# Final Report

## to the

## CENTER FOR MULTIMODAL SOLUTIONS FOR CONGESTION MITIGATION (CMS)

CMS Project Number:  2008-002

CMS Project Title:

Development of a Simulation Program for Two-Lane Highway Analysis

for period 8/1/2008 to 7/31/2010

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Date prepared: August 2010

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# CHAPTER 1      INTRODUCTION

While considerable emphasis is being placed on congestion mitigation for arterial and freeway facilities, there is still a need to address congestion for other facilities as well. While urban areas and the corresponding traffic demand continue to grow, rural areas are experiencing significant growth as well. This growth is now resulting in congestion on facilities that previously did not have any. One area that is becoming a concern, particularly in Florida, is rural areas transitioning into more developed areas. Access to these areas is usually by two-lane highways, but within these areas, there may be an occasional traffic signal and possibly segments of multilane highway as well.

In order to manage the growth and resulting traffic demands in these areas, it is essential that transportation planners and engineers have tools by which they can analyze these situations. Currently, however, no analysis tool exists for analyzing two-lane highway facilities with occasional intersections. The signal spacing and other general characteristics of these roadways do not fit with the analysis criteria for signalized arterials in the Highway Capacity Manual (HCM), and the two-lane highway analysis procedure does not account for interruptions to the flow, such as from signals.

To pursue further investigation of the traffic operation within these areas and to develop a facility-level analysis methodology, a simulation tool is required. However, the existing simulation tools cannot fully meet the research demands. The current state-of-the-art tool in two-lane highway simulation is a software program named TWOPAS. This program performs a microscopic and stochastic simulation, and provides the ability to include considerable detail about two-lane segments in the modeling process. However, TWOPAS does not provide the ability to include signalized intersections within the modeled two-lane highway facility. There are several simulation programs capable of simulating two-lane roads with signalized intersections (e.g., CORSIM). However, these programs cannot simulate the most distinctive and significant traffic operation feature of two-lane highways; that is, passing by utilizing the lane in the opposing direction.

The objective of this project was to develop a simulation tool that is capable of modeling the combination of two-lane highway segments and signalized intersections. The development approach used was to incorporate this modeling capability into CORSIM by making the necessary additions and modifications to the existing CORSIM software code base. The resulting two-lane highway modeling capabilities incorporated into CORSIM provides functionality to address the application demands of both the academic and practicing communities.

# CHAPTER 2    REVIEW OF EXISITING TWO-LANE HIGHWAY ANALYSIS METHODOLOGIES AND TOOLS

## HCM 2000

Chapter 20 of the Highway Capacity Manual (HCM) [TRB, 2000] provides an operations-analysis methodology (for either both directions of traffic flow combined or a single direction of traffic flow) for two-lane highway segments. The two-way and directional segment analysis procedures can both be applied to segments with the general terrain classification of level or rolling. For segments in mountainous terrain or with grades of 3 percent or more with a length of 0.6 miles or more, and/or segments with a passing lane, must be analyzed with the directional methodology. The performance measures of Average Travel Speed (ATS) and/or Percent Time-Spent-Following (PTSF) are used to determine the level of service (LOS) for a two-lane highway. The LOS criteria for two-lane highways are presented in Table 2-1. Note that LOS F applies whenever the demand flow rate exceeds the segment capacity.

**Table 2-1    HCM LOS Criteria for Two-Lane Highways**

| LOS | Class I | | Class II |
| --- | --- | --- | --- |
| | Percent Time-Spent-Following | Average Travel Speed (mi/h) | Percent Time-Spent-Following |
| A | $\leq 35$ | > 55 | $\leq 40$ |
| B | > 35-50 | > 50-55 | > 40-55 |
| C | > 50-65 | > 45-50 | > 55-70 |
| D | > 65-80 | > 40-45 | > 70-85 |
| E | > 80 | $\leq 40$ | > 85 |

The calculations for ATS and PTSF for directional two-lane segments without a passing lane are given by Eqs. 1-3.

$$ATS_d = FFS_d - 0.00776\ (v_d + v_o) - f_{np} \tag{1}$$

$$BPTSF_d = 100 \left(1 - e^{a v_d^b}\right) \tag{2}$$

$$PTSF_d = BPTSF_d + f_{np} \tag{3}$$

*where*

   $ATS_d$: average travel speed in the analysis direction (mi/h),

   $FFS_d$: free-flow speed in the analysis direction (mi/h),

   $v_d$: passenger-car equivalent flow rate for the peak 15-minute period in the analysis direction (pc/h),

$v_o$: passenger-car equivalent flow rate for the peak 15-minute period in the opposing direction (pc/h),

$f_{np}$: adjustment for percentage of no-passing zones in the analysis direction,

$BPTSF_d$: base percent time-spent-following in the direction analyzed, and

$PTSF_d$: percent time-spent-following in the direction analyzed.

The reader is referred to Chapter 20 of the HCM 2000, specifically Exhibits 20-19 and 20-20, for the $f_{np}$ adjustment factor values.

For segments that contain passing lanes, the ATS and PTSF values calculated with Eqs. 1 and 3 are adjusted by applying Eqs. 4 and 5.

$$ATS_{pl} = \frac{ATS_d \times L_t}{L_u + L_d + \dfrac{L_{pl}}{f_{pl}} + \dfrac{2\,L_{de}}{1 + f_{pl}}} \tag{4}$$

$$PTSF_{pl} = \frac{PTSF_d \left[ L_u + L_d + f_{pl} L_{pl} + \left( \dfrac{1 + f_{pl}}{2} \right) L_{de} \right]}{L_t} \tag{5}$$

*where*

$ATS_{pl}$: average travel speed for the entire segment including the passing lane (mi/h),

$PTSF_{pl}$: percent time-spent-following for the entire segment including the passing lane,

$L_t$: total length of analysis segment (mi),

$L_u$: length of two-lane highway upstream of the passing lane (mi),

$L_d$: length of two-lane highway downstream of the passing lane and beyond its effective length (mi),

$L_{pl}$: length of the passing lane including tapers (mi),

$L_{de}$: length of the passing lane, and

$f_{pl}$: factor for the effect of a passing lane on average travel speed.

Again, the reader is referred to Chapter 20 of the HCM 2000 for the adjustment factor values of Eqs. 4 and 5.

It should be noted that analysis methodologies of Chapter 20 do not accommodate two-lane highways with occasional signalized intersections (i.e., signal spacing such that the facility would not be classified as an arterial).

## TWOPAS

TWOPAS (TWO-lane PASsing) rural-highway simulation software is used for modeling traffic conditions on two-lane, two-way roadways. This software was used extensively in developing the two-lane analysis methodology in the HCM 2000 and other previous studies. While the original implementation of TWOPAS runs only in the DOS operating system environment and is essentially unsupported, the TWOPAS simulation model has been built in to the Traffic Analysis Module (TAM) of the Interactive Highway Safety Design Model (IHSDM) [ITT Corporation, 2007].

As a microscopic, stochastically based model, TWOPAS simulates traffic operations on a two-lane highway by reviewing the position, speed, and acceleration of each individual vehicle along the roadway at 1-second intervals and advancing those vehicles along the given study section in a realistic manner. The model takes into account driver preferences, vehicle size and performance characteristics, and the oncoming and same-direction vehicles that are in sight at any given time. The model incorporates realistic passing and pass-abort decisions by drivers in two-lane highway passing zones. The model can also simulate traffic operations in passing and climbing lanes added in one or both directions on two-lane highways including the lane addition and lane drops. However, the model does not currently simulate traffic turning on or off the highway at intersections and driveways although work is underway to incorporate this capability [ITT Corporation, 2007].

As for outputs, TWOPAS presents flow rates from the simulation, percent time-spent-following, average travel speed, trip time, traffic delay, geometric delay, total delay, number of passes, vehicle-kilometers traveled and total travel time. The IHSDM documentation states "2000 vph is the documented limitation in TWOPAS, but experience indicates that flow rates over 1700 vph usually create congestion that stalls the program." [ITT Corporation, 2007] However, field evidence that 1700 veh/h/ln generally corresponds to capacity conditions for a two-lane highway is essentially nonexistent.

## TRARR

TRARR (TRAffic on Rural Roads) was developed in the 1970s and 1980s by the Australian Road Research Board. TRARR is designed for two-lane rural highways, with occasional passing-lane sections. It is a microscopic simulation model, which models each vehicle individually. Each vehicle is randomly generated, placed at one end of the road and monitored as it travels to the other end. Different driver behavior and vehicle performance factors determine how the vehicle simulated reacts to changes in alignment and traffic. TRARR uses traffic flow, vehicle performance and geometric alignment to establish the speeds of vehicles along the given study segment. This determines the driver demand for passing and whether passing maneuvers may be executed. TRARR can be used to obtain a more precise calculation of travel time, frustration (via time spent following), and benefits resulting from passing lanes or road realignments. For strategic assessment of road links, TRARR can also be used to evaluate the relative benefits of passing lanes at various spacing.

Similar to TWOPAS, TRARR has no ability to handle varying traffic flows down the highway, particularly due to major side roads or signalized intersections. However, TWOPAS

was developed with U.S. data, and thus is considered to be generally more applicable for modeling conditions in the U.S. than TRARR.

**Yu and Washburn**

Yu and Washburn [2009] developed a facility-based evaluation methodology for two-lane highways. This methodology allows the various features (e.g., isolated intersections, passing lanes) that are typical to an extended length of two-lane highway to be analyzed as a single facility. The main idea of this methodology is to divide the facility into appropriate segments, and properly account for the operational effects of traffic flow transitioning from one segment to another. A two-lane highway with an isolated signalized intersection was used as a model in Yu and Washburn's study. For a two-lane highway facility with signalized intersections, the entire length of the facility is divided into three types of segments, which are the basic two-lane highway, the signal influence area, and the affected downstream segment. Percent delay (*PD*) was selected as the common service measure for the interrupted-flow facility of a two-lane highway with signalized intersections. Percent delay is defined as the ratio of delay to free-flow travel time, expressed as a percentage. Delay is defined as the average travel time incurred by motorists traveling on the facility in excess of the free-flow travel time. *PD* is calculated by

$$PD = \frac{\sum_{H,S} (D_H + D_S)}{\sum_{H,S} \left( \frac{L_H}{FFS_H} + \frac{L_S}{FFS_S} \right)} \times 100 \qquad (6)$$

*where*

        *PD* = average percent delay per vehicle for the entire facility (%),
        $D_H$ = average delay time per vehicle for the two-lane highway segment (s/veh),
        $D_S$ = average delay time per vehicle for the signalized intersection influence area (s/veh),
        $FFS_H$ = free flow speed for the two-lane highway segment (ft/s),
        $FFS_S$ = free flow speed for the signalized intersection influence area (ft/s),
        $L_H$ = length of the two-lane highway segment (ft), and
        $L_S$ = length of the signalized intersection influence area (ft).

Percent delay is a measure that represents a traveler's freedom to maneuver in the traffic stream (i.e., ability to maintain their desired speed). It also reflects the effects of speed reductions due to traffic control (e.g., signalized intersections), restrictive geometric features (e.g., no-passing zones), and other traffic (e.g., opposing traffic flow, heavy vehicles). The LOS criteria for two-lane highway facilities, based on percent delay, are shown in Table 2-2.

**Table 2-2      LOS Criteria for Two-lane Highway Analysis**

| Level of service | Percent Delay (%) |
|:---:|:---:|
| A | ≤ 7.5% |
| B | > 7.5% - 15 |
| C | > 15% - 25 |
| D | > 25% - 35 |
| E | > 35% - 45 |
| F | > 45 |

An outline of the methodology is as follows:

Step 1: Divide the facility into segments;
Step 2: Determine the free-flow speed;
Step 3: Determine segment length;
Step 4: Calculate the unaffected average travel speed on basic two-lane highway segments;
Step 5: Calculate control delay at the signalized or unsignalized intersection influence area;
Step 6: Determine average travel speed on the affected downstream segment;
Step 7: Determine the delay time on every segment; and
Step 8: Determine the percent delay and LOS of the entire facility.

A simulation-based approach was used to develop the computational methodology, due to the difficulties of measuring the field data needed. However, because there was no simulation tool that could simulate the combination of two-lane highway segments and signalized intersections, when this study was conducted, a hybrid simulation approach was applied, as summarized below:

(1) The CORSIM simulation program was used to model vehicular operations on a two-lane roadway in the vicinity of a traffic signal and to determine the effective length of the upstream influence area of the signalized intersection.

(2) The TWOPAS simulation program was used to determine the length of the downstream segment affected by an upstream signalized intersection, incorporating work done previously by Dixon et al. [2006].

**Kim**

Finding two-lane highway sites that operate at or near capacity has been difficult; thus, determining capacity for a two-lane highway from field data alone is a difficult proposition. Kim [2006], therefore, developed a new microscopic simulator with MATLAB 6.5, called TWOSIM, to estimate the capacity for two-lane, two-way highways under a variety of prevailing geometric and traffic conditions. Field data, such as vehicle counts, speed, vehicle length, headways,

directional distribution, lane and shoulder width and terrain type were collected for the calibration of input parameters in the newly developed simulation model.

TWOSIM was developed in three stages. TWOSIM I was developed with a straight tangent level segment, no opposing traffic, no additional traffic entering or exiting within a given segment, and no passing maneuvers. TWOSIM II includes an additional algorithm for overtaking behavior. TWOSIM III includes more advanced options that consider the presence of a driveway, horizontal curves, grades along a given segment, and truck traffic. The logic for the primary operations on two-lane highways (i.e., car-following, passing) are supported by Gipp's car-following model, AASHTO criteria of minimum passing sight distance, and McLean's modified-time hypothesis as to the stimulus perceived by drivers in making stream-crossing gap-acceptance decisions).

The results of Kim's experiments indicate that, 1) the capacity of two-lane, two-way highways is found to be a function of average free-flow speed; 2) the presence of a passing zone does not affect capacity; 3) the directional capacity is independent of the opposing flow rate; and 4) capacity varies due to the changes of presence of trucks and driveways, horizontal curvature, and grade. Therefore, he suggested that, 1) the HCM present varying capacities as a function of the geometric and traffic conditions, following the guidelines on capacity reduction due to each geometric or traffic condition factor; 2) the capacity of two-lane, two-way highways be expressed only in directional terms, because it is extremely rare in reality that both directions could reach capacity conditions at the same time; 3) the car-following model be improved with the development of a model reflecting the behavior of a passenger car driver around large trucks.

# CHAPTER 3     DEVELOPMENT APPROACH

## 3.1     INTRODUCTION

The objective of the development approach was to incorporate the ability to model two-lane highways into CORSIM. This was accomplished through the following tasks.

- Develop traffic flow modeling routines for two-lane highway operations
- Develop a mechanism for integrating signalized intersections into a two-lane highway facility
- Modify the input and output mechanisms of CORSIM as necessary for the two-lane highway-modeling capability

Each of these tasks is described in detail in the following sections[1].

## 3.2     DEVELOP TRAFFIC FLOW MODELING ROUTINES FOR TWO-LANE HIGHWAY OPERATIONS

The logic of the various components involved in modeling the two-lane highway passing maneuvers (either oncoming lane or passing lane) are described in the following subsections.

### 3.2.1     Car following

The car-following model currently employed in CORSIM is the Pitt car following model [Halati et al., 1997]. This car-following model was also retained for use in the two-lane highway modeling. This model incorporates the distance headway and speed differential between the lead and follower vehicle as two independent variables, and the basic assumption is that the follower vehicle will try to maintain a safe space headway.

### 3.2.2     Passing in an oncoming lane

The most distinguishing feature of traffic operations on two-lane highways is passing in the oncoming lane (when passing lanes are not present). Therefore, this passing maneuver is constrained by not only the amount of opposing-lane distance used in the execution of a passing maneuver, but also the sight distance and clear-distance (or gap size) a follower requires before attempting a passing maneuver. The former issue depends on road design and markings of no-passing zone, while the latter issue depends on traffic demands. The following subsections describe the various components of logic employed to determine when and how a vehicle will perform a passing maneuver in the oncoming lane.

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[1] This chapter generally describes the logic and models employed in CORSIM to facilitate two-lane highway modeling in a qualitative manner. There is another version of this chapter that also describes the logic and models in quantitative detail. However, because of intellectual property issues, research requests for this version of the chapter must be submitted to McTrans. If approved, a signed non-disclosure agreement will be required.

*3.2.2.1 When will a vehicle attempt to pass a vehicle in front of it?*

1. Determine if the subject vehicle is in a following mode

Currently, the program defines a vehicle as being in a following mode when the time headway between it and the vehicle immediately in front of it is equal to or less than 3 seconds — this is currently the logic the HCM uses to approximate PTSF[2]. The value of 3 seconds, however, can be changed by the analyst in the input file (see Follower Headway Threshold input in Table 3-4). Additionally, the trailing vehicle must be traveling at a speed at least equal to the speed of the leading vehicle. If the subject vehicle is determined to be in a following mode, then the following steps are carried out to determine if the following vehicle will attempt a passing maneuver.

2. Determine tolerable speed

If it is determined that a vehicle is in a following mode, then the *tolerable speed* for that vehicle is calculated. *Tolerable speed* is defined as the maximum speed at which the desire to pass for a following driver will be 100 percent. A driver's *tolerable speed* will vary between 80 percent and 90 percent of its desired speed, with the lower percentages corresponding to the more conservative driver types. Note that a driver's desired speed is a function of free-flow speed and driver type. For example, a driver of Type 1 will have a desired speed of 88 percent of the link free-flow speed, while a driver of Type 10 will have a desired speed of 112 percent of the link free-flow speed (these percentages of free-flow speed can be modified by users on RT 147 of the TRF input file).

3. Determine the desire to pass

The main factor influencing a driver's desire to pass (*DTP*) is the difference between his actual travel speed and his desired speed. If a driver's current speed is equal to his desired speed, the driver will have no desire to pass. If a driver's current speed is less than his tolerable speed, the driver will have a 100 percent desire to pass. If the driver's current speed is between his tolerable speed and desired speed, the desire to pass is based on a non-linear (exponential) interpolation. The DTP is also adjusted based on the length of the trailing vehicle and the length of the leading vehicle. A longer leading vehicle, such as a large truck, will increase the DTP value for the trailing vehicle. Conversely, the DTP value will be decreased for a longer trailing vehicle. Trailing and leading vehicles of the same length will result in the same value of DTP previously calculated.

Finally, the *DTP* value is adjusted by an impatience factor. For vehicles that have a positive *DTP*, but are in a following mode and have not yet initiated a passing maneuver, the impatience factor will incrementally increase the *DTP* value with each simulation time step; thus increasing the probability of a passing maneuver being initiated. The default increment value is 0.001, but can be changed on Record Type 155. The impatience factor is also a function of the driver type, with the increment being increased for more aggressive drivers. The time spent

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[2] It is anticipated that alternative approaches to the determination of whether a vehicle is in a following mode will eventually be considered for incorporation into the program, such as the probabilistic approach by Hideki, et al. [2008].

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wanting to pass (*TSWTP*) counter will initiate when a vehicle has a *DTP* value greater than zero and will reset when the vehicle completes a pass or its *DTP* value goes to zero.

The adjusted *DTP* value is then compared to a generated uniform random number to determine if the subject vehicle will continue to follow the leading vehicle or if the subject vehicle will initiate a passing maneuver, subject to other constraints as described in the following section.

*3.2.2.2 Constraints governing whether a pass will be initiated*

If it has been determined that a vehicle wants to initiate a passing maneuver, the following issues are considered.

1. Is the vehicle in a passing-allowed section?

The program logic currently dictates that all passing maneuvers must be initiated in a passing-allowed section of the roadway (i.e., skip striping in the applicable direction)[3]. However, it is possible for a passing maneuver to be completed in a no-passing-allowed section, consistent with the field observations from Harwood et al. [2008] study. This is described in more detail under step 7.

2. Check whether a vehicle upstream of the subject vehicle is performing a passing maneuver

If the subject vehicle is currently in the process of being passed by another vehicle, the subject vehicle will not initiate its passing maneuver.

3. Check whether the maximum number of allowed passing maneuvers is currently in progress

The number of vehicles that can be simultaneously executing a passing maneuver in the oncoming lane is limited to three per each platoon of vehicles. Thus, the maximum number of vehicles that can be executing a passing maneuver along the defined length of highway is three times the number of platoons within that defined length of highway. A platoon is defined by a leading vehicle that is not in a following mode and trailing vehicles that are all considered to be in a following mode.

4. Check the number of vehicles that must be passed to complete the passing maneuver

A vehicle is prevented from starting a passing maneuver when, due to insufficient gaps for merging between the vehicles ahead, there are more than five vehicles that would need to be passed.

5. Determine the required passing sight distance

If the subject vehicle is allowed to initiate a passing maneuver per the above constraints, then the passing sight distance (*PSD*) will be calculated. *PSD* is the minimum distance necessary between the potential passing vehicle and an oncoming vehicle that will still allow the potential passing vehicle to safely initiate and complete a passing maneuver of a leading slower vehicle in the oncoming lane. If the horizontal and/or vertical alignment aspects of a highway do not

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[3] For computational efficiency reasons, this check is actually performed before the desire to pass calculations.

provide unobstructed sight distance at least equal in length to the *PSD*, then the highway is typically striped with solid yellow center lines (i.e., no-passing allowed)[4].

The default *PSD* model used in CORSIM is the model provided in *A policy on Geometric Design of Highways and Streets* [AASHTO, 2004]. However, it is also possible to use the *PSD* values provided in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) [FHWA, 2003]. The AASHTO *PSD* model is presented first, followed by the modifications necessary to implement the MUTCD *PSD* values.

The current AASHTO *PSD* model is described in Table 3-1 and Figure 3-1.

**Table 3-1      Components and values of passing sight distance (AASHTO)**

| Component of passing maneuver | Speed range (mi/h) | | | |
|---|---|---|---|---|
| | 30-40 | 40-50 | 50-60 | 60-70 |
| | Average passing speed (mi/h) | | | |
| | 34.9 | 43.8 | 52.6 | 62.0 |
| Initial maneuver: | | | | |
| $a$ | 1.40 | 1.43 | 1.47 | 1.50 |
| $t_1$ | 3.6 | 4.0 | 4.3 | 4.5 |
| $d_1$ | $1.467\ t_1\left(v - m + \dfrac{at_1}{2}\right)$ (16) | | | |
| Occupation of left lane: | | | | |
| $t_2$[5] | 9.9 | | | |
| $d_2$ | $1.467 \times v \times t_2$ (17) | | | |
| Clearance distance: | | | | |
| $d3$ | 100 | 180 | 250 | 300 |
| Opposing vehicle: | | | | |
| $d4$ | $0.667 \times d_2$ (18) | | | |
| Minimum *PSD* | $d_1 + d_2 + d_3 + d_4$ (19) | | | |

*where*

$d_1$ = initial maneuver — distance traveled from start of passing maneuver until passing vehicle encroaches upon oncoming lane,
$t_1$ = time required for initial maneuver (sec),
$a$ = acceleration of passing vehicle when initiating passing maneuver (mi/h/s),
$v$ = average speed of passing vehicle (mi/h),
$m$ = difference in speed of passed vehicle and passing vehicle (mi/h),

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[4] CORSIM does not compute available passing sight distance based on the specified roadway geometry; thus, it is necessary for the user to explicitly identify the allowable passing zones along the length of the highway.

[5] The original AASHTO criteria included four separate values for $t_2$, based on the passing vehicle speed. The Harwood et al. [2008] study did not "…provide any evidence to support the hypothesis that the left lane travel time increases with increasing passed vehicle speed. Therefore, it is recommended that a constant value of $t_2$, independent of speed, should be used…". The chosen value was the mean value of 9.9 seconds from their study.

$d_2$ = the distance traveled by the passing vehicle from the point of encroachment in the oncoming lane to the point of return to the normal lane,

$t_2$ = time spent traveling in the oncoming lane,

$d_3$ = the shortest desirable distance between the front bumpers of the passing and opposing vehicle when the passing vehicle returns to the normal lane (ft), and

$d_4$ = the distance traveled by the opposing vehicle during the time the passing vehicle travels from the position of being directly abreast of the vehicle being passed to the return to the normal lane (ft).

The *PSD* distance components are illustrated in Figure 3-1.
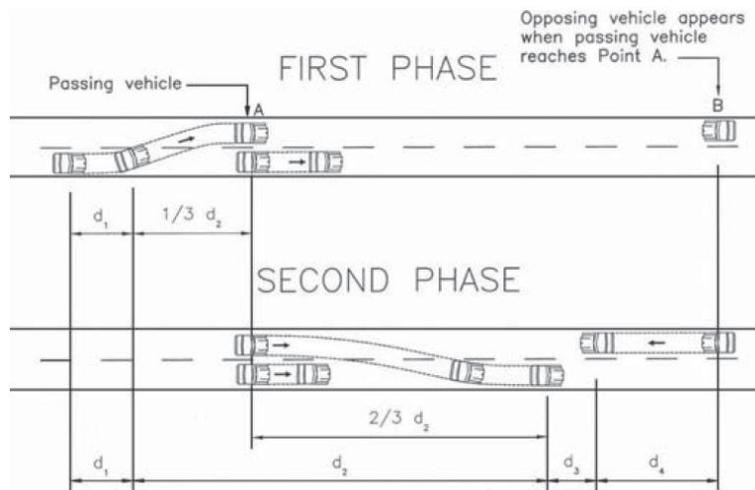


**Figure 3-1      Elements of Passing Sight Distance for Two-Lane Highways (AASHTO)**

For computational convenience, the same formulas used in the AASHTO *PSD* model are used for generating the MUTCD *PSD* values. To implement the MUTCD *PSD* values in CORSIM, the values shown in Table 3-1 should be revised as shown in Table 3-2. These values can be changed on Record Type 156 of the TRF input file.

**Table 3-2      Revised Values of the AASHTO *PSD* Model Variables for Approximating the MUTCD *PSD* Values**

| Component of passing maneuver | Speed range (mi/h) | | | |
|---|---|---|---|---|
| | 30-40 | 40-50 | 50-60 | 60-70 |
| | Average passing speed (mi/h) | | | |
| | 34.9 | 43.8 | 52.6 | 62.0 |
| Initial maneuver: | | | | |
| $t_1$ | 3.0 | 2.5 | 2.0 | 1.6 |
| Occupation of left lane: | | | | |
| $t_2$ | 5.9 | 6.0 | 6.2 | 6.4 |
| Clearance distance: | | | | |
| $d_3$ | 80 | 100 | 120 | 140 |

Table 3-3 shows the *PSD* values computed with the revised variable values as well as the actual MUTCD-recommended *PSD* values. The approximated MUTCD *PSD* values compare very favorably with the actual *PSD* values.

**Table 3-3    Comparison of the Approximation and the Original MUTCD PSD Values**

|  | Design speed (mi/h) | | | | | | |
|---|---|---|---|---|---|---|---|
|  | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| Modified AASHTO *PSD* | 605 | 708 | 801 | 909 | 1000 | 1111 | 1202 |
| MUTCD *PSD* | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 |

6. Check length of passing zone and compare to the minimum passing zone length

The length of the passing zone (as indicated by roadway markings) is compared to the minimum passing zone length (which is equal to $d_1 + d_2$, (See Fig 3-1)). A vehicle will not initiate a passing maneuver unless the available passing zone length is equal to or greater than the minimum passing zone length. If the marked passing zone length is greater than the minimum passing zone length, then the following check is made.

7. Determine effective passing zone length and compare to the distance needed to complete the pass

As mentioned earlier, it is possible for a vehicle to complete its passing maneuver in a section of roadway marked as no-passing-allowed. The length of the available passing zone (from the current position of the passing vehicle) is initially determined from just the roadway markings. This value is then adjusted based on the permissible amount of distance beyond the marked passing zone allowed for the passing vehicle's driver type. The permissible amount of distance beyond the marked passing zone is equal to the MinPct (see Table 3-4, RT 155) for driver Type 1 and the MaxPct for driver Type 10. For other driver types, the value is linearly interpolated between MinPct and MaxPct.

The distance needed to complete the pass (*DNTCP*), which before the passing maneuver is initiated is equal to the *PSD*, is compared to the distance available for the pass (i.e., effective passing zone length). If the *DNTCP* is less than the *PSD*, then the passing maneuver can be initiated.

*3.2.2.3 How does a potential passer execute its passing maneuver?*

If all the requirements discussed in the previous section are satisfied for a potential passing vehicle, it will initiate the passing maneuver. The general logic of executing a passing maneuver is divided into three stages, described as follows.

Stage 1: Initiate passing in the normal lane

At the beginning of a passing maneuver, the potential passer starts to accelerate at the acceleration rate based on its own speed according to Table 3-1. At the same time, the potential passer moves over to the opposing lane.

Stage2: Passing in the opposing lane

After the potential passer moves into the opposing lane, it will keep on accelerating until it reaches a speed 12 mi/h (this value can be changed on RT 155) greater than the speed of the vehicle being passed[6]. Meanwhile, the variable *DNTCP* (distance needed to complete pass) is compared to the variable *DTC*[7] (distance to collision with the oncoming vehicle) every time step.

As mentioned previously, before the passing maneuver is initiated, the *DNTCP* is equal to the *PSD*. However, once the passing maneuver is in progress, the *DNTCP* is continually changing (generally decreasing).

The *DNTCP* and *DTC* values are calculated via standard kinematic equations. At every time step of the simulation, the value of *DNTCP* is compared to the value of *DTC*. The result of this comparison leads to the following different situations that must be considered.

(1) *DNTCP < DTC*

If the *DNTCP* is less than the *DTC*, the passer will continue its passing maneuver as planned. Another issue related to the completion of passing is the gap size in front of the vehicle being passed, which is included in the calculation of *DNTCP*. The passer requires a certain gap size to be able to return to the normal lane in order to complete passing. The default value for this gap size is 75 ft, but can be revised on Record Type 155. The passing vehicle only accepts the gap in front of the vehicle being passed if it is greater than or equal to the minimum gap.

(2) *DNTCP ≥ DTC*

If the *DNTCP* is greater than or equal to the *DTC*, the decision on whether the passing vehicle will continue or abort its passing maneuver is dependent on the relative position of the passing vehicle to the passed vehicle. If the passing vehicle has reached the *critical position*, the passing vehicle will continue its passing maneuver. If the passing vehicle has not reached the critical position, it will abort the passing maneuver. In CORSIM, the critical position is considered to be the point when the passing vehicle and vehicle being passed are directly abreast of one another.

a. The passer has not reached the critical position:

If the passing vehicle has not yet reached the critical position when *DNTCP* is greater than *DTC*, it will abort the passing maneuver. The process of returning to the normal lane is similar to that of completing a passing maneuver. The gap behind the vehicle being passed will be checked for the return. The minimum gap here is also set as three times the length of the

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[6] Based on NCHRP Report 605 [Harwood et al, 2008].
[7] The *DTC* will be infinite when no oncoming vehicle is present.

passing vehicle, and the passing vehicle will only accept a gap greater than or equal to the minimum gap.

b. The passer has reached the critical position:

If the passer has reached the critical position when *DNTCP* is greater than *DTC*, the passer will continue with completing the passing maneuver. In order to accommodate this without collision, the passing vehicle will speed up and/or the oncoming vehicle will decelerate. The specific amount of acceleration by the passing vehicle and/or deceleration by the oncoming vehicle is a function of the current acceleration rate of each vehicle, the passing vehicle's acceleration capabilities, the oncoming vehicle's deceleration capabilities and the current DTC value.

Stage3: Return to the normal lane:

For a passing maneuver being completed, the passer will return to the normal lane in front of the vehicle being passed when the gap is sufficient. For an aborted passing maneuver, the passer will return to the normal lane behind the vehicle being passed if there is a sufficient gap. The existing mandatory lane-changing logic in CORSIM is utilized for this situation.

Under certain conditions, the passing vehicle will consider passing more than one vehicle. Specifically, if the passing vehicle's speed is greater than the speed of the vehicle in front of the current vehicle being passed, and the gap in front of the current vehicle being passed is insufficient, the passing vehicle will attempt to pass the vehicle in front of the current vehicle being passed, subject to the logic and constraints as previously discussed.

### 3.2.3 Passing in a Passing-Lane Section

A passing lane is defined as a lane added to improve passing opportunities in one direction of travel on a conventional two-lane highway. Although it may vary by jurisdiction, the logic implemented in this simulation program assumes that slower vehicles will move to the right lane in a passing lane section and the passing vehicles will pass on the left (usually this is indicated by a sign such as "Keep Right Unless Passing"). Ideally, each driver will drive following the guidance. However, it is recognized that this does not always happen; thus, the developed logic allows for the possibility of an impeding vehicle not moving over.

For each vehicle in a passing-lane section (hereafter referred to as the subject vehicle), the logic first checks the headway between this subject vehicle and the vehicle immediately behind, and then checks the headway between this subject vehicle and the vehicle immediately ahead. If the subject vehicle has a vehicle behind it in following mode (i.e., headway ≤ follower headway threshold) and is not in following mode itself, the willingness to move over (*WTMO*) to the right lane of the passing lane section for the subject vehicle will be considered. The value of *WTMO* is a function of subject vehicle's speed and the free-flow speed, with slower vehicles being more likely to move over.

This parameter is further adjusted by the driver type if the length of the subject vehicle is less than 40 feet (the length of a single-unit truck); otherwise, it remains as the original value (resulting in a higher probability to move over for trucks). The adjusted willingness to move over is compared to a generated uniform random number to determine if the subject vehicle will move over to the right lane or stay in the left lane.

The existing CORSIM logic is utilized for determining when a vehicle will move from the right lane (which drops at the end of the passing lane section) back to the normal lane. Generally, the discretionary lane change logic will apply for vehicles in the right lane (either slow vehicles that moved out of the way, or faster vehicles that are trying pass slower vehicles that did not move over) until such a vehicle gets near to the end of the right lane, in which case the mandatory lane change logic will be applied.

## 3.3    INTEGRATING SIGNALIZED INTERSECTIONS INTO A TWO-LANE HIGHWAY FACILITY

CORSIM consists of two microscopic stochastic simulation models: 1) NETSIM, which models traffic on urban streets, including intersections, and 2) FRESIM, which models traffic on freeways. The previous two-lane highway modeling features were built into the FRESIM model.

Since the capability to connect FRESIM links to NETSIM links already existed, it was not necessary to make any special modifications to the underlying CORSIM models to accommodate the modeling of signalized intersections within a two-lane highway. Thus, the rest of this section simply provides guidelines for defining two-lane highway networks that contain signalized intersections, particularly the interface (i.e., connection) between the two-lane highway links and the signalized intersection links.

The signalized intersection and two-lane highway features should be defined as usual in the TRF file. Then, according to the CORSIM node numbering scheme[8], two nodes numbered between 7000 and 7999 should be added along the two-lane highway direction as the exit nodes for the NETSIM links, and also the entry nodes for the FRESIM links. The length of the link between a "7" node and a NETSIM node should be no less than 100 feet (see an example in Figure 3-2), since some vehicles with high speeds could possibly "jump over" a short link in a single time step. It is recommended that no-passing zone markings extend at least 200 feet upstream and downstream of the intersection [DelDOT, 2009]. Passing in the opposing lane is not allowed on NETSIM links; thus, if the NETSIM links are less than 200 feet in length, no-passing zone markings should be specified for the adjoining FRESIM links.
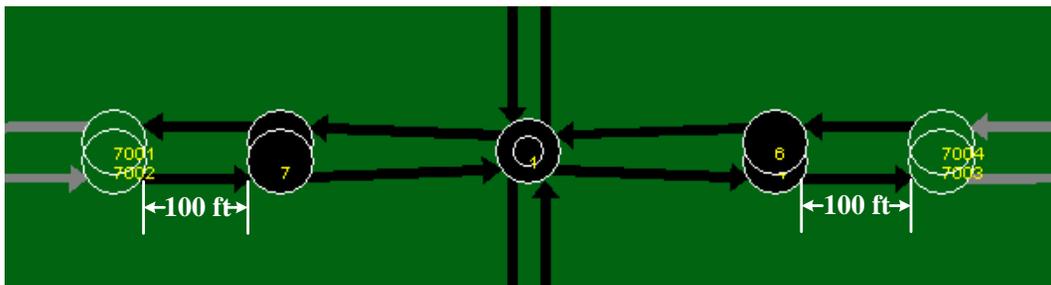


**Figure 3-2    Example of the Interface between FRESIM Links and the NETSIM Links**

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[8] Node numbers 1 through 6999 can be used for internal nodes. Node numbers 7000 through 7999 can be used for interface nodes and node numbers 8000 through 8999 can be used for entry or exit nodes.

## 3.4  INPUTS AND OUTPUTS OF THE SIMULATION PROGRAM

Several new inputs were added to CORSIM to accommodate user revision of various parameters for the two-lane highway modeling logic. Several new outputs were added to CORSIM to accommodate a variety of new performance measures and passing lane diagnostics. Table 3-4 provides information on the new inputs. Table 3-5 provides information on the new outputs.

**Table 3-4      New TRF File Inputs for Two-lane Highway Simulation**

| Parameter | Description | Range | Default | Field | Record Type |
|---|---|---|---|---|---|
| Passing Zone (See Appendix A for the corresponding marking configuration) | Specifies the center-line marking of a two-lane highway segment. | 0 – Not Applicable<br>1 – Passing Not Allowed<br>2 – Passing Allowed<br>3 – Passing Allowed in Both Directions | 0 | 74 | 20 |
| Entry node of eastbound segment of a two-lane highway | Specifies the two-lane highway link's entry node number (for EB). | 7000-8999 | none | 1-4 | 154 |
| Entry node of westbound segment of a two-lane highway | Specifies the two-lane highway link's entry node number (for WB). | 7000-8999 | none | 5-8 | 154 |
| Follower Headway Threshold (sec) | Specifies the follower headway threshold in seconds. It is used to set the time headway value that is used to determine whether a vehicle is in a following mode. | 1.0 – 10.0 | 3 | 1-4 | 155 |
| MinPct (%) | Specifies the illegal passing distance percentage acceptable for driver type 1 (most conservative driver). | 0 – 100 | 0 | 5-8 | 155 |
| MaxPct (%) | Specifies the illegal passing distance percentage acceptable for driver type 10 (most aggressive driver). | 0 – 100 | 25 | 9-12 | 155 |
| Minimum clearance distance between passing vehicle and passed vehicle (ft) | Specifies the shortest distance between the front bumper of the passed vehicle and the rear bumper of the passing vehicle, when the passing vehicle moves back to the normal lane, which allows the passing vehicle to safely complete its pass. | 10-100 | 75 | 13-16 | 155 |
| TimeToCollisionMin (sec) | Specifies the time to collision that will cause a type 10 driver to abandon passing an additional vehicle during passing maneuver. | 0-100 | 5 | 17-20 | 155 |
| TimeToCollisionMax (sec) | Specifies the time to collision that will cause a type 1 driver to abandon passing an additional vehicle during passing maneuver. | 0-100 | 10 | 21-24 | 155 |
| Speed differential between passing vehicle and passed vehicle (mi/h) | Specifies the difference in speed between the passing vehicles and vehicle being passed when the passing vehicle has reached its top passing speed. | 5-20 | 12 | 25-28 | 155 |

| | | | | | |
|---|---|---|---|---|---|
| Impatience Value | Specifies the increment to the desire to pass value for each second of time spent wanting to pass. | 0.000 – 0.001 | 0.001 | 61-64 | 155 |
| Passing acceleration | Specifies the acceleration that will be applied to accelerate the passing vehicle to the desired passing speed when a passing maneuver is initiated. | $a_1$, if speed $\leq$ 40 mi/h<br>$a_2$, if 40 < speed $\leq$ 50 mi/h<br>$a_3$, if 50 < speed $\leq$ 60 mi/h<br>$a_4$, if speed > 60 mi/h | $a_1$ = 1.40 mi/h/s<br>$a_2$ = 1.43 mi/h/s<br>$a_3$ = 1.47 mi/h/s<br>$a_4$ = 1.50 mi/h/s | 1-16 | 156 |
| Time required for initial passing maneuver | Specifies the amount of time the passing vehicle spends moving from the normal lane to the point of encroachment in the oncoming lane | $t_1$, if speed $\leq$ 40 mi/h<br>$t_2$, if 40 < speed $\leq$ 50 mi/h<br>$t_3$, if 50 < speed $\leq$ 60 mi/h<br>$t_4$, if speed > 60 mi/h | $t_1$ = 3.6 sec<br>$t_2$ = 4.0 sec<br>$t_3$ = 4.3 sec<br>$t_4$ = 4.5 sec | 17-32 | 156 |
| Time spent traveling in the oncoming lane | Specifies the amount of time the passing vehicle spends from the point of encroachment in the oncoming lane until it returns to the normal lane. | $t_1$, if speed $\leq$ 40 mi/h<br>$t_2$, if 40 < speed $\leq$ 50 mi/h<br>$t_3$, if 50 < speed $\leq$ 60 mi/h<br>$t_4$, if speed > 60 mi/h | $t_1$ = 9.9 sec<br>$t_2$ = 9.9 sec<br>$t_3$ = 9.9 sec<br>$t_4$ = 9.9 sec | 33-48 | 156 |
| Minimum clearance distance | Specifies the minimum acceptable clearance distance between the passing vehicle and the first oncoming vehicle. | $c_1$, if speed $\leq$ 40 mi/h<br>$c_2$, if 40 < speed $\leq$ 50 mi/h<br>$c_3$, if 50 < speed $\leq$ 60 mi/h<br>$c_4$, if speed > 60 mi/h | $c_1$ = 100 ft<br>$c_2$ = 180 ft<br>$c_3$ = 250 ft<br>$c_4$ = 300 ft | 49-64 | 156 |
| Two-Lane Highways by Direction | Allows the user to define a two-lane highway by direction | N/A | N/A | | 190 |
| Two-Lane Highway Direction Links | Used in conjunction with RT 190 to specify the links that comprise the highway direction | N/A | N/A | | 191 |

Four example TRF input file printouts are included in Appendix B. These printouts can be copied and pasted into a text file (just rename the filename extension to '.trf') and then loaded into CORSIM.

**Table 3-5    New Outputs for Two-lane Highway Simulation (by direction)**

| Output | Description | Formula | Facility-based or link-based |
|---|---|---|---|
| Follower density | Indicates the average density of vehicles which are in the following mode. | Percentage of followers $\times$ Traffic density (Followers per mile) | Both |
| Percent time spent following | Indicates the average percentage of travel time spent by vehicles following in platoons behind slower vehicles. | $$\frac{\sum_{\text{All vehicles}} \dfrac{\text{Travel time spent in platoons}}{\text{Total travel time}}}{\text{Total number of vehicles}} \; (\%)$$ | Both |
| Average travel speed | Indicates the average travel speed of vehicles. | $$\frac{\sum_{\text{All vehicles}} \dfrac{\text{Total travel distance}}{\text{Total travel time}}}{\text{Total number of vehicles}} \; (\text{mi/h})$$ | Both |
| Average speed of vehicles while performing a passing maneuver | Indicates the average travel speed of all the passers during their processes of passing maneuvers (i.e. from initiating passing to returning to the normal lane) | $$\frac{\sum_{\substack{\text{All successful} \\ \text{passers}}} \dfrac{\text{Total distance traveled during passing maneuver}}{\text{Total travel time spent during passing maneuver}}}{\text{Total number of successful passers}} \; (\text{mi/h})$$ | Facility |
| Number of attempted passes | Indicates the total amount of the initiated passing maneuvers, including both completed and aborted passes, over the whole facility. | N/A | Facility |
| Number of aborted passes | Indicates the total number of passes that are initiated but not completed. | N/A | Facility |
| Clearance distance and/or time | Indicates the average clearance (in terms of distance or time) between passing vehicle and opposing vehicle when the passer completes the passing maneuver and returns to the normal lane. | $$\frac{\sum_{\substack{\text{All successful} \\ \text{passers}}} \text{Clearance of the successful passers}}{\text{Total number of successful passers}} \; (\text{ft or sec})$$ | Facility |
| Average distance spent in opposing lane | Indicates the average distance the passer travels in opposing lane during the passing maneuver. | $$\frac{\sum_{\substack{\text{All successful} \\ \text{passers}}} \text{Distance of all the successful passers in opposing lane}}{\text{Total number of successful passers}} \; (\text{ft})$$ | Facility |
| Average proportion of illegal passing distance | Indicates the average proportion of passing distance used beyond a passing zone, relative to the total passing distance. | $$\frac{\sum_{\substack{\text{All successful} \\ \text{passers}}} \dfrac{\text{Passing distance beyond passing zone}}{\text{Total passing distance}}}{\text{Total number of successful passers}} \; (\%)$$ | Facility |

Most of these outputs are specified through the output processor tool in TSIS. The outputs specified in the output processor dialogs are generally written to '.csv' files that can then be loaded into a spreadsheet program. Facility-wide values of average travel speed, PTSF, and follower density are included in the default output file ('.out) of CORSIM.

Screen captures of the output processor tool, illustrating the new outputs, are shown in the following figures.
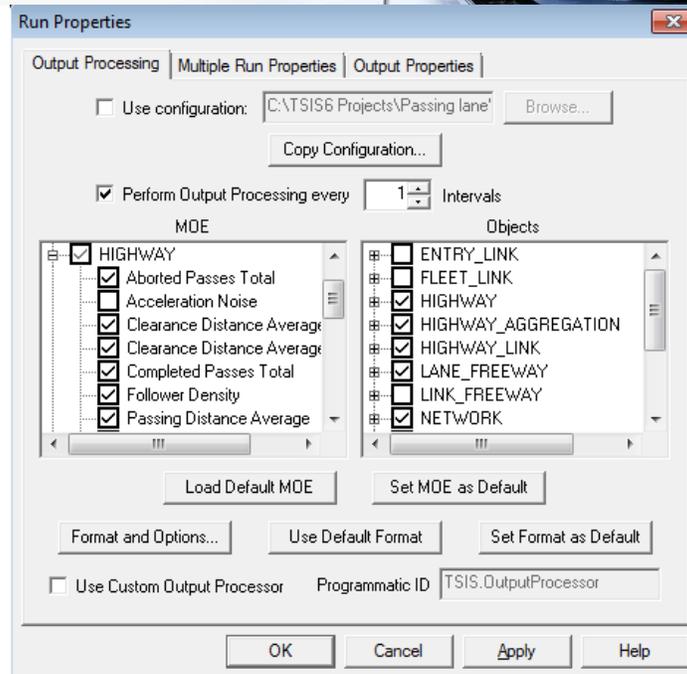
**Figure 3-3      Output processor and the Highway MOE category**
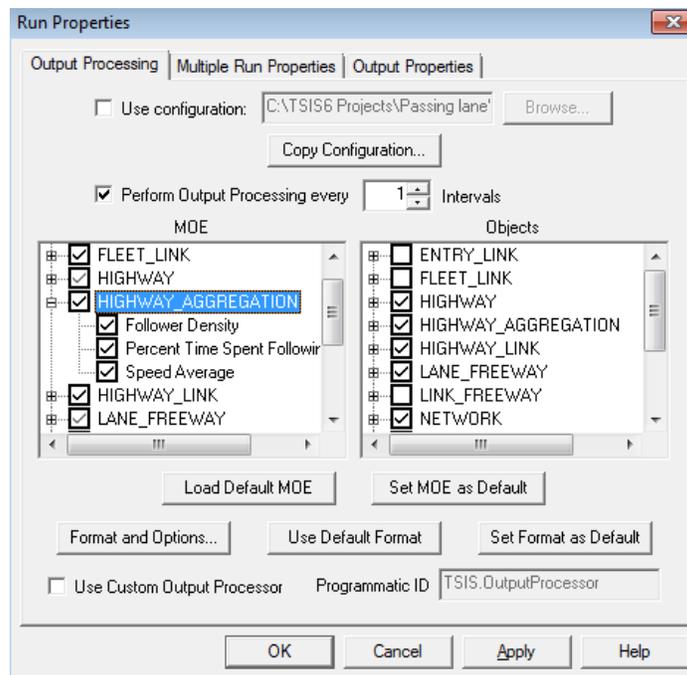


**Figure 3-4      Output processor and the Highway_Aggregation MOE category**
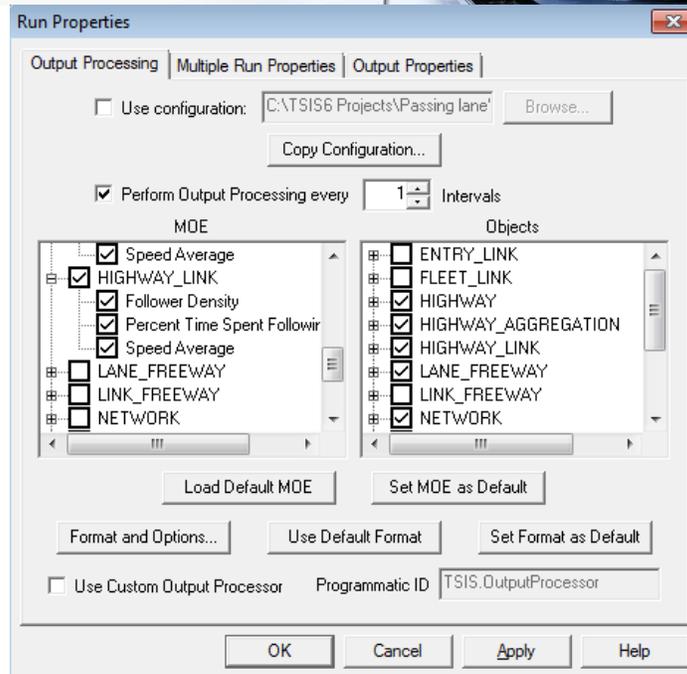
**Figure 3-5    Output processor and the Highway_Link MOE category**
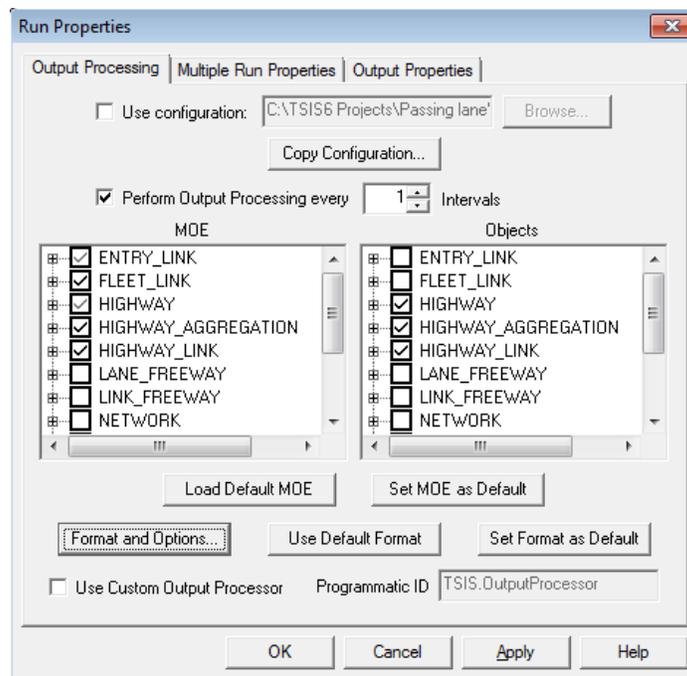


**Figure 3-6    Output processor and the Highway, Highway_Aggregation and Highway_Link object categories**

These screen captures show the three new 'MOE' and 'Objects' categories added to the output processor tool: 'Highway,' 'Highway_Aggregation' and 'Highway_Link.' The 'Highway' category allows one to specify the entire highway, by direction, for selected MOE reporting. The 'Highway_Aggregation' category allows one to specify the routes/paths that have been specified on record types 190 and 191 for selected MOE reporting. The 'Highway-Link' category allows one to specify individual links (i.e., segments), by direction, for selected MOE reporting.

# CHAPTER 4 TESTS AND EVALUATION

In this chapter, the results of numerous simulation experiments are presented. These tests were conducted for the purpose of comparing the simulation results (based on the logic described in the previous chapter) to commonly accepted traffic-flow theories for two-lane highways. In these experiments, follower density, percent time-spent-following and average speed were chosen as the performance measure outputs.

## 4.1 BASIC TWO-LANE HIGHWAY TESTS

The basic two-lane highway here is specified as a two-lane highway segment with a consistent passing condition along its extended length — either 100 percent no-passing-allowed or 100 percent passing-allowed. All of the basic two-lane highway tests are based on different combinations of traffic-flow inputs (including two-way volume, volume split and truck percentage), listed in Table 4-1. The results for both 100 percent no-passing-allowed and 100 percent passing-allowed are shown on the same graph. Note that directional volume was limited to 2,000 veh/h).

**Table 4-1 Experiment Scenarios**

| Two-way Volume (veh/h) | 100 | | | | | | 500 | | | | | | 1000 | | | | | | 1500 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Directional Splits (EB/WB) | 50/50 | | 60/40 | | 70/30 | | 50/50 | | 60/40 | | 70/30 | | 50/50 | | 60/40 | | 70/30 | | 50/50 | | 60/40 | | 70/30 | |
| HV Percentage | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 |
| Scenarios | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |

| Two-way Volume (veh/h) | 2000 | | | | | | 2500 | | | | | | 3000 | | | | 3500 | | 4000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Directional Splits (EB/WB) | 50/50 | | 60/40 | | 70/30 | | 50/50 | | 60/40 | | 70/30 | | 50/50 | | 60/40 | | 50/50 | | 50/50 | |
| HV Percentage | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 |
| Scenarios | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 |

### 4.1.1 Basic two-lane highway without trucks tests

The test facility is 10 miles long, level terrain, no passing lane added, and no passing zone exists (see Figure 4-1 for the screen shot) or 100 percent passing-allowed (see Figure 4-2 for the screen shot, and the passing vehicle is flagged while performing its passing maneuver). The free-flow speed is 65 mi/h. A total of 44 experiments (i.e., different combination of input values) were run, and 10 iterations of each experiment were run. The presented results are the average of the 10 iterations.
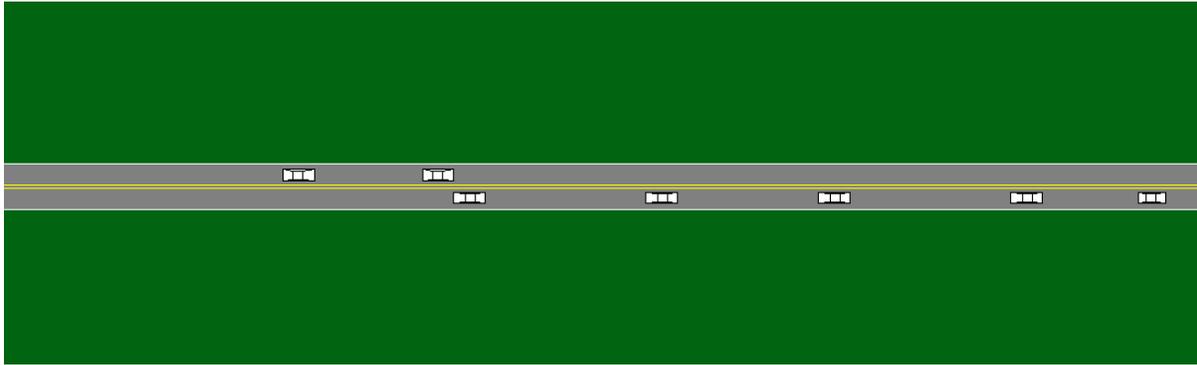
**Figure 4-1     Basic Two-lane Highway without Passing Zones**
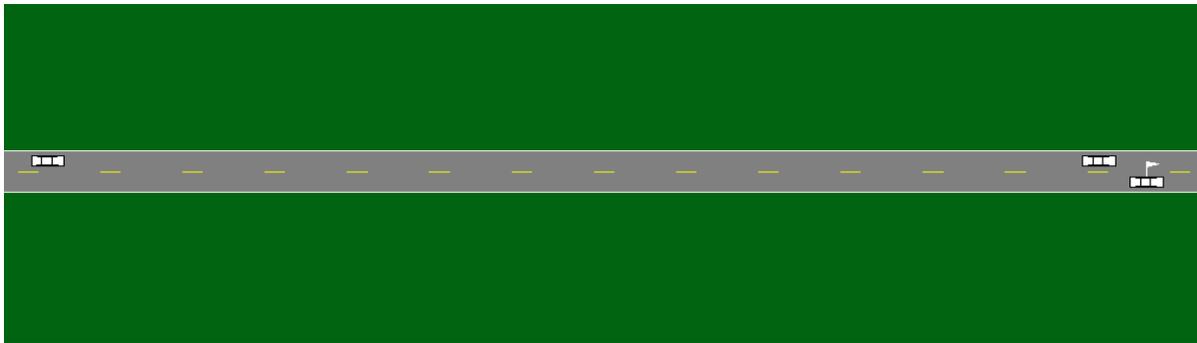


**Figure 4-2     Basic Two-lane Highway with Passing Zones**

The testing results are presented as follows:

    (1) Directional average speed vs. flow rate

    Figure 4-3 illustrates the relationship between directional average speed and two-way flow rate.
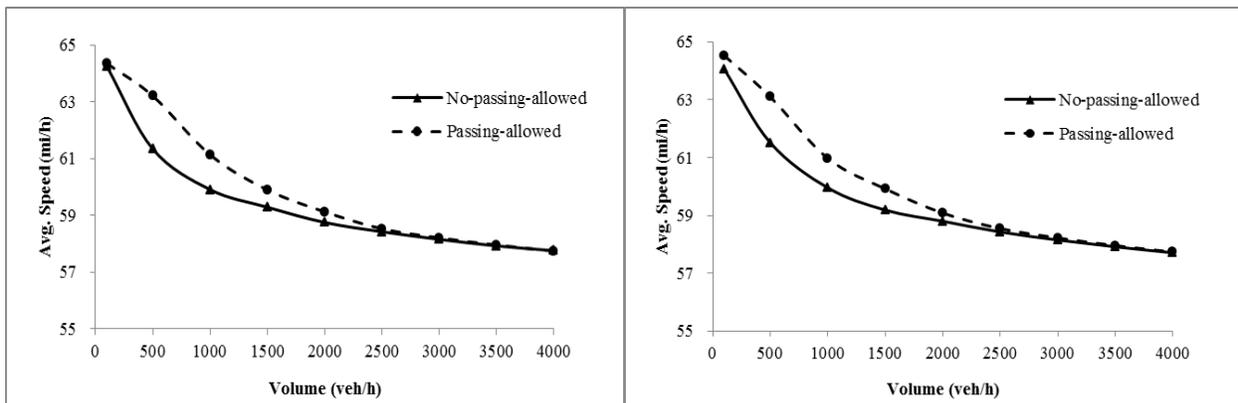


(a) EB Avg. Speed, 50/50 Traffic Volume Split  (b) WB Avg. Speed, 50/50 Traffic Volume Split
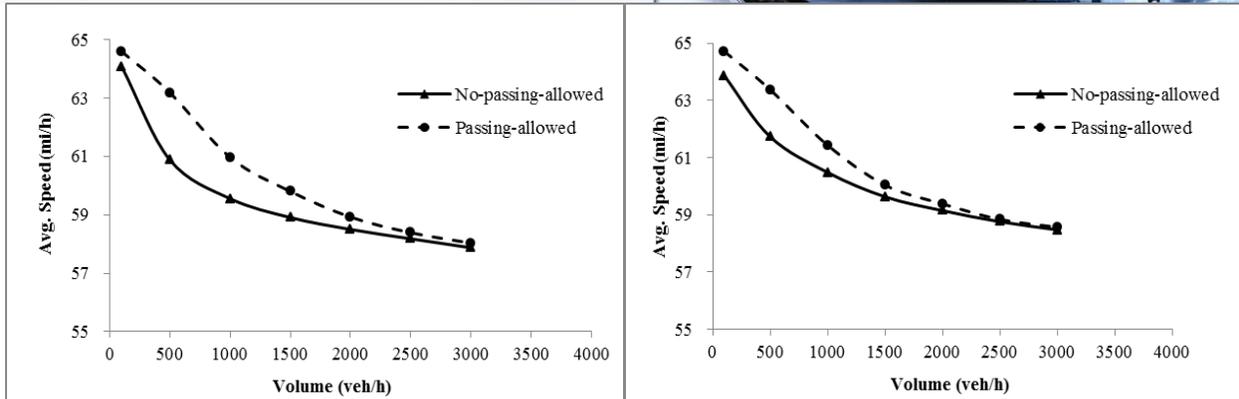
(c) EB Avg. Speed, 60/40 Traffic Volume Split (d) WB Avg. Speed, 40/60 Traffic Volume Split
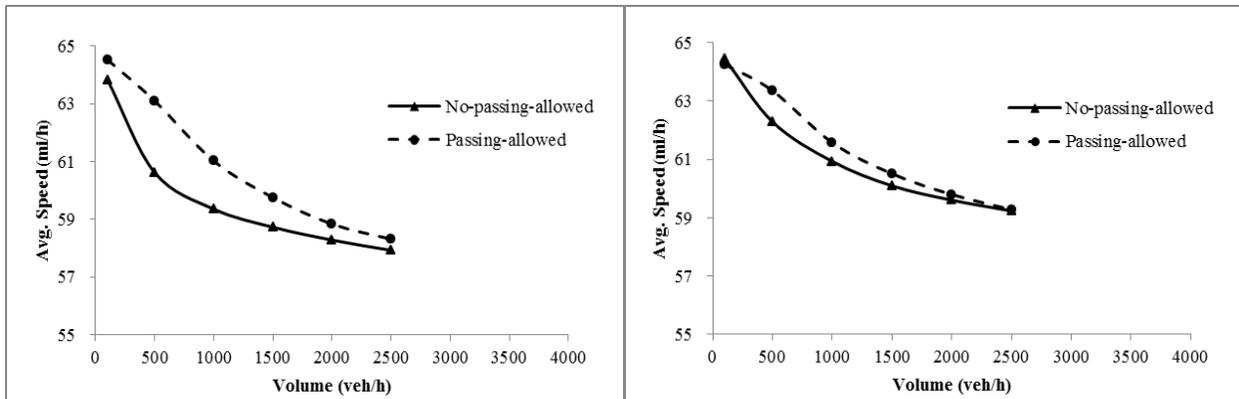


(e) EB Avg. Speed, 70/30 Traffic Volume Split (f) WB Avg. Speed, 30/70 Traffic Volume Split

**Figure 4-3    Avg. speed results for basic two-lane highway tests without trucks**

These results follow the expected trends and relationships: When the traffic flow rates are approximately equal on each lane of the two-lane highway, the average speed for each direction is similar; as the traffic directional split becomes more imbalanced, the average speeds in the peak direction are lower than in the off-peak direction, and the average speeds decline with increasing flow rates in each direction. Furthermore, the average speeds are higher for the passing allowed condition than the no-passing allowed condition, for each flow-rate scenario, until you get to high flow rates (approximately 2,500 veh/h two-way flow rate), at which point the average speeds are similar. High flow rates severely limit the passing opportunities; thus, essentially creating a no-passing-allowed condition. Also, the improvement to peak direction average speed for the passing-allowed condition relative to the no-passing-allowed condition increases with increasing traffic directional split imbalance, as expected. Also as expected, whether for the passing-allowed or no-passing-allowed condition, the average speed levels off in the moderate to high two-way flow rate range.

(2) Directional PTSF vs. flow rate

Figure 4-4 illustrates the relationship between directional PTSF and two-way flow rate.
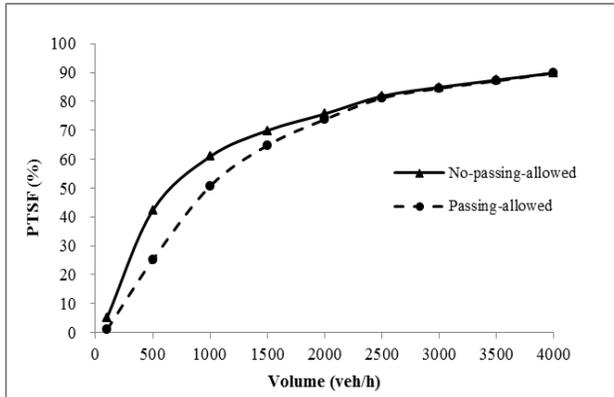


(a) EB PTSF, 50/50 Traffic Volume Split
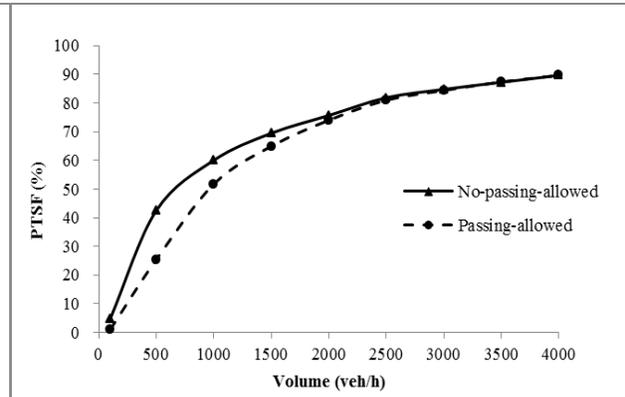


(b) WB PTSF, 50/50 Traffic Volume Split
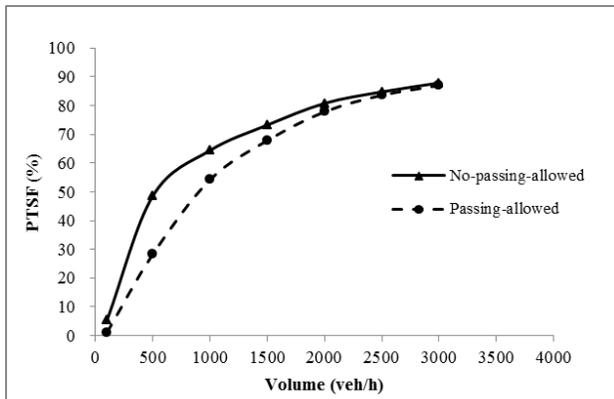


(c) EB PTSF, 60/40 Traffic Volume Split



(d) WB PTSF, 40/60 Traffic Volume Split



(e) EB PTSF, 70/30 Traffic Volume Split



(f) WB PTSF, 30/70 Traffic Volume Split

**Figure 4-4    PTSF results for basic two-lane highway tests without trucks**

The results of the relationship between the PTSF values and flow rate are as expected. When the traffic flow rates are approximately equal on each lane of the two-lane highway, the PTSF value for each direction is similar; as the traffic directional split becomes uneven, the PTSF in the peak direction is higher than in the off-peak direction, and the PTSF value increases with increasing flow rates in each direction. Furthermore, the PTSF values are lower for the passing-allowed condition than the no-passing-allowed condition, for each flow rate scenario, until the two-way flow rates reaches approximately 2,500 veh/h, where the PTSF values are similar. This is consistent with the results for average speed. And the improvement to peak direction PTSF for the passing allowed condition relative to the no-passing-allowed condition increases with increasing traffic directional split imbalance, as expected. Also as expected, whether for the passing-allowed or no-passing-allowed condition, the PTSF levels off in the moderate to high two-way flow rate range.

(3) Directional follower density vs. flow rate
Figure 4-5 illustrates the relationship between directional follower density and two-way flow rate.
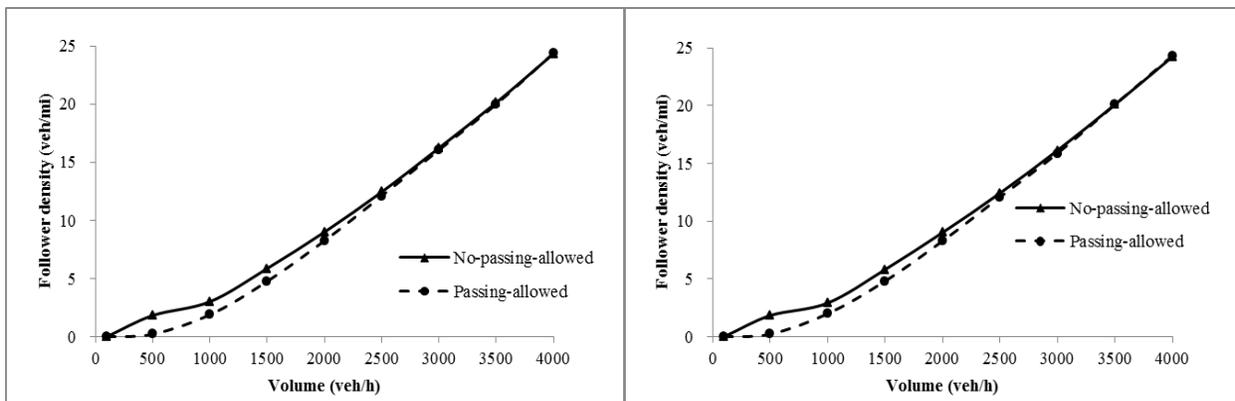


(a) EB Fo. Density, 50/50 Traffic Volume Split  (b) WB Fo. Density, 50/50 Traffic Volume Split
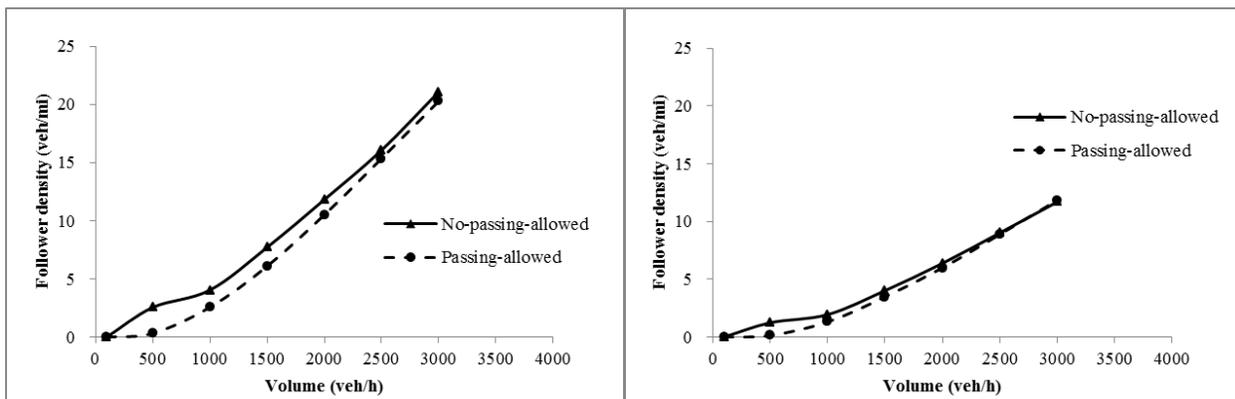


(c) EB Fo. Density, 60/40 Traffic Volume Split  (d) WB Fo. Density, 40/60 Traffic Volume Split
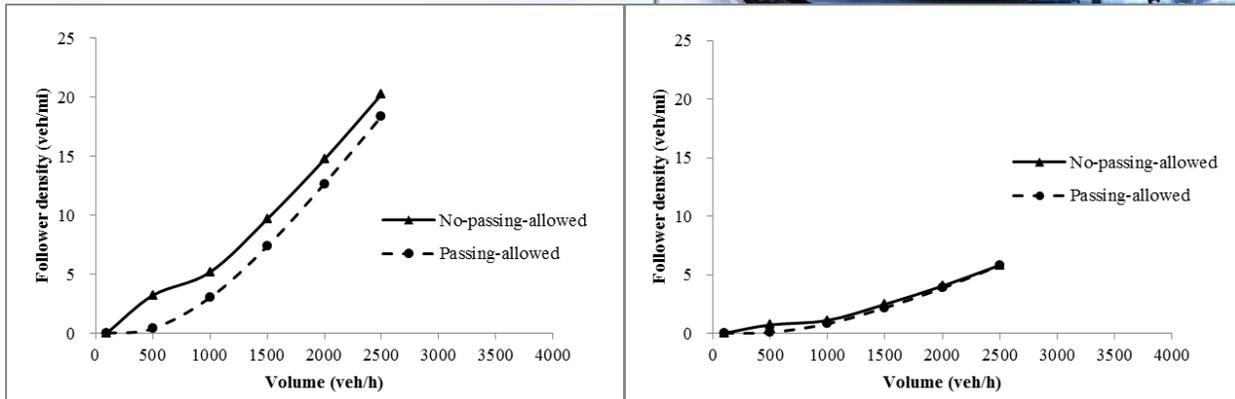
(e) EB Fo. Density, 70/30 Traffic Volume Split  (f) WB Fo. Density, 30/70 Traffic Volume Split

**Figure 4-5    Follower density results for basic two-lane highway tests without trucks**

The results of the relationship between the follower density values and flow rate are as expected: When the traffic-flow rates are equally split on each lane of the two-lane highway, the follower density for each direction is similar; as the traffic directional split becomes more imbalanced, the follower density in the peak direction is higher than in the off-peak direction, and increases with increasing flow rates in each direction. Moreover, the follower densities are lower for the passing-allowed condition than the no-passing-allowed condition. For each flow rate scenario, until you get to high flow rates (approximately 2,500 veh/h two-way flow rate), at which point the follower densities become similar. Again, this is because high flow rates severely limit the passing opportunities, essentially creating a no-passing-allowed condition. Also, the improvement to peak direction follower density for the passing allowed condition relative to the no passing-allowed-condition increases with increasing traffic directional split imbalance, as expected.

### 4.1.2    Basic two-lane highway with 10 percent trucks tests

The roadway characteristics of the test facility are the same as in the previous tests. The only traffic characteristic that is different from the previous tests is that 10 percent trucks (50 percent 30-foot long truck, 24 percent 53-foot long medium load truck, 23 percent 53-foot long full load truck, 3 percent 64-foot long truck) were included in the traffic stream. Again, a total of 44 experiments were run, and 10 iterations of each experiment were run. The presented results are the average of the 10 iterations.

The testing results are summarized as follows:

(1) Directional average speed vs. flow rate

Figure 4-6 illustrates the relationship between directional average speed and two-way flow rate.
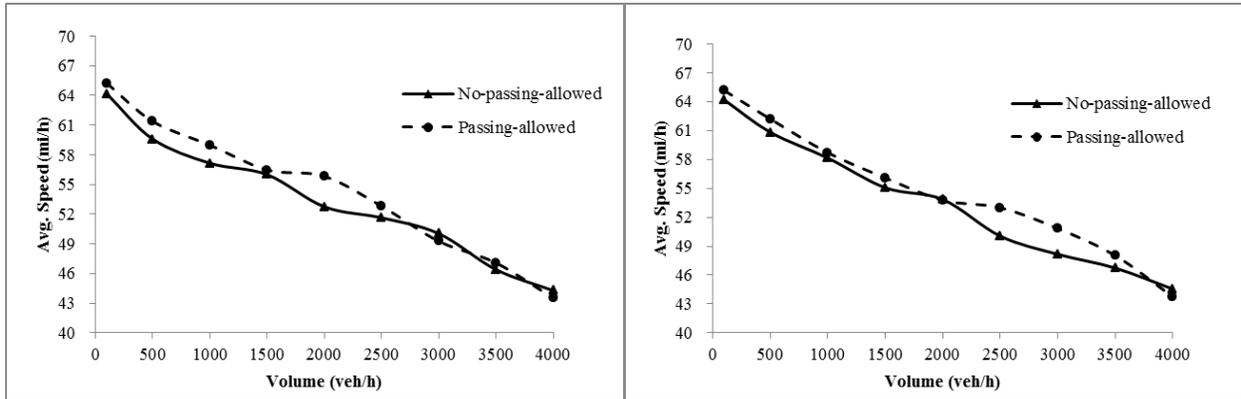


(a) EB Avg. Speed, 50/50 Traffic Volume Split (b) WB Avg. Speed, 50/50 Traffic Volume Split
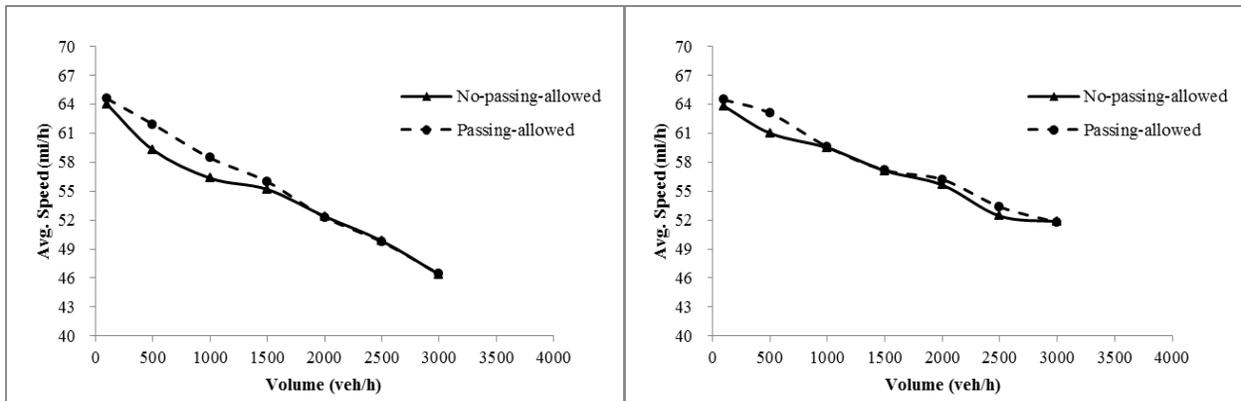
(c) EB Avg. Speed, 60/40 Traffic Volume Split (d) WB Avg. Speed, 40/60 Traffic Volume Split
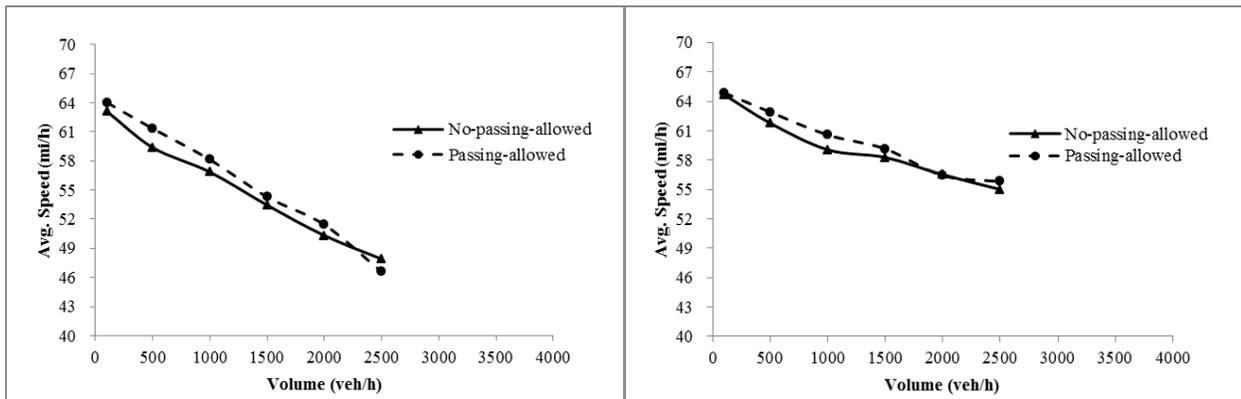
(e) EB Avg. Speed, 70/30 Traffic Volume Split (f) WB Avg. Speed, 30/70 Traffic Volume Split

**Figure 4-6     Avg. speed results for basic two-lane highway tests with trucks**

The results for average speed in the 10 percent truck tests exhibit many of the same trends and relationships as for the passenger car only results. The main difference is that the average speed values for the 10 percent trucks traffic stream are generally lower than the passenger car only speed values, as expected, and the speed-flow relationship is more linear in nature for the 10 percent truck stream than the passenger car only traffic stream. Additionally, the two-way flow rate (approximately 2,000-2,500 veh/h) at which the average speed between the passing allowed and no passing allowed conditions become similar is not as consistent as for the passenger car only traffic stream, indicating that the presence of trucks introduces more randomness into the traffic flow characteristics and corresponding performance measure results.

(2) Directional PTSF vs. flow rate
Figure 4-7 illustrates the relationship between directional PTSF and two-way flow rate.
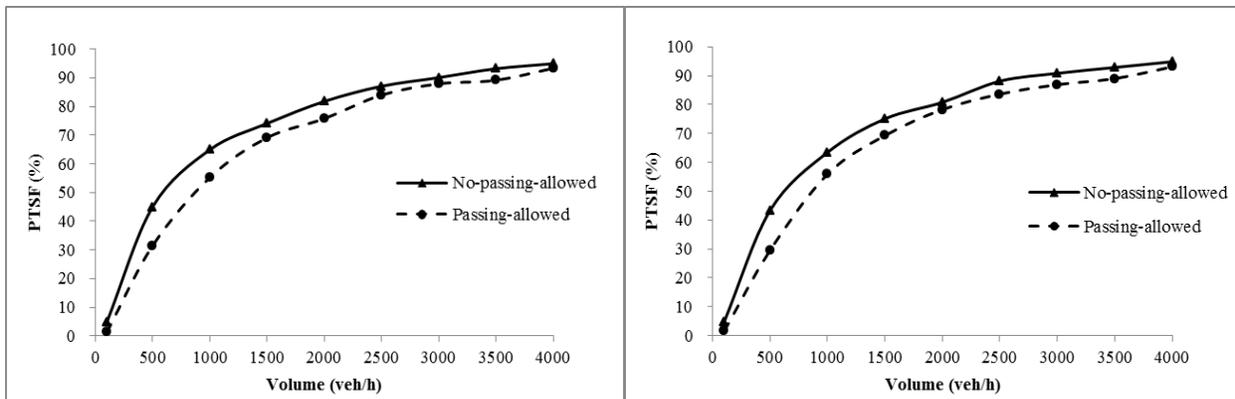


(a) EB PTSF, 50/50 Traffic Volume Split    (b) WB PTSF, 50/50 Traffic Volume Split
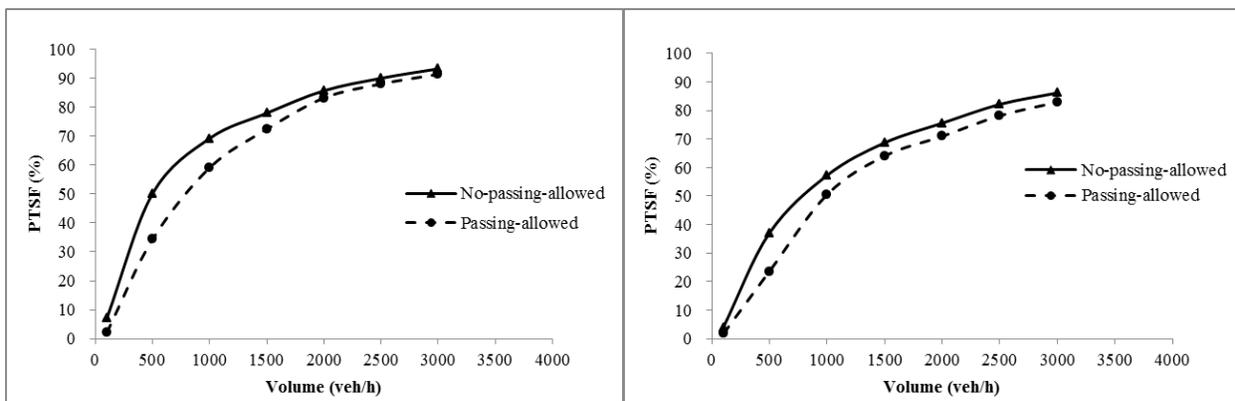
(c) EB PTSF, 60/40 Traffic Volume Split    (d) WB PTSF, 40/60 Traffic Volume Split
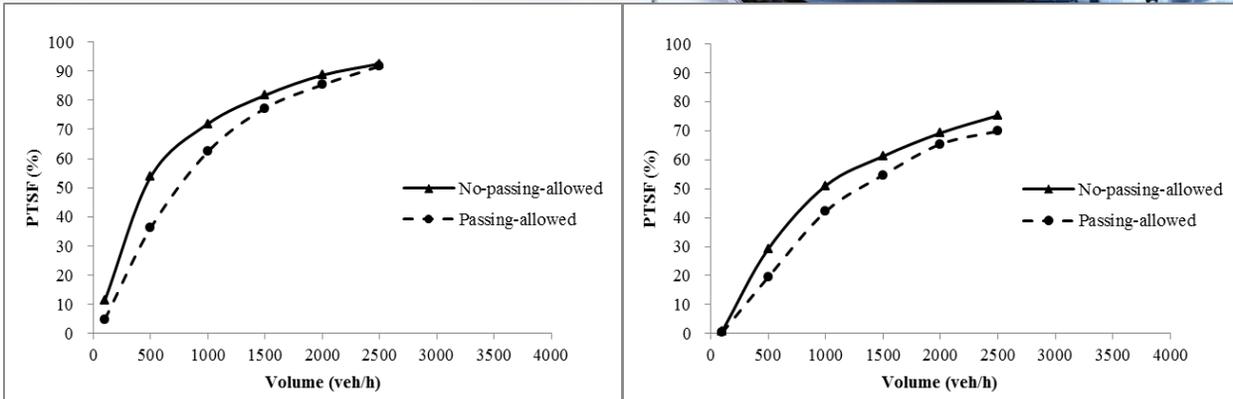
(e) EB PTSF, 70/30 Traffic Volume Split    (f) WB PTSF, 30/70 Traffic Volume Split

**Figure 4-7    PTSF results for basic two-lane highway tests with trucks**

The results of the relationship between the PTSF values and flow rate are very similar to the PTSF results for the passenger car only tests. The main difference is that the PTSF values for the 10 percent trucks traffic stream are generally higher than the passenger car only PTSF values, as expected. Also, as for the average speeds, there is not a completely consistent flow rate at which the PTSF values converge. Again, this is likely due to the additional randomness introduced into the traffic flow by the trucks.

(3) Directional follower density vs. flow rate
Figure 4-8 illustrates the relationship between directional follower density and two-way flow rate.
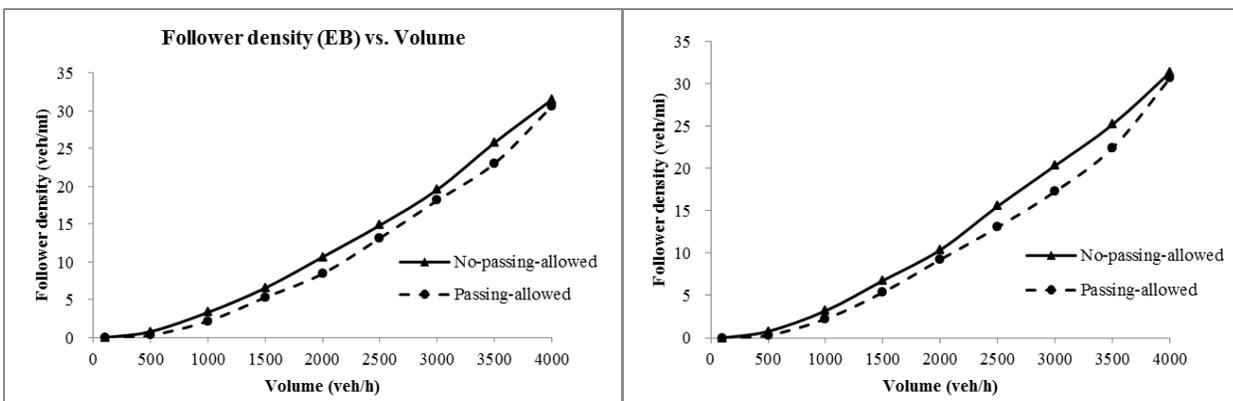


(a) EB Fo. Density, 50/50 Traffic Volume Split  (b) WB Fo. Density, 50/50 Traffic Volume Split
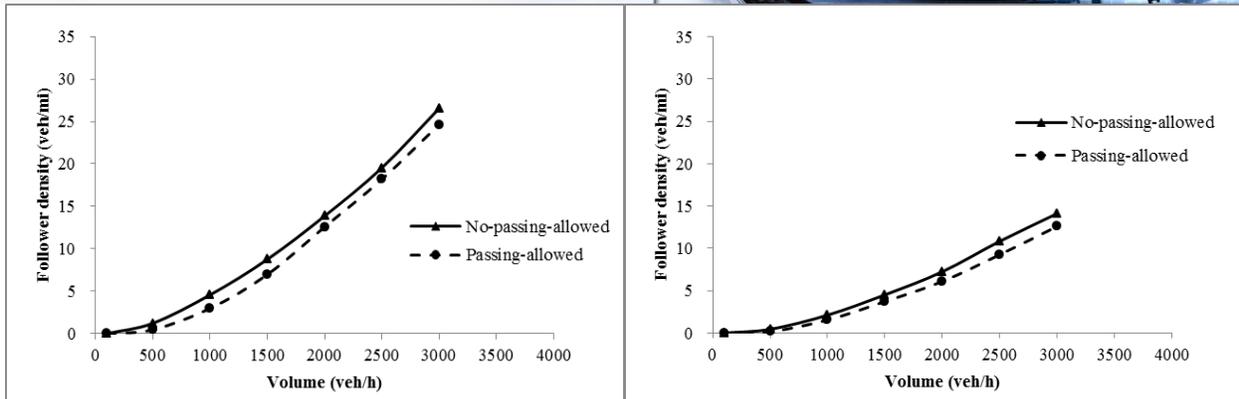
(c) EB Fo. Density, 60/40 Traffic Volume Split  (d) WB Fo. Density, 40/60 Traffic Volume Split
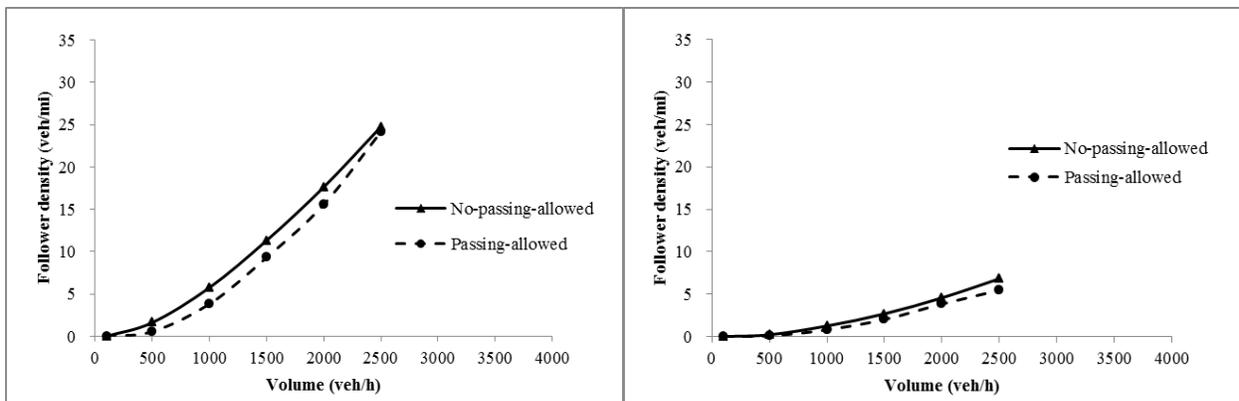


(e) EB Fo. Density, 70/30 Traffic Volume Split  (f) WB Fo. Density, 30/70 Traffic Volume Split

**Figure 4-8      Follower density results for basic two-lane highway tests with trucks**

The results of the relationship between the follower density values and flow rate are very similar to the follower density results for the passenger-car-only tests. The main difference is that the follower density values for the 10 percent trucks traffic stream are generally higher than the passenger-car-only follower density values, as expected. Also, as for the average speed and PTSF values, there is not a completely consistent flow rate at which the follower density values converge.

## 4.2      COMPLEX TWO-LANE HIGHWAY TESTS

The complex two-lane highway is specified as a two-lane highway with a combination of different features, e.g., inconsistent passing zone configuration, or a passing-lane added, or the presence of a signalized intersection. These tests will also be based on the scenarios listed in Table 4-1.

### 4.2.1      Partial passing zone condition tests

The test highway is 10 miles long, level terrain, no trucks, no passing lane added, and 50 percent continuous no-passing-allowed and 50 percent continuous passing-allowed (see Figure 4-9 for the illustration). The free-flow speed is 65 mi/h. Twenty-two experiments were run, and 10 iterations of each experiment were run. The presented results are the average of the 10 iterations.

WB ←

→ EB

| 5-mile no-passing zone | 5-mile passing zone |

10 miles
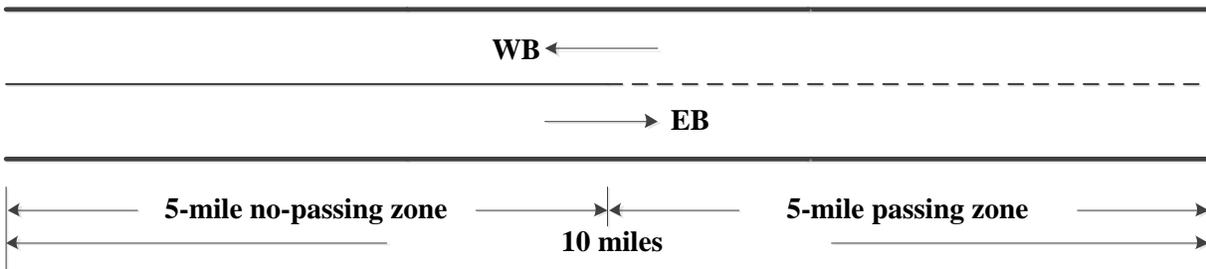
**Figure 4-9       Configuration of partial passing zone condition**

The testing results are summarized as follows:
          (1) Directional average speed vs. flow rate
          Figure 4-10 illustrates the relationship between directional average speed and two-way flow rate.
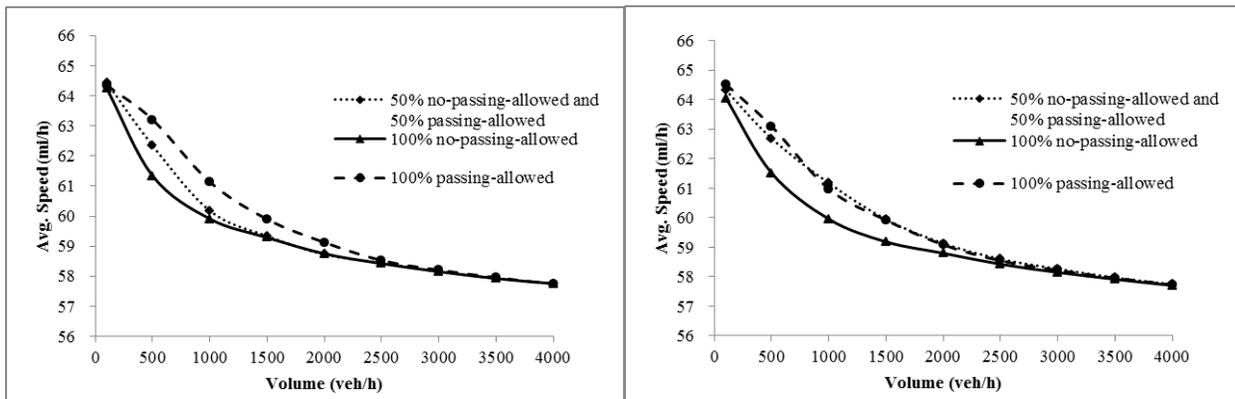


(a) EB Avg. Speed, 50/50 Traffic Volume Split  (b) WB Avg. Speed, 50/50 Traffic Volume Split
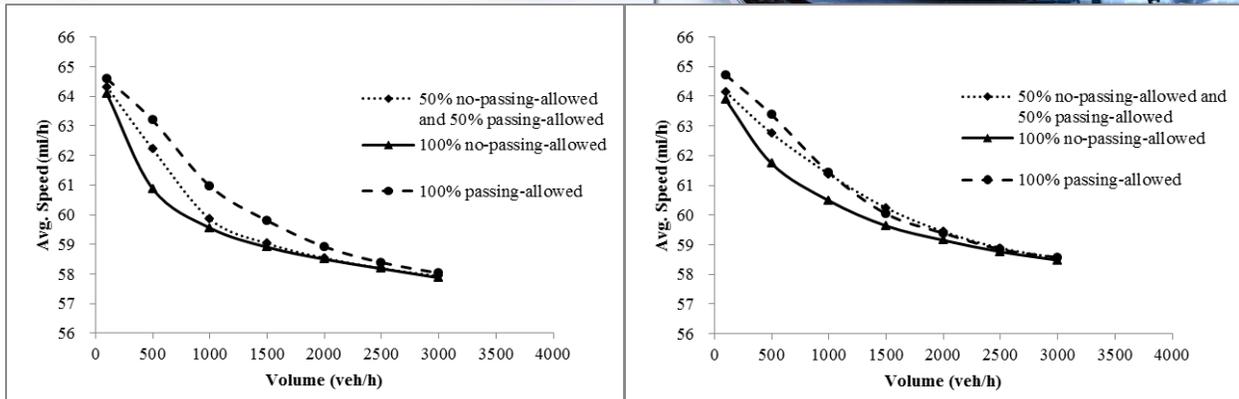
(c) EB Avg. Speed, 60/40 Traffic Volume Split  (d) WB Avg. Speed, 40/60 Traffic Volume Split
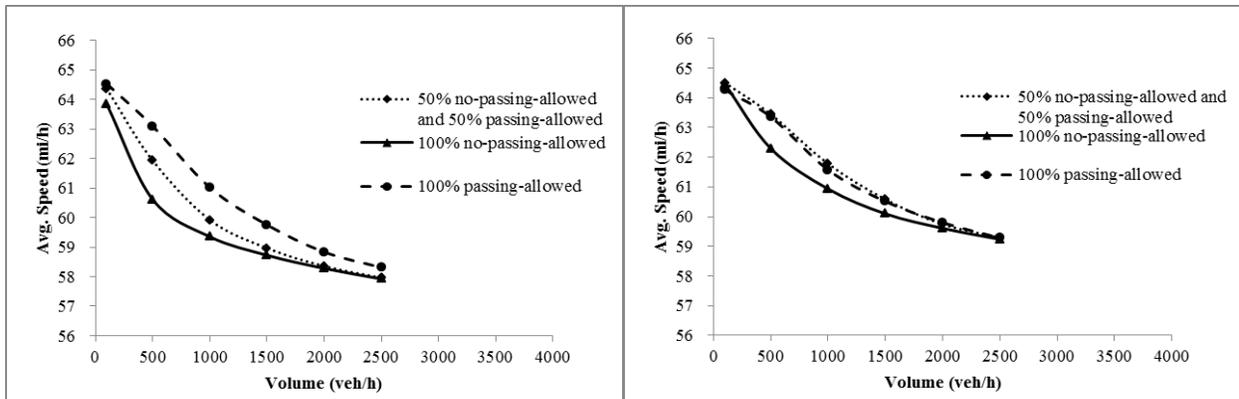


(e) EB Avg. Speed, 70/30 Traffic Volume Split  (f) WB Avg. Speed, 30/70 Traffic Volume Split

**Figure 4-10     Avg. speed results for partial passing zone condition tests**

These results generally follow the expected trends and relationships. The 100 percent passing-
allowed condition provides better performance than the 100 percent no-passing-allowed
condition. For the EB direction, the performance of the 50 percent passing-allowed condition is
initially (i.e., at lower flow rates) in between the performance of the two 100 percent conditions
until it converges to the 100 percent no-passing-allowed values, which it does at a lower flow
rate than the 100 percent passing-allowed condition. This suggests that the effect of proportion of
passing zone on the performance measures is not linear. For the WB direction, the average
speeds for the 50 percent passing-allowed condition generally follow those for the 100 percent
passing allowed condition. This may seem to be a somewhat unexpected result, but it is
plausible. The passing logic allows a vehicle to complete its pass a certain distance downstream
of the end of the passing zone (as mentioned in section 3.2.2.2). The passing logic also requires a
passing maneuver to be completed before it exits the coded highway facility. For the facility
configuration shown in Figure 4-9, passing vehicles traveling in the EB direction must complete
their pass before reaching the end of the 5-mile passing zone; whereas passing vehicles traveling
in the WB direction can complete their pass partially into the no-passing allowed zone. Thus, the
effective passing zone length is longer for the WB direction than it is for the EB direction, which

explains why the 50 percent passing-allowed results are better in the WB direction than in the EB direction.

(2) Directional PTSF vs. flow rate
Figure 4-11 illustrates the relationship between directional PTSF and two-way flow rate.
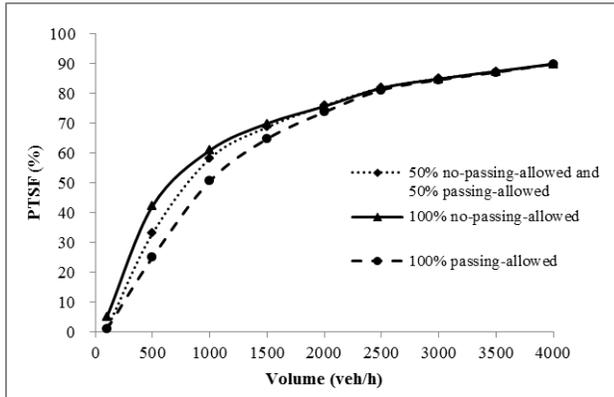


(a) EB PTSF, 50/50 Traffic Volume Split
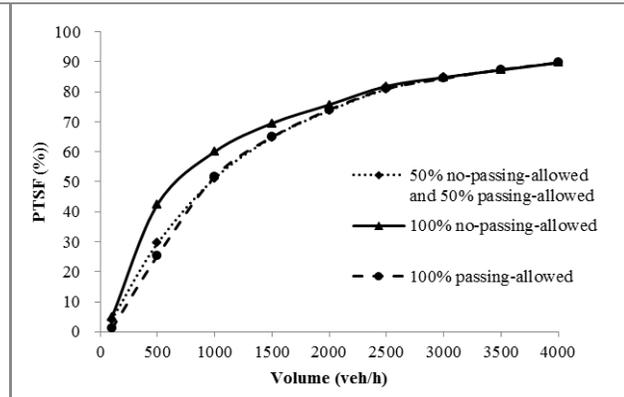
(b) WB PTSF, 50/50 Traffic Volume Split
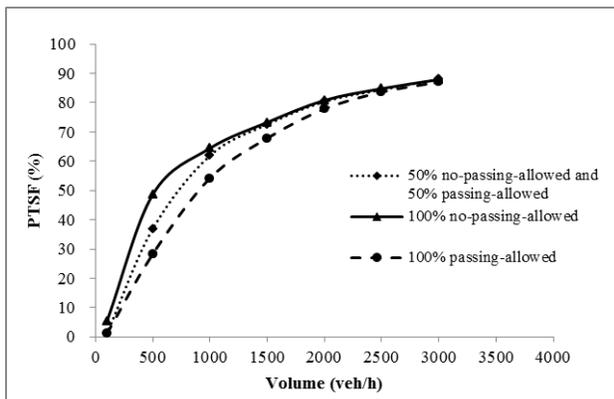
(c) EB PTSF, 60/40 Traffic Volume Split
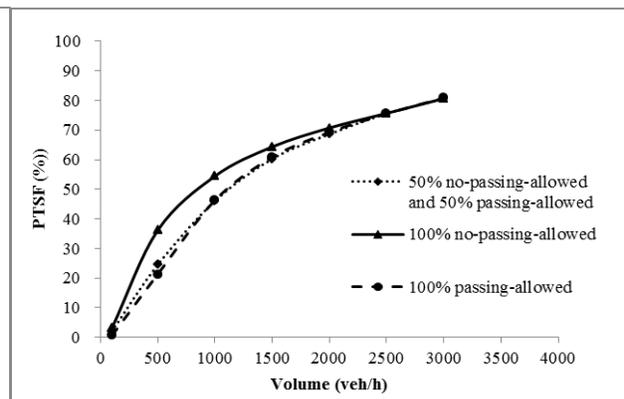
(d) WB PTSF, 40/60 Traffic Volume Split
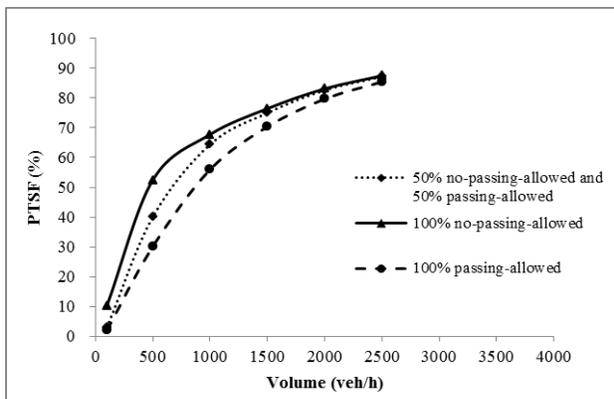
(e) EB PTSF, 70/30 Traffic Volume Split
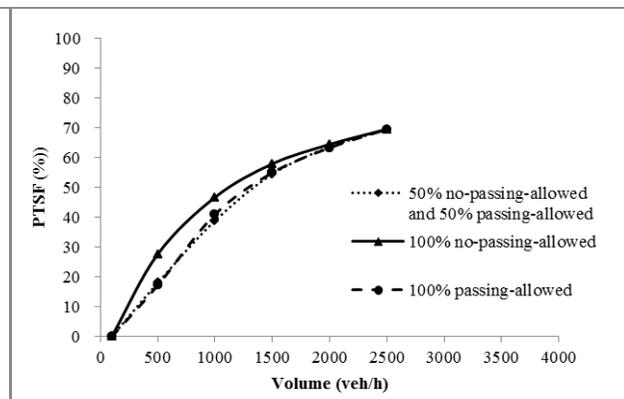
(f) WB PTSF, 30/70 Traffic Volume Split

**Figure 4-11    PTSF results for partial passing zone condition tests**

The results for the PTSF values follow the same trends and relationships as described for the average speed results.

(3) Directional follower density vs. flow rate
Figure 4-12 illustrates the relationship between directional follower density and two-way flow rate.
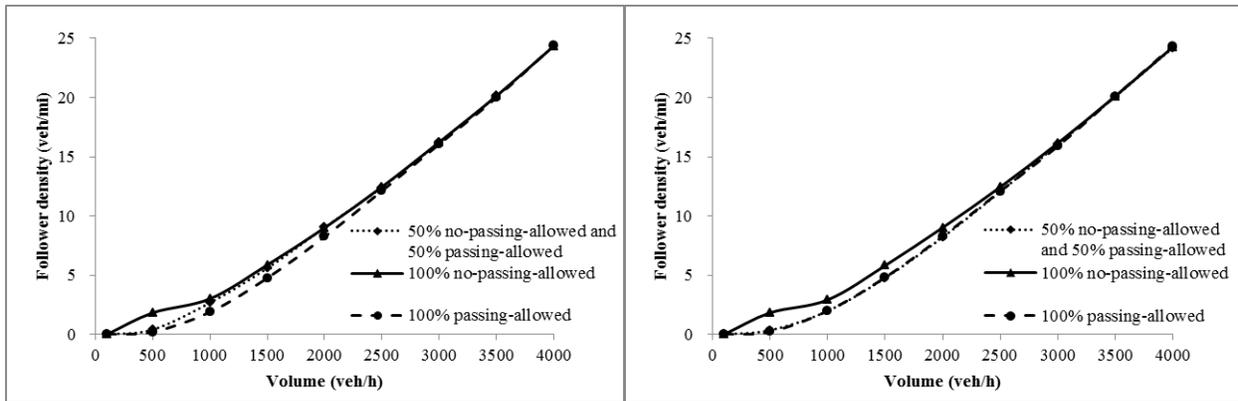


(a) EB Fo. Density, 50/50 Traffic Volume Split  (b) WB Fo. Density, 50/50 Traffic Volume Split
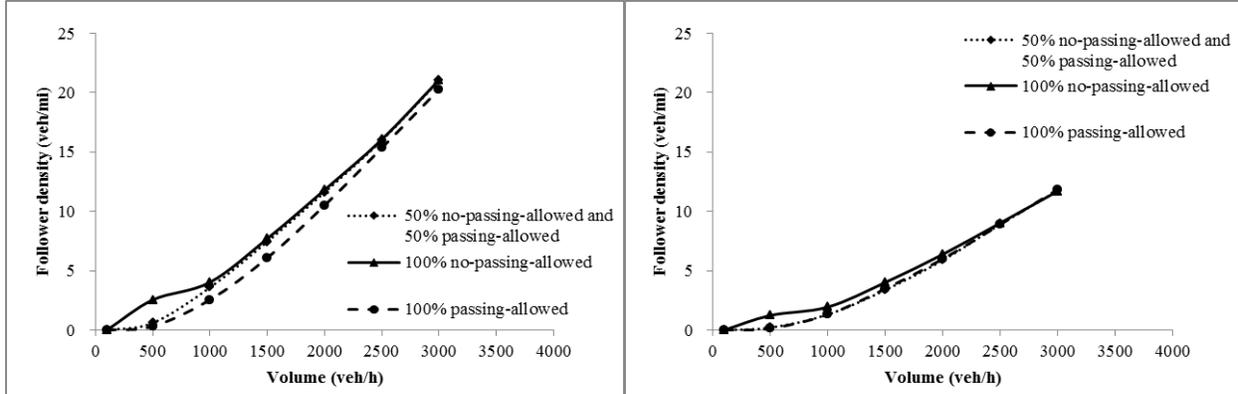
(c) EB Fo. Density, 60/40 Traffic Volume Split  (d) WB Fo. Density, 40/60 Traffic Volume Split
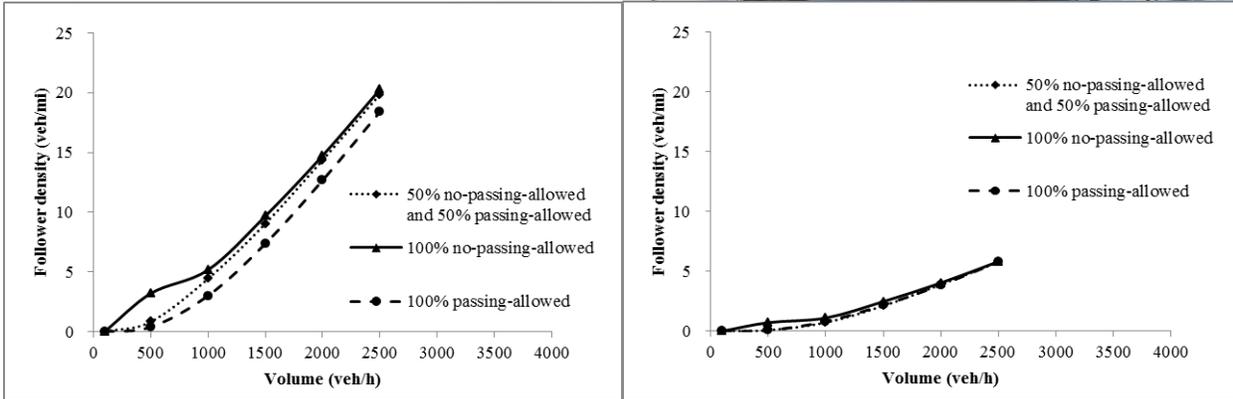
(e) EB Fo. Density, 70/30 Traffic Volume Split  (f) WB Fo. Density, 30/70 Traffic Volume Split

**Figure 4-12    Follower density results for partial passing zone condition tests**

The results for the follower density values follow the same trends and relationships as described for the average speed results.

### 4.2.2    Two-lane highway with a passing lane tests

1. Comparison of the performance measures over the entire length of the highway facility
        The test highway is 10 miles long, level terrain, 10% trucks, and a passing lane added in the middle of the EB direction (from milepost 4 to milepost 5). The no-passing-allowed marking is applied along the entire length of the highway. The free flow speed is 65 mi/h. Twenty-two experiments were run, and 10 iterations of each experiment were run. The presented results (compared with 100 percent no-passing-allowed and no-passing lane condition) are the average of the 10 iterations.

The facility-based testing results are summarized as follows:
        (1)  Directional average speed vs. flow rate
        Figure 4-13 illustrates the relationship between directional average speed and two-way flow rate.
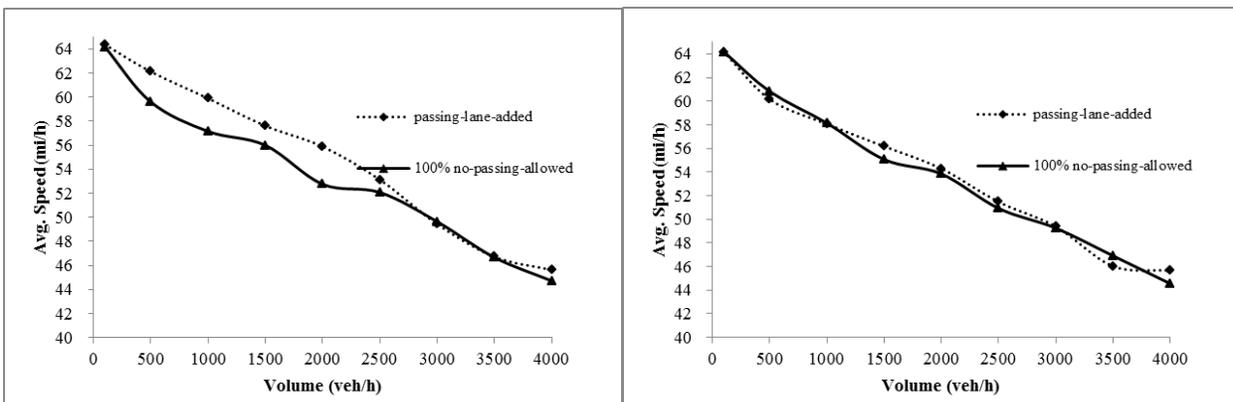


(a) EB Avg. Speed, 50/50 Traffic Volume Split  (b) WB Avg. Speed, 50/50 Traffic Volume Split
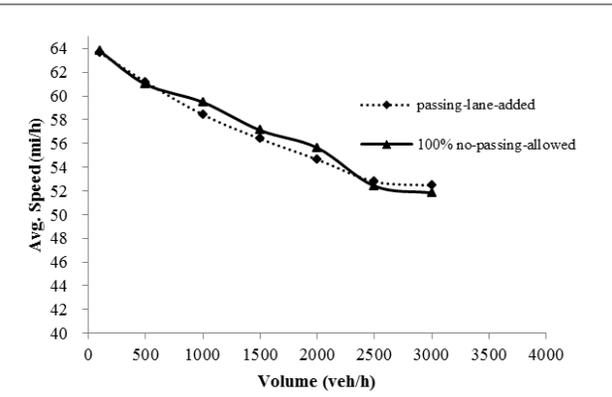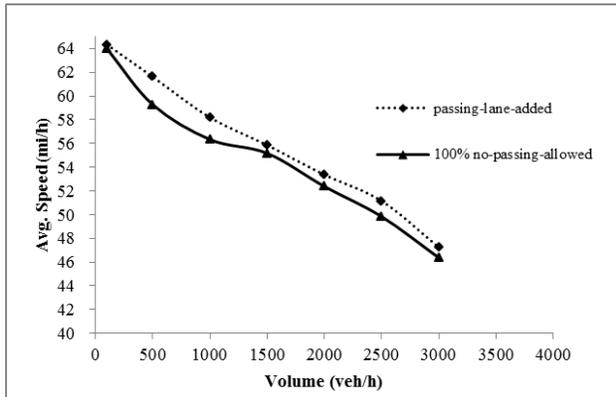
(c) EB Avg. Speed, 60/40 Traffic Volume Split  (d) WB Avg. Speed, 40/60 Traffic Volume Split
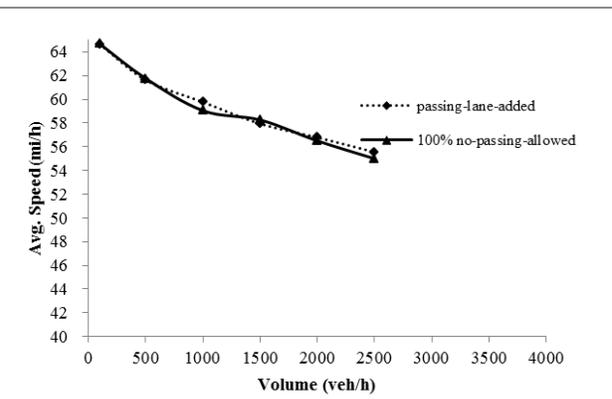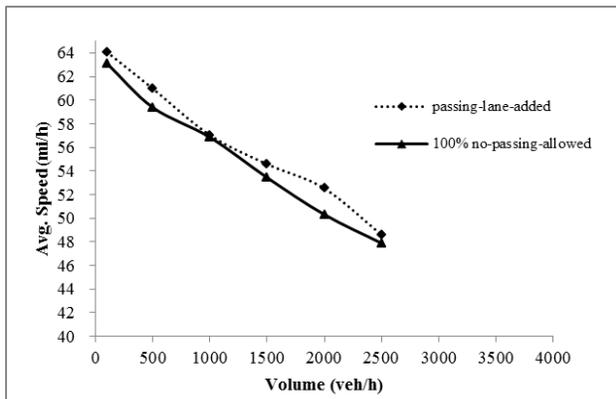


(e) EB Avg. Speed, 70/30 Traffic Volume Split  (f) WB Avg. Speed, 30/70 Traffic Volume Split

**Figure 4-13    Avg. speed results for passing-lane tests**

The results for average speed generally follow the expected trends and relationships. In the EB direction (where the passing lane is present), the average speeds are generally higher than the speeds for the 100 percent no-passing-allowed and no-passing lane condition. The average speeds for the WB direction (with no passing lane) are similar to the speeds for the 100 percent no-passing-allowed condition. The results indicate that the improvement to average speed will diminish around 2,500 veh/h. This is because at high flow rates, there is enough turbulence (particularly from trucks) created at the merge point at the end of the passing lane to offset the addition of the passing lane. The WB results show that the passing lane added in the EB direction does not offer any speed benefit to the WB direction, which is as expected. Other trends and relationships in the average speed results are as previously described for the other average speed results.

(2) Directional PTSF vs. flow rate
Figure 4-14 illustrates the relationship between directional PTSF and two-way flow rate.
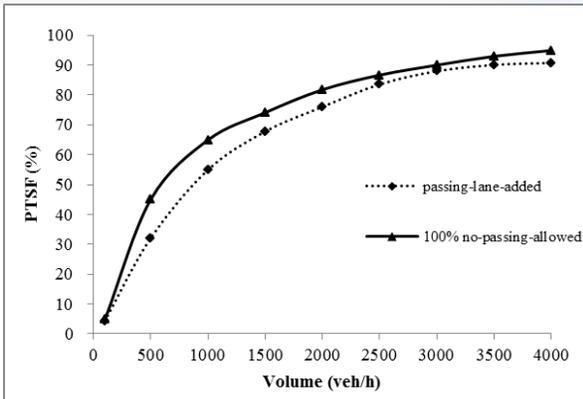
(a) EB PTSF, 50/50 Traffic Volume Split
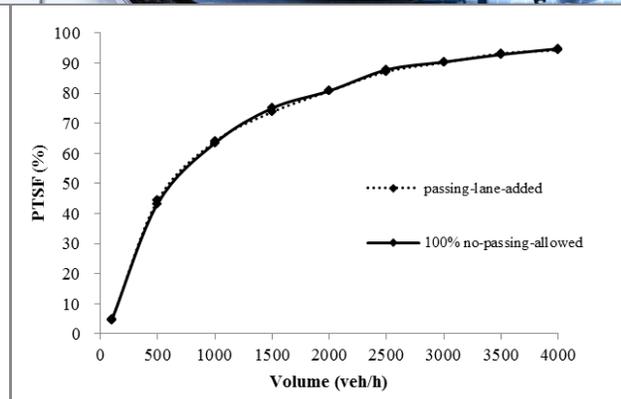
(b) WB PTSF, 50/50 Traffic Volume Split
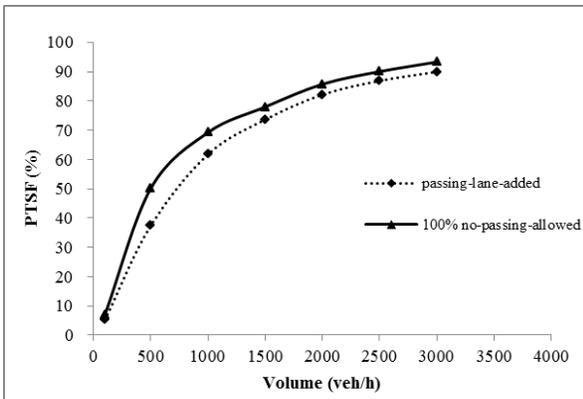
(c) EB PTSF, 60/40 Traffic Volume Split
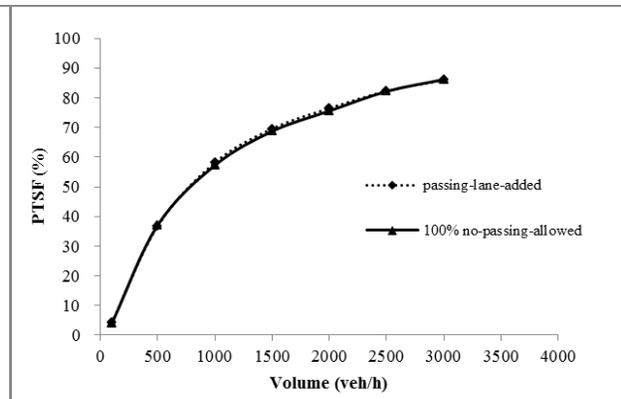
(d) WB PTSF, 40/60 Traffic Volume Split
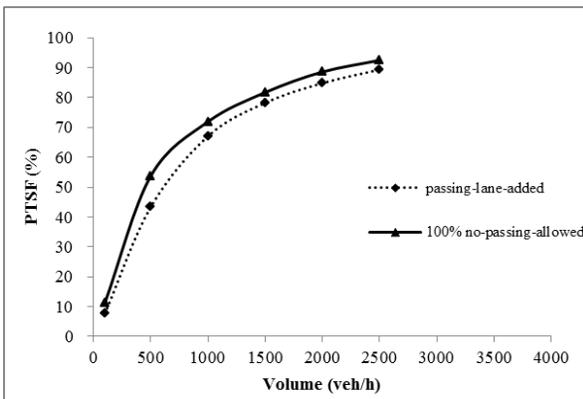
(e) EB PTSF, 70/30 Traffic Volume Split
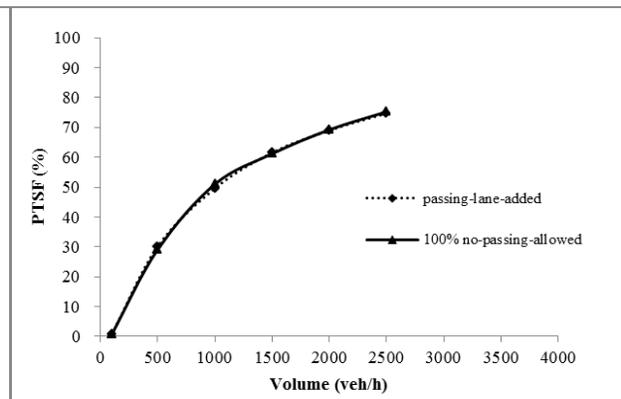
(f) WB PTSF, 30/70 Traffic Volume Split

**Figure 4-14    PTSF results for passing-lane tests**

The presence of the passing lane generally provides similar improvements to the PTSF values in the EB direction as found for the average speed results. Likewise, for the WB direction (with no passing lane), the PTSF results are virtually identical.

(3) Directional follower density vs. flow rate

Figure 4-15 illustrates the relationship between directional follower density and two-way flow rate.
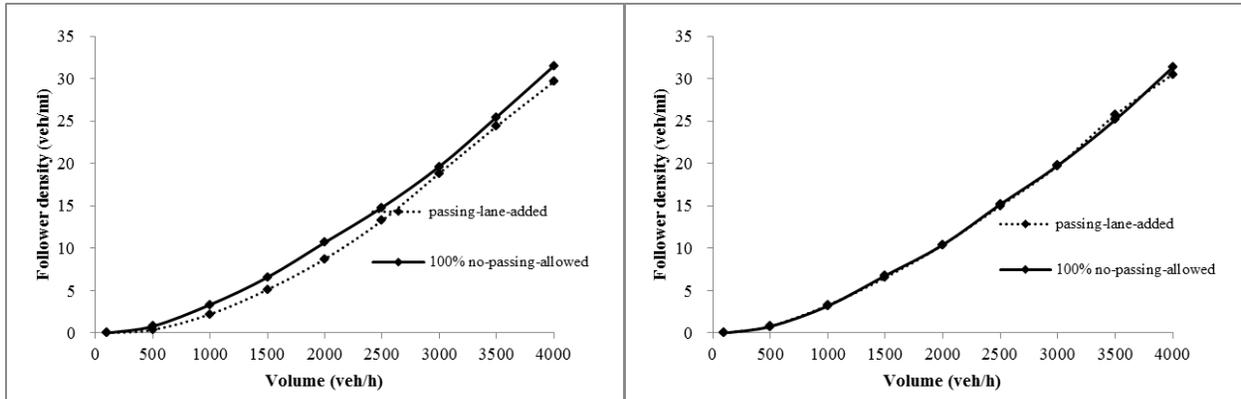


(a) EB Fo. Density, 50/50 Traffic Volume Split  (b) WB Fo. Density, 50/50 Traffic Volume Split
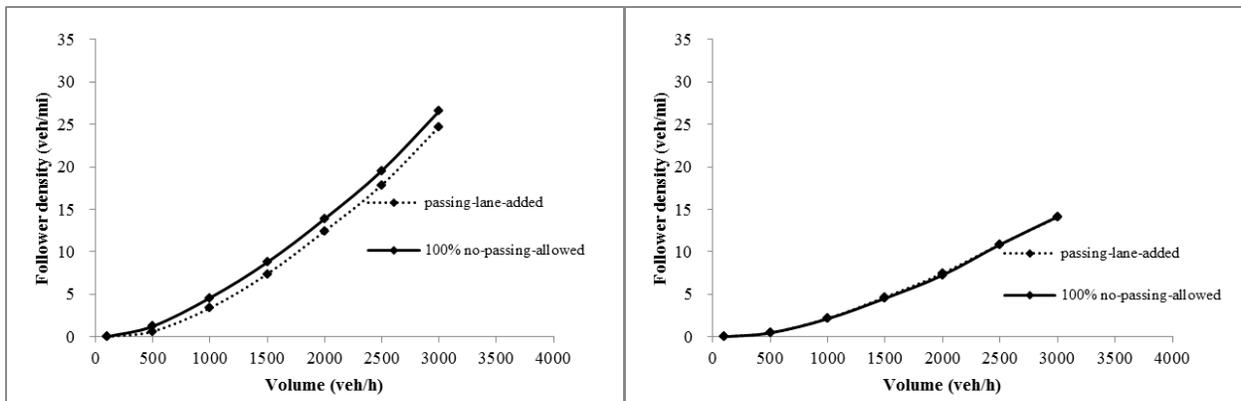
(c) EB Fo. Density, 60/40 Traffic Volume Split  (d) WB Fo. Density, 40/60 Traffic Volume Split
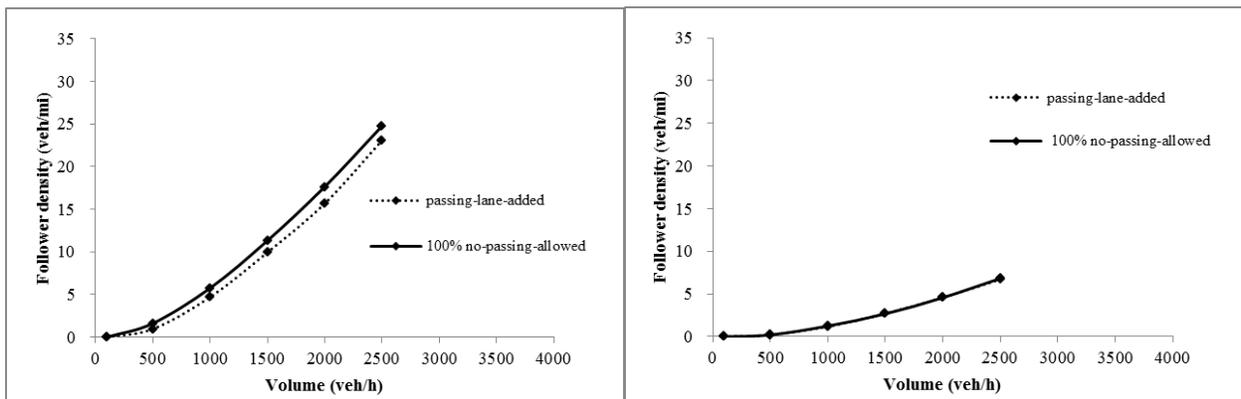
(e) EB Fo. Density, 70/30 Traffic Volume Split  (f) WB Fo. Density, 30/70 Traffic Volume Split

**Figure 4-15    Follower density results for passing-lane tests**

The presence of the passing lane generally provides similar improvements to the follower density values in the EB direction as found for the average speed results. Likewise, for the WB direction (with no passing lane), the follower density results are virtually identical.

2. Comparison of the performance measures on the segments immediately upstream and downstream of the passing lane segment

The test highway is 13 miles long, level terrain, 10 percent trucks (60 percent 30-foot long truck, 40 percent 64-foot long truck), and a passing lane added in the EB direction (the upstream segment is 10 miles long). No-passing-allowed marking is applied along the entire length of the highway. The free flow speed is 65 mi/h. Twenty-two experiments were run, and 10 iterations of each experiment were run. The presented results are the average of the 10 iterations.

The performance measures of the immediately upstream segment (1 mile) and the immediately downstream segment (1 mile) to the passing lane segment (see Figure 4-16 for the configuration) are compared to show the benefits of adding a passing lane. Only EB performance measures are compared here, as the performance of the westbound direction is not affected by the passing lane segment.
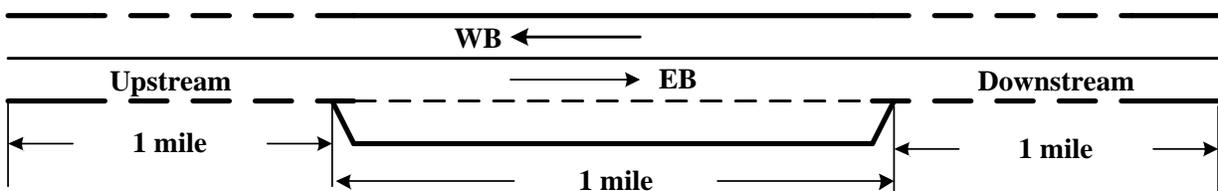


**Figure 4-16    Configuration of the Passing Lane Section**

(1)  EB average speed vs. flow rate

Figure 4-17 illustrates the relationship between EB average speed and two-way flow rate.
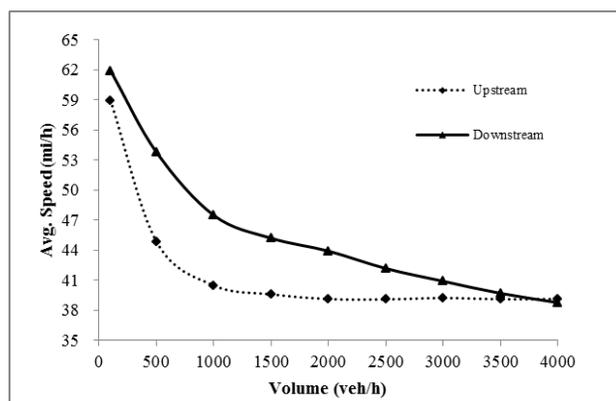


(a) EB Avg. Speed, 50/50 Traffic Volume Split
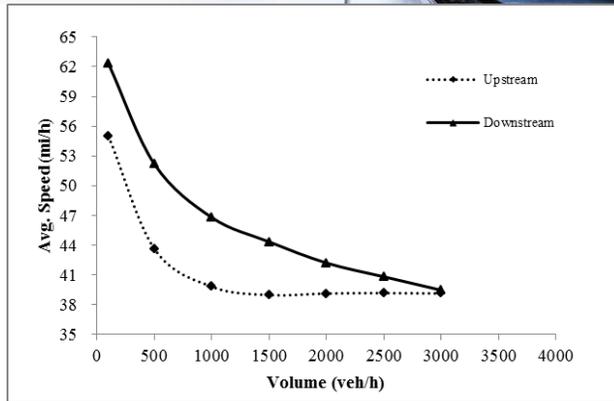
(b) EB Avg. Speed, 60/40 Traffic Volume Split
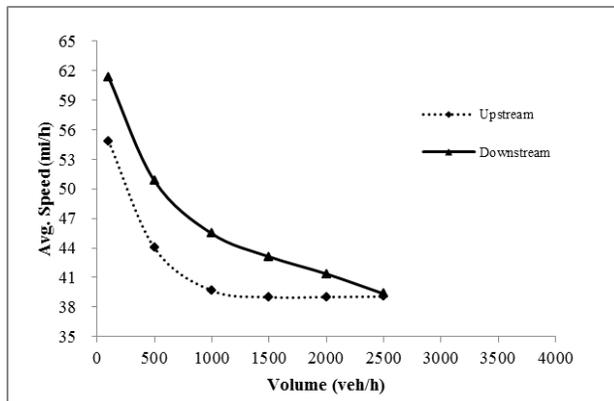


(c) EB Avg. Speed, 70/30 Traffic Volume Split

**Figure 4-17    Comparison of Average Speed Results between Upstream and Downstream Segments**

(2)  EB PTSF vs. volume

Figure 4-18 illustrates the relationship between EB follower density and two-way flow rate.
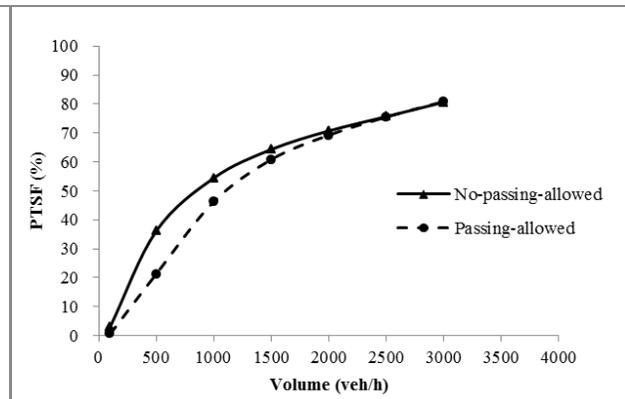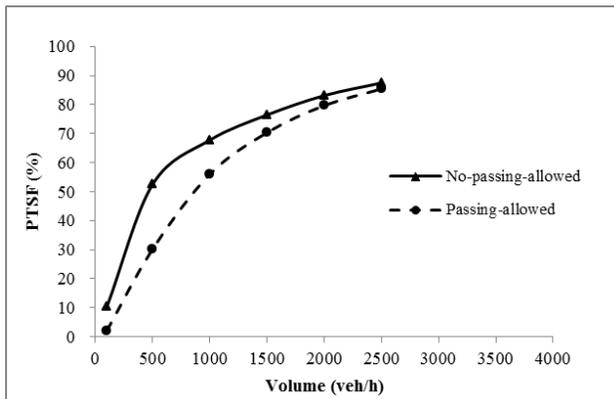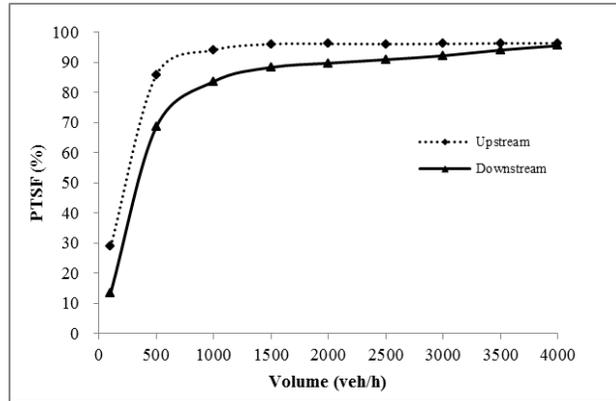


(a) EB PTSF, 50/50 Traffic Volume Split
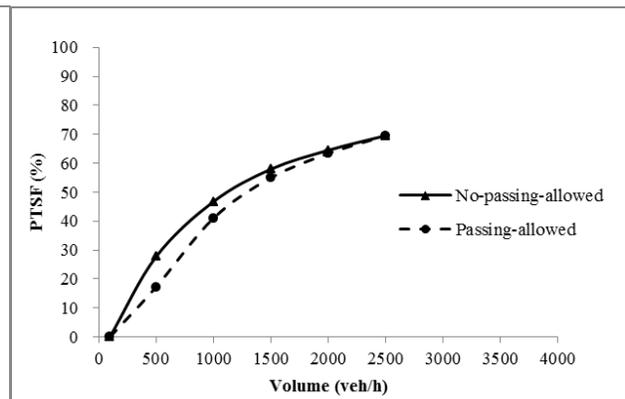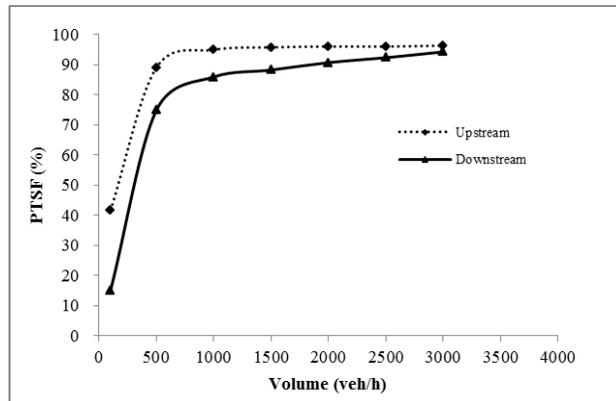


(b) EB PTSF, 60/40 Traffic Volume Split
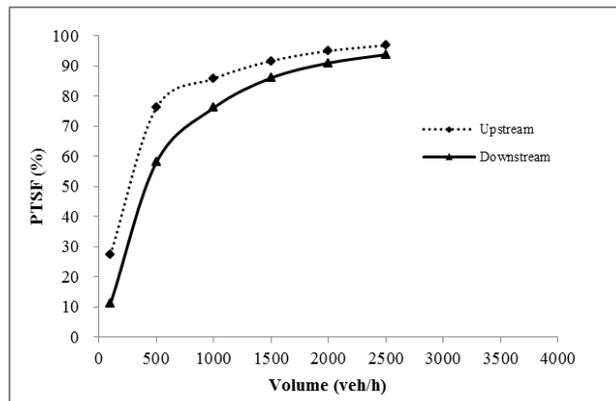


(c) EB PTSF, 70/30 Traffic Volume Split

**Figure 4-18    Comparison of PTSF Results between Upstream and Downstream Sections**

Figures 4-17 and 4-18 confirm the expectation that the passing lane results in improvements to the performance measures immediately downstream of the passing lane, relative to the conditions immediately upstream of the passing lane.

### 4.2.3 Two-lane highway with a signalized intersection tests

The test highway is 3 miles long, level terrain, no trucks, no passing lane and a signalized intersection is present in the middle (see Figure 4-19 for the facility configuration). Passing is not allowed in the NETSIM links used for modeling the signalized intersection operations. Additionally, passing is not allowed on the adjacent upstream and downstream 600-foot segments. Passing is allowed on all other segments. Only one experiment was run for this configuration, just to demonstrate that the effect of the signalized intersection is reflected in the facility performance measure results. The flow rate for the major highway is 500 veh/h (no trucks) for each direction, and the flow rate for the minor crossing street is 100 veh/h (no trucks) for each direction. The cycle length is 100 seconds. The results are compared to the passing-allowed but no signalized intersection condition results (all other inputs are the same). The results for the two scenarios are shown in Table 4-2.

**Table 4-2      Two-lane highway with a signalized intersection testing results**

|  |  | Avg. Speed (mi/h) | PTSF | Follower Density |
|---|---|---|---|---|
| Signalized intersection added | EB | 54.70 | 46.38 | 1.53 |
|  | WB | 54.67 | 46.87 | 1.56 |
| No signalized intersection | EB | 62.27 | 34.58 | 0.62 |
|  | WB | 62.20 | 35.03 | 0.65 |

The results in Table 4-2 confirm the expectation that adding a signalized intersection will worsen the performance measure results for the main two-lane highway. Additional investigation of the effects of signalized intersections along a two-lane highway will be conducted as part of a follow-up study.
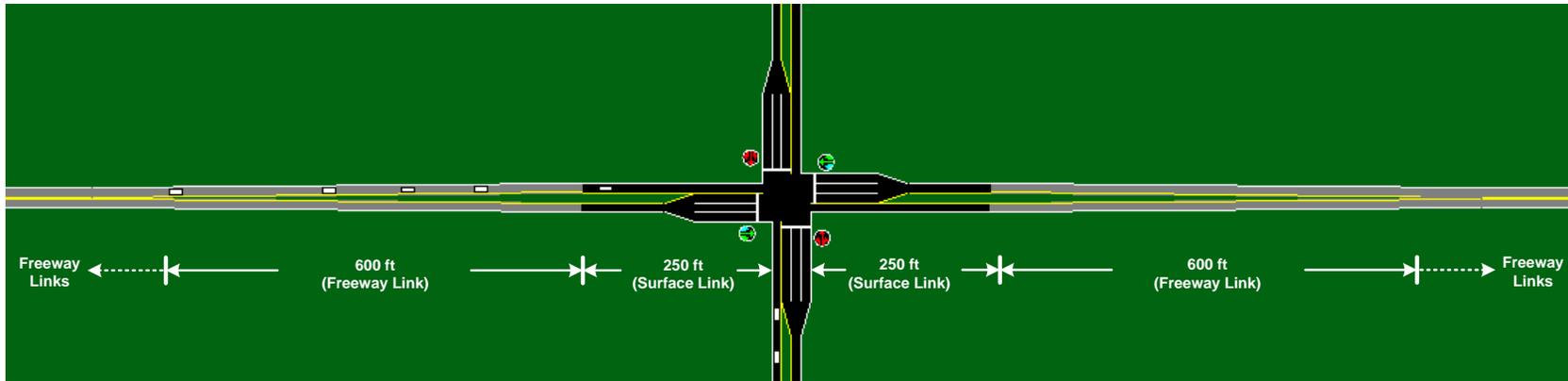
**Figure 4-19    Two-lane highway with a signalized intersection**

# CHAPTER 5    SUMMARY

In this project, the objective of implementing into CORSIM the ability to model two-lane highways was accomplished. More specifically, the modeling capabilities and features incorporated into CORSIM under this project include:

1. Basic two-lane highway segments with passing maneuvers (including passing one vehicle or multiple vehicles at a time) in the oncoming lane.
2. Two-lane highway segments with a passing lane.
3. Two-lane highway segments connecting to signalized intersections.
4. New TRF file inputs that allow the user to modify certain parameters of the two-lane highway modeling logic.
5. New performance measure outputs (e.g., PTSF and follower density) and passing maneuver data outputs.

With this new simulation capability in CORSIM, traffic operations on complex two-lane highways (e.g., two-lane highway with occasional signalized intersections) can be analyzed. It is anticipated that this tool will be used to revise or refine the two-lane facility analytical methodology developed by Yu and Washburn in a future project. Additionally, it is expected that this tool will be used to investigate the adequacy and accuracy of the existing HCM two-lane highway analysis methodology, which has been the subject of considerable debate and criticism over the years.

While the two-lane modeling logic is reasonably consistent with theories and field observations discussed in the literature, and the modeling results are generally reasonable and consistent with expected traffic-flow theory for two-lane highways, there are certainly several areas where additional research can be done to further refine and/or validate the current modeling logic as well as improve the capabilities. These areas include:

- Refinement of desire to pass (*DTP*) and willingness to move over (*WTMO*) algorithms through direct traveler input (e.g., through focus groups).
- Incorporation of additional performance measures as proposed in the literature.
- Modify the graphical network editor (TRAFED) to be able to accommodate editing of two-lane highway networks.

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# Appendices

**Appendix A: Passing zone codes and corresponding marking configurations**

| Scenario | Passing zone code | | Configuration | Description |
|---|---|---|---|---|
| | EB | WB | | |
| 1 | 1 | 1 | | Both directions are passing-not-allowed. |
| 2 | 2 | 1 | | Only EB lane is passing-allowed |
| 3 | 1 | 2 | | Only WB lane is passing-allowed |
| 4 | 3 | 3 | | Both directions are passing-allowed. |

## Appendix B:  Example TRF input files for two-lane highway configurations

1. Basic condition: 10 miles long, 50 percent passing-allowed and 50 percent no-passing-
   allowed, two-way volume is 1,000 veh/h, directional split is 60/40 (EB/WB), no trucks.

```
Created by TSIS Thu Oct 23 12:01:16 2008 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                       8  272008                           0   1
       1    0    1   20 97165909 0000   0              81917    6799963041456717   2
3600                                                                           3
           1       60                                                          4
     0        0    0    0    0    0    0    0    0    0    0    0               5
 101 102 103 52800 1                           1                              19
 102 103 104 52800 1                           1                              19
 103 104 105 52800 1                           1                              19
 104 105 106 52800 1                           1                              19
 105 106 107 52800 1                           1                              19
 106 107 108 52800 1                           1                              19
 107 108 109 52800 1                           1                              19
 108 109 110 52800 1                           1                              19
 109 110 115 52800 1                           1                              19
 110 1158003 52800 1                           1                              19
 201 206 207 52800 1                           1                              19
 206 207 208 52800 1                           1                              19
 207 208 209 52800 1                           1                              19
 208 209 210 52800 1                           1                              19
 209 210 211 52800 1                           1                              19
 210 211 212 52800 1                           1                              19
 211 212 213 52800 1                           1                              19
 212 213 214 52800 1                           1                              19
 213 214 215 52800 1                           1                              19
 214 2158004 52800 1                           1                              19
8100 101 102     0 1                           1                              19
8200 201 206     0 1                           1                              19
 101 102 0 0     0 11065                                          100 1       20
 102 103 0 0     0 11065                                          100 1       20
 103 104 0 0     0 11065                                          100 1       20
 104 105 0 0     0 11065                                          100 1       20
 105 106 0 0     0 11065                                          100 1       20
 106 107 0 0     0 11065                                          100 3       20
 107 108 0 0     0 11065                                          100 3       20
 108 109 0 0     0 11065                                          100 3       20
 109 110 0 0     0 11065                                          100 3       20
 110 115 0 0     0 11065                                          100 3       20
 201 206 0 0     0 11065                                          100 3       20
 206 207 0 0     0 11065                                          100 3       20
 207 208 0 0     0 11065                                          100 3       20
 208 209 0 0     0 11065                                          100 3       20
 209 210 0 0     0 11065                                          100 3       20
 210 211 0 0     0 11065                                          100 1       20
 211 212 0 0     0 11065                                          100 1       20
 212 213 0 0     0 11065                                          100 1       20
 213 214 0 0     0 11065                                          100 1       20
 214 215 0 0     0 11065                                          100 1       20
8100 101 0 0     0 11065                                                      20
8200 201 0 0     0 11065                                                      20
 101 102 103 100                                                              25
 102 103 104 100                                                              25
 103 104 105 100                                                              25
```

```
104 105 106 100                                                                        25
105 106 107 100                                                                        25
106 107 108 100                                                                        25
107 108 109 100                                                                        25
108 109 110 100                                                                        25
109 110 115 100                                                                        25
110 1158003 100                                                                        25
201 206 207 100                                                                        25
206 207 208 100                                                                        25
207 208 209 100                                                                        25
208 209 210 100                                                                        25
209 210 211 100                                                                        25
210 211 212 100                                                                        25
211 212 213 100                                                                        25
212 213 214 100                                                                        25
213 214 215 100                                                                        25
214 2158004 100                                                                        25
8100 101 102 100                                                                       25
8200 201 206 100                                                                       25
8100 101 600    0    0  100                                      100                    50
8200 201 400    0    0  100                                      100                    50
   3  35  70 150    0  50    0    0   3 120                                             71
   4  53  70 150    0  24    0    0   4 120                                             71
   5  53  70 150    0  23    0    0   5 120                                             71
   6  64  70 150    0   3    0    0   6 120                                             71
81008200                                                                              154
 300    0  25  75    5  10  12                                    10                   155
 140 143 147 150 100 180 250 300                                                      156
   0                                                                                  170
   0    6    2    2    2    2    2    2  -100-400-800-900-900-900                      173
   1Eastbound                                                                         190
   2Westbound                                                                         190
   18100 101 102 103 104 105 106 107 108 109 110 1158003                              191
   28200 201 206 207 208 209 210 211 212 213 214 2158004                              191
 101    300        0                                                                  195
 102   5580        0                                                                  195
 103  10860        0                                                                  195
 104  16140        0                                                                  195
 105  21420        0                                                                  195
 106  26700        0                                                                  195
 107  31980        0                                                                  195
 108  37260        0                                                                  195
 109  42540        0                                                                  195
 110  47820        0                                                                  195
 115  53100        0                                                                  195
 201  53100        0                                                                  195
 206  47820        0                                                                  195
 207  42540        0                                                                  195
 208  37260        0                                                                  195
 209  31980        0                                                                  195
 210  26700        0                                                                  195
 211  21420        0                                                                  195
 212  16140        0                                                                  195
 213  10860        0                                                                  195
 214   5580        0                                                                  195
 215    300        0                                                                  195
8003  53200        0                                                                  195
8004    200        0                                                                  195
8100    200        0                                                                  195
8200  53200        0                                                                  195
   1   0    0                                                                         210
```

2. 10 percent-truck condition: 10 miles long, 100 percent passing-allowed, two-way volume is 1,000 veh/h, directional split is 60/40 (EB/WB), 10 percent trucks.

```
Created by TSIS Thu Oct 23 12:01:16 2008 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                    8  272008                              0   1
      1    0    1   20 97165909 0000   0                81917   6799963041456717   2
3600                                                                          3
           1       60                                                         4
     0         0   0   0    0    0    0    0    0    0    0    0               5
 101 102 103 52800 1                         1                                19
 102 103 104 52800 1                         1                                19
 103 104 105 52800 1                         1                                19
 104 105 106 52800 1                         1                                19
 105 106 107 52800 1                         1                                19
 106 107 108 52800 1                         1                                19
 107 108 109 52800 1                         1                                19
 108 109 110 52800 1                         1                                19
 109 110 115 52800 1                         1                                19
 110 1158003 52800 1                         1                                19
 201 206 207 52800 1                         1                                19
 206 207 208 52800 1                         1                                19
 207 208 209 52800 1                         1                                19
 208 209 210 52800 1                         1                                19
 209 210 211 52800 1                         1                                19
 210 211 212 52800 1                         1                                19
 211 212 213 52800 1                         1                                19
 212 213 214 52800 1                         1                                19
 213 214 215 52800 1                         1                                19
 214 2158004 52800 1                         1                                19
8100 101 102     0 1                         1                                19
8200 201 206     0 1                         1                                19
 101 102 0 0    0 11065                                            100 3      20
 102 103 0 0    0 11065                                            100 3      20
 103 104 0 0    0 11065                                            100 3      20
 104 105 0 0    0 11065                                            100 3      20
 105 106 0 0    0 11065                                            100 3      20
 106 107 0 0    0 11065                                            100 3      20
 107 108 0 0    0 11065                                            100 3      20
 108 109 0 0    0 11065                                            100 3      20
 109 110 0 0    0 11065                                            100 3      20
 110 115 0 0    0 11065                                            100 3      20
 201 206 0 0    0 11065                                            100 3      20
 206 207 0 0    0 11065                                            100 3      20
 207 208 0 0    0 11065                                            100 3      20
 208 209 0 0    0 11065                                            100 3      20
 209 210 0 0    0 11065                                            100 3      20
 210 211 0 0    0 11065                                            100 3      20
 211 212 0 0    0 11065                                            100 3      20
 212 213 0 0    0 11065                                            100 3      20
 213 214 0 0    0 11065                                            100 3      20
 214 215 0 0    0 11065                                            100 3      20
8100 101 0 0    0 11065                                                       20
8200 201 0 0    0 11065                                                       20
 101 102 103 100                                                              25
 102 103 104 100                                                              25
 103 104 105 100                                                              25
 104 105 106 100                                                              25
 105 106 107 100                                                              25
```

```
 106 107 108 100                                                                25
 107 108 109 100                                                                25
 108 109 110 100                                                                25
 109 110 115 100                                                                25
 110 1158003 100                                                                25
 201 206 207 100                                                                25
 206 207 208 100                                                                25
 207 208 209 100                                                                25
 208 209 210 100                                                                25
 209 210 211 100                                                                25
 210 211 212 100                                                                25
 211 212 213 100                                                                25
 212 213 214 100                                                                25
 213 214 215 100                                                                25
 214 2158004 100                                                                25
8100 101 102 100                                                                25
8200 201 206 100                                                                25
8100 101 600  10   0  100                                      100              50
8200 201 400  10   0  100                                      100              50
    3  35  70 150   0  50   0   0   3 120                                       71
    4  53  70 150   0  24   0   0   4 120                                       71
    5  53  70 150   0  23   0   0   5 120                                       71
    6  64  70 150   0   3   0   0   6 120                                       71
81008200                                                                       154
 300   0  25  75   5  10  12                                    10             155
 140 143 147 150 100 180 250 300                                               156
   0                                                                           170
   0   6    2   2   2   2   2   2  -100-400-800-900-900-900                     173
   1Eastbound                                                                   190
   2Westbound                                                                   190
   18100 101 102 103 104 105 106 107 108 109 110 1158003                        191
   28200 201 206 207 208 209 210 211 212 213 214 2158004                        191
 101    300      0                                                              195
 102   5580      0                                                              195
 103  10860      0                                                              195
 104  16140      0                                                              195
 105  21420      0                                                              195
 106  26700      0                                                              195
 107  31980      0                                                              195
 108  37260      0                                                              195
 109  42540      0                                                              195
 110  47820      0                                                              195
 115  53100      0                                                              195
 201  53100      0                                                              195
 206  47820      0                                                              195
 207  42540      0                                                              195
 208  37260      0                                                              195
 209  31980      0                                                              195
 210  26700      0                                                              195
 211  21420      0                                                              195
 212  16140      0                                                              195
 213  10860      0                                                              195
 214   5580      0                                                              195
 215    300      0                                                              195
8003  53200      0                                                              195
8004    200      0                                                              195
8100    200      0                                                              195
8200  53200      0                                                              195
   1   0   0                                                                    210
```

3. Passing-lane condition: 10 miles long, 1-mile passing lane from mile 4 to mile 5, two-way
   volume is 1,000 veh/h, directional split is 60/40 (EB/WB), 10 percent trucks.

```
Created by TSIS Mon Jan 26 10:50:28 2009 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                      8  272008                              0   1
      1    0    1  20 97165909 0000   0                81917    6799963041456717   2
3600                                                                             3
           1        60                                                            4
    0         0    0    0    0    0    0    0    0    0    0    0                  5
 101 102 103 52800 1                           1                                 19
 102 103 104 52800 1                           1                                 19
 103 104 105 52800 1                           1                                 19
 104 105 106 52800 1                           1                                 19
 105 106 107 52800 1                           1                                 19
 106 107 108 52800 1                           1                                 19
 107 108 109 52800 1                           1                                 19
 108 109 110 52800 1                           1                                 19
 109 110 111 52800 1                           1                                 19
 110 1118003 52800 1                           1                                 19
 201 202 203 52800 1                           1                                 19
 202 203 204 52800 1                           1                                 19
 203 204 205 52800 1                           1                                 19
 204 205 206 52800 1                           1                                 19
 205 206 207 52800 1                           1                                 19
 206 207 208 52800 1                           1                                 19
 207 208 209 52800 1                           1                                 19
 208 209 210 52800 1                           1                                 19
 209 210 211 52800 1                           1                                 19
 210 2118004 52800 1                           1                                 19
8100 101 102     0 1                           1                                 19
8200 201 202     0 1                           1                                 19
 101 102 0 0     0 11065                                          100 1          20
 102 103 0 0     0 11065                                          100 1          20
 103 104 0 0     0 11065                                          100 1          20
 104 105 0 0     0 11065                                          100 1          20
 105 106 0 0     0 11065                                          100 1          20
 106 107 0 0     0 11065                                          100 1          20
 107 108 0 0     0 11065                                          100 1          20
 108 109 0 0     0 11065                                          100 1          20
 109 110 0 0     0 11065                                          100 1          20
 110 111 0 0     0 11065                                          100 1          20
 201 202 0 0     0 11065                                          100 1          20
 202 203 0 0     0 11065                                          100 1          20
 203 204 0 0     0 11065                                          100 1          20
 204 205 0 0     0 11065                                          100 1          20
 205 206 0 0     0 11065                                          100 1          20
 206 207 0 0     0 11065                                          100 1          20
 207 208 0 0     0 11065                                          100 1          20
 208 209 0 0     0 11065                                          100 1          20
 209 210 0 0     0 11065                                          100 1          20
 210 211 0 0     0 11065                                          100 1          20
8100 101 0 0     0 11065                                                         20
8200 201 0 0     0 11065                                                         20
 101 102 103 100                                                                 25
 102 103 104 100                                                                 25
 103 104 105 100                                                                 25
 104 105 106 100                                                                 25
 105 106 107 100                                                                 25
```

```
 106 107 108 100                                                                  25
 107 108 109 100                                                                  25
 108 109 110 100                                                                  25
 109 110 111 100                                                                  25
 110 1118003 100                                                                  25
 201 202 203 100                                                                  25
 202 203 204 100                                                                  25
 203 204 205 100                                                                  25
 204 205 206 100                                                                  25
 205 206 207 100                                                                  25
 206 207 208 100                                                                  25
 207 208 209 100                                                                  25
 208 209 210 100                                                                  25
 209 210 211 100                                                                  25
 210 2118004 100                                                                  25
8100 101 102 100                                                                  25
8200 201 202 100                                                                  25
 105 106   1 1      50              2 1    5000 1500                              32
8100 101 600  10   0  100                                     100                 50
8200 201 400  10   0  100                                     100                 50
   3  35  70 150   0  50   0   0   3 120                                          71
   4  53  70 150   0  24   0   0   4 120                                          71
   5  53  70 150   0  23   0   0   5 120                                          71
   6  64  70 150   0   3   0   0   6 120                                          71
81008200                                                                        154
 300   0  25  75   5  10  12                                  10                 155
 140 143 147 150 100 180 250 300                                                156
   0                                                                            170
   0   6    2   2   2   2   2   2  -100-400-800-900-900-900                      173
   1Eastbound                                                                    190
   2Westbound                                                                    190
   18100 101 102 103 104 105 106 107 108 109 110 1118003                        191
   28200 201 202 203 204 205 206 207 208 209 210 2118004                        191
 101    300      0                                                              195
 102   5580      0                                                              195
 103  10860      0                                                              195
 104  16140      0                                                              195
 105  21420      0                                                              195
 106  26700      0                                                              195
 107  31980      0                                                              195
 108  37260      0                                                              195
 109  42540      0                                                              195
 110  47820      0                                                              195
 111  53100      0                                                              195
 201  53100      0                                                              195
 202  47820      0                                                              195
 203  42540      0                                                              195
 204  37260      0                                                              195
 205  31980      0                                                              195
 206  26700      0                                                              195
 207  21420      0                                                              195
 208  16140      0                                                              195
 209  10860      0                                                              195
 210   5580      0                                                              195
 211    300      0                                                              195
8003  53200      0                                                              195
8004    200      0                                                              195
8100    200      0                                                              195
8200  53200      0                                                              195
   1   0   0                                                                    210
```

4. Signalized intersection condition: 10 miles long, a signalized intersection in the middle, two-way volume is 1,000 veh/h, directional split is 50/50 (EB/WB), 10 percent trucks.

```
Created by TSIS Thu Sep 10 17:41:20 2009 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                    8  272008                          0   1
     1   0   1  20 97165909 0000  0              31917    6799963041456717   2
3600                                                                        3
          1       60                                                        4
   0       0   0   0   0   0   0   0   0   0   0   0                         5
   1   4 150          1      01           7003           20  18  30  0      11
   1   5 400          1      01           8002           20  18  30  0      11
   1   2 150          1      01           7001           20  18  30  0      11
   1   3 400          1      01           8001           20  18  30  0      11
   3   1 400 100 100 1 1 1 01        4    5    2     5   20  18  30  0      11
   5   1 400 100 100 1 1 1 01        2    3    4     3   20  18  30  0      11
   6   1 150 100 100 1 1 1 01        5    2    3         20  18  30  0      11
   7   1 150 100 100 1 1 1 01        3    4    5         20  18  30  0      11
   27001 100          1      01                          20  18  30         11
7002   7 100          1      01            1             20  18  30  0      11
   47003 100          1      01                          20  18  30         11
7004   6 100          1      01            1             20  18  30  0      11
8001   3              1      01            1             20  18      0      11
8002   5              1      01            1             20  18      0      11
   1   4     100                                                           21
   1   5     100                                                           21
   1   2     100                                                           21
   1   3     100                                                           21
   3   1  20  60  20   0                                                    21
   5   1  20  60  20   0                                                    21
   6   1  20 460  20   0                                                    21
   7   1  20 460  20   0                                                    21
   27001     100                                                           21
7002   7     100                                                           21
   47003     100                                                           21
7004   6     100                                                           21
8001   3     100                                                           21
8002   5     100                                                           21
   2   1                                                                    35
   3       18001                                                            35
   4   1                                                                    35
   5       18002                                                            35
   6    7004                                                                35
   7    7002                                                                35
   2 1                                                                      36
   3 11                                                                     36
   4 1                                                                      36
   5 11                                                                     36
   6 1                                                                      36
   7 1                                                                      36
   1   7   1   5   1   6   1   3   1          0                             43
   1   1 22222      22222      22122      22222                             45
   1   2 22222      22222      11122      22222                             45
   1   3 22222      22222      22222      11122                             45
   1   5 12222      22222      22222      22222                             45
   1   6 11122      22222      22222      22222                             45
   1   7 22222      11122      22222      22222                             45
   1 1   14 1030   0   0      100   0   0 300 300 20 0000010000000   0   0 0   0 47
   1 2   66 4430   0   0      640   0   0 300 300 20 20000010010000  0   0 0   0 47
```

```
    1 3   38 2630    0   0      60    0   0 300 300 20 20000010000000    0    0 0    0   47
    1 5   14 1030    0   0     100    0   0 300 300 20  0000010000000    0    0 0    0   47
    1 6   66 4430    0   0     640    0   0 300 300 20 20000010010000    0    0 0    0   47
    1 7   38 2630    0   0      60    0   0 300 300 20 20000010000000    0    0 0    0   47
 8002    5 100   10   0  100                                                             50
 8001    3 100   10   0  100                                                             50
  100   81  69   40  50   15    0                                                       141
    8                                                                                   170
  104 105 106 26400 1                             1                                      19
  105 1067002 44300 1                             1                                      19
  107 108 109 44300 1                             1                                      19
  108 1098005 26400 1                             1                                      19
  204 205 206 26400 1                             1                                      19
  205 2067004 44300 1                             1                                      19
  207 208 209 44300 1                             1                                      19
  208 2098006 26400 1                             1                                      19
 7001 207 208  6000 1                             1                                      19
 1067002       6000 1                             1                                      19
 7003 107 108  6000 1                             1                                      19
 2067004       6000 1                             1                                      19
 8003 204 205     0 1                             1                                      19
 8004 104 105     0 1                             1                                      19
  104 105 0 0     0 11065                                                    100 3       20
  105 106 0 0     0 11065                                                    100 3       20
  107 108 0 0     0 11065                                                    100 3       20
  108 109 0 0     0 11065                                                    100 3       20
  204 205 0 0     0 11065                                                    100 3       20
  205 206 0 0     0 11065                                                    100 3       20
  207 208 0 0     0 11065                                                    100 3       20
  208 209 0 0     0 11065                                                    100 3       20
 7001 207 0 0     0 11065                                                    100 1       20
 1067002 0 0     0 11065                                                    100 1       20
 7003 107 0 0     0 11065                                                    100 1       20
 2067004 0 0     0 11065                                                    100 1       20
 8003 204 0 0     0 11065                                                                20
 8004 104 0 0     0 11065                                                                20
  104 105 106 100                                                                        25
  105 1067002 100                                                                        25
  107 108 109 100                                                                        25
  108 1098005 100                                                                        25
  204 205 206 100                                                                        25
  205 2067004 100                                                                        25
  207 208 209 100                                                                        25
  208 2098006 100                                                                        25
 7001 207 208 100                                                                        25
 7003 107 108 100                                                                        25
 8003 204 205 100                                                                        25
 8004 104 105 100                                                                        25
 8003 204 500   0   0  100                                   100                         50
 8004 104 500   0   0  100                                   100                         50
    3   35  70 150   0  50    0   0   3 120                                              71
    4   53  70 150   0  24    0   0   4 120                                              71
    5   53  70 150   0  23    0   0   5 120                                              71
    6   64  70 150   0   3    0   0   6 120                                              71
80037003                                                                               154
80047001                                                                               154
    0                                                                                  170
    0    6    2   2   2   2   2   2 -100-400-800-900-900-900                            173
    1Eastbound                                                                          190
    2Westbound                                                                          190
    18004 104 105 1067002    7   1   47003 107 108 109                                  191
```

```
 28003 204 205 2067004    6    1    27001 207 208 209                                     191
    1     26500        500                                                                195
    2     26350        506                                                                195
    3     26500        900                                                                195
    4     26650        494                                                                195
    5     26500        100                                                                195
    6     26650        506                                                                195
    7     26350        494                                                                195
  104     18580        500                                                                195
  105     21220        500                                                                195
  106     25650        500                                                                195
  107     27350        500                                                                195
  108     31780        500                                                                195
  109     34420        500                                                                195
  204     34420        500                                                                195
  205     31780        500                                                                195
  206     27350        500                                                                195
  207     25650        500                                                                195
  208     21220        500                                                                195
  209     18580        500                                                                195
 7001     26250        506                                                                195
 7002     26250        494                                                                195
 7003     26750        494                                                                195
 7004     26750        506                                                                195
    1      0    0                                                                         210
```