Due to the macroscopic nature of FREEVAL, flexibility of capacity adjustment factor (CAF) to match the field speeds can be insufficient
4. Vissim will generally match the FREEVAL density output expressed in veh/mi/ln. Additional adjustments are necessary in order to ‘translate’ Vissim output to HCM measurements. More research is necessary to develop sets of equations to account for heavy vehicles impact and make microsimulation density output comparable to HCM
5. Vissim reported density is lower than PCE in most of the cases. PCE factor should not be underestimated
6. LOS tends to differ by up to one grade value. The authors expect these discrepancies to be higher as congestion forms. Thus, special attention has to be placed when trying to compare HCM methodology and microsimulation for congested conditions

7. The higher the congestion is, the more time and effort it is required to calibrate FREEVAL
8. Vissim is microscopic in nature, while FREEVAL is a macroscopic tool. The practitioners have to be aware that the outputs can vary due to different granularity levels of these tools

Both tools can replicate the field conditions well. For undersaturated conditions, they will produce similar segment-based density outputs and LOS values. Still, the output will have some differences and additional research is necessary to come up with the methodology on how to 'translate' microsimulation output to be compatible with HCM measures.
This study deals with limited number of segments, and for undersaturated conditions only. Better granularity of the data (e.g., availability of vehicle headways, traffic video recordings, and exact weaving maneuvers) can contribute to the validity of this study. Future research should include testing additional freeway segments, various heavy vehicle percentages in the traffic flow, and the methodology for translating and comparing Vissim density outputs to the HCM values. Oversaturated conditions should be considered as well, because FREEVAL utilizes different methodology in that case.

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