Implementing Two-lane Highway Simulation Modeling into CORSIM

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Abstract

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 a more developed area. 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.

Currently, 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 operations within these areas and to assist with developing a facility-level analysis methodology, a simulation tool is required. However, the existing simulation tools cannot fully meet the research demands.

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 primary issues that had to be addressed to implement this modeling capability included: developing the model components that deal with passing maneuvers in an oncoming lane, developing the model components that deal with passing lanes, and developing a mechanism to link highway segments to signalized intersections. Preliminary testing showed that the developed two-lane highway modeling logic produced results that are reasonably consistent with expected traffic flow theory and field observations discussed in the literature.

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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. Furthermore, it is designed to run in the DOS operating system, which makes it very difficult to run on modern computers. 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.

To fill this void, a simulation tool that is capable of modeling the combination of two-lane highway segments and signalized intersections was developed in the CORSIM environment. 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.

2. Modeling components of two-lane highway operations

The major components involved in modeling the two-lane highway passing maneuvers (either oncoming lane or passing lane) are car following, passing in oncoming lane, passing in a passing lane section. Each of these components is described in detail in the following subsections.

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 desired gap between it and the leading vehicle.

2.2. Passing in 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.

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 percent time-spent-following (PTSF). The value of 3 seconds, however, can be changed by the analyst in the input file. 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. Tolerable speed varies for different driver types (See Eq. 1 for the computation), due to the different degree of aggressiveness for each driver type. 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% of the link free-flow speed, while a driver of type 10 will have a desired speed of 112% of the link free-flow speed (these percentages of free-flow speed can be modified by users on record type 147 of the input file).

\[
TolerableSpeed_i = \frac{DesiredSpeed_i}{80+i} \times \frac{100}{100}
\]  

where

\(TolerableSpeed_i\) = tolerable speed for driver type \(i\) (mi/h), and

\(DesiredSpeed_i\) = desired speed for driver type \(i\) (mi/h).

3. Determine the desire to pass

The main factor influencing a driver’s desire to pass is the difference between their actual travel speed and their desired speed. The degree of the following driver’s desire to pass is quantified as a number between 0 and 1 based on a non-linear function of the current speed of the subject vehicle. The initial desire to pass (DTP) value is given by

\[
DTP = \begin{cases} 
1, & \text{if Current speed } < \text{Tolerable speed} \\
0, & \text{if Current speed } = \text{Desired speed} \\
\left(\frac{1}{\text{(Desired speed } - \text{Current speed))} \times \left(\frac{1}{\text{Desired speed } - \text{Tolerable speed}}\right)\right)^b, & \text{otherwise}
\end{cases}
\]

The \(DTP\) is illustrated graphically in Figure 1 for one example driver.

![Figure 1. An Example of Desire to Pass for a Specific Driver](image-url)
The \( DTP \) value is first 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 impatience factor is also a function of the driver type, with larger increments being associated with more aggressive drivers. The \( TSWTP \) 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 impatience value can be adjusted on record type 155. The impatience factor value is given by the following equation

\[
ImpatienceFactor = TSWTP \times ImpatienceValue \times \sqrt{DT}
\]  

where

- \( TSWTP \) = time spent wanting to pass (s),
- \( DT \) = driver type (defined by CORSIM), and
- \( ImpatienceValue \) = degree of impatience in waiting to pass (default = 0.001).

The \( DTP \) is then 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. The final adjustment to the \( DTP \) value \( (AdjDTP) \) is given by

\[
AdjDTP = (DTP + ImpatienceFactor) \times \left[ 1 - \left( \frac{1}{14} - \frac{1}{TrailLeng} \right) \times \ln \left( \exp(1) - \left( \frac{1}{14} - \frac{1}{LeadLeng} \right) \times \left( \frac{LeadLeng}{TrailLeng} \right)^{0.5} \right) \right]
\]

where

- \( TrailLeng \) = Length of the trailing vehicle (ft), and
- \( LeadLeng \) = Length of the leading vehicle (ft).

It should be noted that the value of 14 used in Eq. 4 is the shortest length of vehicle defined in CORSIM.

Finally, if the adjusted \( DTP \) value is not less than 0.25 (considered the practical minimum for a driver to want to make a pass), it will be compared to a generated uniform random number between 0 and 1. If the adjusted \( DTP \) value is greater than or equal to the random number, the subject vehicle will initiate a passing maneuver, subject to other constraints as described in the following section.

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)\(^2\). 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 8.

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.

\(^2\) For computational efficiency reasons, this check is actually performed before the desire to pass calculations.
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 5 vehicles that would need to be passed.

5. Check whether any queued vehicle exists within 1-mile downstream of the subject vehicle
A vehicle whose speed is equal to or less than 30 ft/s within 1-mile downstream from the subject vehicle is considered to be queued. If any queued vehicle is found, the subject vehicle will not initiate its passing maneuver.

6. 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 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)\(^3\). Both *A policy on Geometric Design of Highways and Streets* [AASHTO, 2004] and the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) [FHWA, 2003] provide minimum PSD values for design and marking. However, their respective recommended PSD values vary significantly, with the AASHTO-recommended values being considerably larger than the MUTCD-recommended values.

Harwood et al. [2008] proposed recommendations on the adequacy of current procedures and guidelines used to estimate minimum PSD requirements for highway design and pavement marking. Based on a literature review and a field study, Harwood et al. [2008] indicated that the Glennon model [1988] and the Hassan et al. model [1996] are the most reasonable models, which result in considerably shorter PSD values than the AASHTO-recommended values and values much closer to the MUTCD-recommended values. Furthermore, the Harwood et al. [2008] study argued that crash statistics for two-lane highways do not provide much support for the notion that the current practice for marking passing zones (based on the MUTCD criteria) is in need of revising.

Based on the field data results of the Harwood et al. [2008] study, the authors recommend the following assumptions be used when applying the Glennon and Hassan et al. models:

1. The speeds of the passing and opposing vehicles are equal and represent the design speed of the highway.
2. The vehicle being passed travels at uniform speed and the speed difference between the passing vehicle and vehicle being passed is 12 mi/h.
3. The passing vehicle has sufficient acceleration capability to reach the specified speed difference relative to the passed vehicle by the time it reaches the critical position\(^4\) (same as the assumption that each vehicle will travel at the constant speed after the critical position).
4. The lengths of the passing and passed vehicles are 19 ft.
5. The passing driver’s perception-reaction time in deciding to whether to abort a pass is 1 sec.
6. The deceleration rate used in aborting a pass is 11.1 ft/s\(^2\).
7. For a completed or aborted pass, the headway between the passing and passed vehicles is 1 sec.
8. The minimum clearance headway between the passing and opposing vehicles at the point at which the passing vehicle returns to its normal lane is 1 sec.

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\(^3\) 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.

\(^4\) A study by Harwood and Glennon [1976] defined the critical position as the point at which the sight distances required to abort the pass and to complete the pass are equal. Two studies, one by Van Valkenburg et al. [1971] and one by Weaver et al. [1972] independently recognized a key position of a passing maneuver occurs at the point where the passing driver can no longer safely abort the pass and is, therefore, committed to complete it. However, no unanimously accepted definition of the critical position currently exists. Harwood et al. [2008] suggests that the critical position can be considered to be the point when the passing vehicle and vehicle being passed are directly abreast of one another. This is the definition applied in the CORSIM logic.
By using these assumptions, the Glennon and Hassan et al. models result in \( PSD \) values similar to the MUTCD-recommended \( PSD \) values.

The default \( PSD \) model used in CORSIM is the AASHTO model. However, it is also possible to use the MUTCD \( PSD \) values instead. Users can modify several CORSIM inputs to implement the MUTCD \( PSD \) values. If the available sight distance for the subject vehicle is equal to or greater than the minimum required \( PSD \) value, the following check is made.

7. 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 distance traveled by the passer before it returns to the normal lane during the passing maneuver, as suggested by AASHTO). 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.

8. 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. This results in an effective passing zone length, calculated as follows:

\[
\text{IllegalPassDistPct} = \begin{cases} 
\text{MinPct}, & \text{if Driver Type} = 1 \\
\text{MaxPct}, & \text{if Driver Type} = 10 \\
\text{Linear interpolation}, & \text{otherwise}
\end{cases} \quad (5)
\]

where

\( \text{IllegalPassDistPct} \) = allowable percentage of the total passing distance beyond the passing zone (as indicated by roadway markings),

\( \text{MinPct} \) = allowable percentage of the total passing distance corresponding to vehicle of driver type 1 (default = 0), and

\( \text{MaxPct} \) = allowable percentage of the total passing distance corresponding to vehicle of driver type 10 (default = 25).

\[
\text{DistAvailForPass} = \text{AvailPassZoneDist} + \text{AvailPassZoneDist} \times \frac{\text{IllegalPassDistPct}}{100} \quad (6)
\]

where

\( \text{DistAvailForPass} \) = the total amount of distance available for passing, based on roadway markings and allowable distance downstream of marked passing zone, and

\( \text{AvailPassZoneDist} \) = length of marked passing zone available at beginning of passing maneuver.

The distance needed to complete the pass (\( DNTCP \)), which before the passing maneuver is initiated is equal to the estimated distance traveled by the subject vehicle during its passing maneuver (in the \( PSD \) calculations in step 6), is compared to the distance available for the pass (i.e., effective passing zone length). If the \( DNTCP \) is less than the effective passing zone length, then the passing maneuver can be initiated.

2.2.3. How a potential passer executes 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, as illustrated in Figure 2.

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 the AASHTO criteria or revised AASHTO criteria for approximating the MUTCD criteria. At the same time, the potential passer moves over to the opposing lane.
Stage 2: 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 record type 155) greater than the speed of the vehicle being passed. Meanwhile, the variable $DNTCP$ (distance needed to complete pass) is compared to the variable $DTC$ (distance to collision with the oncoming vehicle) every time step (see Figure 3 for an illustration of these variables). For a subject vehicle that needs to pass more than one vehicle during the passing maneuver (based on available gaps in the traffic stream ahead), the $DNTCP$ is based on the position of the most downstream vehicle to be passed.

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5 Based on NCHRP Report 605 [Harwood et al, 2008].
6 The $DTC$ will be infinite when no oncoming vehicle is present.
As mentioned previously, before the passing maneuver is initiated, the DNTCP is equal to the estimated distance traveled by the subject vehicle during its passing maneuver (in the PSD calculations in step 6). However, once the passing maneuver is in progress, the DNTCP is continually changing (generally decreasing). For calculating DNTCP, the time needed to complete passing (TNTCP) is first calculated. Since the potential passer will stop accelerating when its speed is 12 mi/h (i.e., 17.6 ft/s) greater than the vehicle being passed, the value of TNTCP is computed by

\[
TNTCP = \begin{cases} 
(t_{\text{accel}} - (t - t_0) + t_{\text{const}}, & 0 \leq t - t_0 \leq t_{\text{accel}} \\
(t_{\text{const}} - (t - t_0 - t_{\text{accel}}), & t - t_0 > t_{\text{accel}}
\end{cases}
\] (7)

\[
t_{\text{accel}} = \frac{v_2(0) + m - v_1(0)}{a_1}
\] (8)

\[
t_{\text{const}} = \frac{\text{ClearGap} - (\text{VehPos}_1 - \text{VehPos}_2)}{m}
\] (9)

where

- **TNTCP** = time needed to complete passing (s),
- **t_{\text{accel}}** = time needed to reach the maximum passing speed (s)
- **t_{\text{const}}** = time needed to complete passing after the acceleration period,
- **t_0** = time step when the passing maneuver initiates (s),
- **t** = current time step (s),
- **v_1(0)** = initial speed of the passing vehicle (ft/s),
- **v_2(0)** = initial speed of the vehicle being passed (ft/s),
- **m** = speed differential between the passing vehicle and the vehicle being passed when the passing vehicle reaches the maximum passing speed (12 mi/h by default),
- **a_1** = acceleration of the passing vehicle (ft/s²),
- **VehPos_1** = position of the passing vehicle relative to the upstream end of the segment when it stops accelerating (ft), and
- **VehPos_2** = position of the vehicle being passed relative to the upstream end of the segment when the passing vehicle stops accelerating (ft).

Once the TNTCP is obtained, the DNTCP can be calculated by

\[
DNTCP = \begin{cases} 
\left\{(v_1(t) + a_1[t_{\text{accel}} - (t - t_0)]\right\}TNTCP - \frac{1}{2}a_1[t_{\text{accel}} - (t - t_0)]^2, & 0 \leq t - t_0 \leq t_{\text{accel}} \\
(v_1(t) \cdot TNTCP, & t - t_0 > t_{\text{accel}}
\end{cases}
\] (10)
where
\[ v_1(t) = \text{speed of the passing vehicle at time step } t \text{ (ft/s)}, \text{ and} \]
\[ v_2(t) = \text{speed of the vehicle being passed at time step } t \text{ (ft/s)}. \]

\[ DTC = (\text{VehPos}_3 - \text{VehPos}_2) - v_3(t) \frac{(\text{VehPos}_3 - \text{VehPos}_1)}{v_3(t) + v_2(t)} \quad (11) \]

where
\[ \text{VehPos}_3 = \text{position of the oncoming vehicle relative to the upstream end of the segment at time step } t \text{ (ft)}, \text{ and} \]
\[ v_3(t) = \text{speed of the oncoming vehicle at time step } t \text{ (ft/s)}. \]

After the subject vehicle moves into the opposing lane to perform its passing maneuver, the value of \( DNTCP \) is compared to the value of \( DTC \) at every time step until the passing maneuver is completed or aborted. 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 (i.e., \( \text{ClearGap} \) in Figure 3) is 75 ft, but can be revised on record type 155. Normally, 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. In some cases, the passing vehicle will consider to pass the next vehicle if the gap in front of the vehicle being passed is not sufficient. However, if the passing vehicle has already passed 5 vehicles, it will be forced to squeeze back into the normal lane.

2. \( DNTCP \geq DTC \)
   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.
   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 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. In the simulation, the vehicle being passed is set to be aware of this expedited passing, and it usually slows down to assist the completion of the passing maneuver. Occasionally, the vehicle being passed may not slow down even though it is aware of the situation, and in such cases, the passing vehicle will be forced to abort its passing maneuver.

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.

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 that an impeding vehicle will not move 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 determined as follows:

\[
WTMO = \begin{cases} 
0, & \text{if } SVS > (FFS + 5) \\
\frac{(FFS + 5 - SVS)}{15}, & \text{if } (FFS - 10) < SVS < (FFS + 5) \\
1, & \text{if } SVS < (FFS - 10) 
\end{cases}
\]

where

\[
WTMO = \text{willingness to move over,} \\
SVS = \text{subject vehicle speed (mi/h), and} \\
FFS = \text{free-flow speed (mi/h).}
\]

This parameter will be adjusted by dividing by the square root of driver type if the length of the subject vehicle is less than 40 ft (the length of a single-unit truck), otherwise it remains as the original value (not dividing by the square root of driver type results in a higher probability to move over for trucks). The adjusted willingness to move over is compared to a generated uniform random number between 0 and 1, and if it is greater than the random number the subject vehicle will move over to the right lane; otherwise, it will stay in the left lane.

The existing CORSIM lane-change 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.

2.4. Integrating signalized intersections into a two-lane highway facility

CORSIM consists of two simulation modules: 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 module.

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 modules to accommodate the modeling of signalized intersections within a two-lane highway. To define a two-lane highway network that contains signalized intersections, the interface (i.e., connection) between the two-lane highway links and the signalized intersection links will be made by utilizing the interface nodes defined in CORSIM.
3. Inputs and outputs of the simulation program

3.1. New inputs

Several new inputs were added to CORSIM to accommodate user revision of various parameters for the two-lane highway modeling logic. Many of these inputs have already been mentioned in this paper, but for a complete summary, see Washburn and Li [2010].

3.2. New outputs

Several new outputs were added to CORSIM to accommodate a variety of new performance measures and passing lane diagnostics.

(1) Performance measure outputs
In the HCM 2000, the level of service on a two-lane highway is defined in terms of both percent time-spent-following and average travel speed. In CORSIM, these two measures are calculated on a link and facility basis. Another performance measure that has been used internationally for the assessment of two-lane highway operations, follower density, is also calculated in CORSIM on a link and facility basis.

(2) Passing statistics outputs
Multiple passing maneuver statistics are available for output from CORSIM, including the number of attempted passes, the number of aborted numbers, the number of vehicles passed during a passing maneuver, the time and position when/where the passing maneuver was initiated, and the distance traveled by the passer in the opposing lane during the passing maneuver, among others.

4. Testing and conclusion

4.1. Testing results

A large number of experiments were conducted for the purpose of comparing the simulation results (based on the logic described in the previous sections) to commonly accepted traffic-flow theories for two-lane highways. In these experiments, follower density, percent time-spent-following (PTSF), and average speed were chosen as the performance measure outputs.

Figure 4 shows some results from the 10-mile long basic two-lane highway tests. The volume split is 50/50 in this example, therefore, the results of each performance measure look similar for both directions, only eastbound results are presented here. It’s indicated in Figure 4(a) that the average speeds are higher for the passing allowed condition than the no-passing allowed condition, and the average speeds converge at high flow rates, as expected. High flow rates severely limit the passing opportunities; thus, essentially creating a no-passing-allowed condition. The PTSF results presented in Figure 4(b) and the follower density results in Figure 4(c) are consistent with the results for average speed.
A test on a two-lane highway segment with a signalized intersection was done, and the results 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.

4.2. Conclusion

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 [2010] 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.

The two-lane highway modeling logic is reasonably consistent with theories and field observations discussed in the literature, and the testing results are generally reasonable and consistent with expected traffic-flow theory for two-lane highways. Nonetheless, it is expected that additional enhancements will be implemented in response to user modeling needs as they arise and/or revised traffic flow theories as developed from field studies.

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References


