USING TWOPAS SIMULATION MODEL TO PROVIDE DESIGN AND OPERATIONS INFORMATION ON THE PERFORMANCE OF IDAHO'S TWO-LANE HIGHWAYS

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National Institute for Advanced Transportation Technology

UNIVERSITY OF IDAHO

Michael P. Dixon

Sarah Haderlie

Satya Sai Kumar Sarepalli

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1 INTRODUCTION TO TWOPAS

Two-lane rural highways are the predominant highway facility in the state of Idaho and ITD has given much attention in recent years to improving the operations and safety of these highways. Some of the design options that have been considered for these facilities are the introduction of passing lanes, improvement of sight distance, and roadway re-alignment. Software packages are available for evaluating these different design alternatives. In the past ITD has occasionally used a software package called TWOPAS to analyze these design options, but currently, ITD has limited capability in using the TWOPAS software because of the time required to learn the program. Furthermore, recent changes in the program have rendered obsolete some of the experience that ITD has with TWOPAS.

In this document, the first chapter describes the purpose of the model, its history, the program structure, and the model capabilities and limitations. The second chapter describes the input process beginning with the overall organization of the data in terms of time and location, then a description of the input data, and finally an overview of the user interface. The third chapter describes the output data that are available as well as the methods for accessing and outputting the data with particular emphasis given to the new user interface. Next, three test projects are presented in chapter four. As data is input, comments are provided to clarify the selection of model options in TWOPAS. Screen shots are included to give the reader a frame of reference and resulting values are pointed out at regular intervals so the reader can assure themselves that they are following the example correctly. In chapter five, a sensitivity analysis of common design variables related to two lane highways is presented. Variables included in this analysis are traffic volumes, horizontal curvature, passing lane length, shoulder width, lane width, and grade. In chapter six, comparisons of Highway Capacity Manual procedure results to specific TWOPAS results are made to illustrate commonalities and inconsistencies between the two methods. Finally, the seventh chapter summarizes the work, giving emphasis to areas of particular concern when using the model.

1.1 Purpose of the model

The TWOPAS simulation model is used to provide design and operations information regarding the performance of two-lane rural highways. The traffic flows on two-lane two-way

rural highways are affected by different variables such as highway geometry, traffic control, the traffic characteristics, and the driver population. However, field data collection is expensive, nearly always incomplete relative to some measures of effectiveness (i.e., speed, delay, etc.) and there is no opportunity to examine the traffic operational effects of systematic variations in traffic control, geometry, flow rates, and vehicle characteristics.

An attractive support for field data is modeling traffic operations given the prevailing conditions of the roadway being analyzed. An analytic simulation model that contains a realistic account of highway geometry, traffic control, traffic characteristics, and driver behavior can be used to study the impact of these variables on traffic operations and this is the purpose of TWOPAS.

1.2 History

The TWOPAS model is a microscopic computer simulation model of traffic on two-lane highways. The predecessor of TWOPAS was originally developed by Midwest Research Institute (MRI) between 1971 and 1974 as a part of the NCHRP Project 3-19, "Grade Effects on Traffic Flow Stability and Capacity" [1]. The model was initially known as TWOWAF (TWO Way Flow) and was improved by MRI in 1981 in an FHWA study entitled, "Implications of Light-Weight, Low-Powered Vehicles in the Traffic Stream" [2]. Then, in 1983, the Texas transportation Institute (TTI) and KLD and Associates made further updates to TWOWAF, which resulted in the version of the model that was used in the development of 1985 Highway Capacity Manual (HCM) [3]. TWOWAF had the capability to simulate traffic operations on normal two-lane highways, including both passing and no-passing zones, as well as the effects of horizontal curves, grades, vertical curves and sight distance. Subsequent to the publication of the 1985 HCM, MRI developed the TWOPAS model by adding to TWOWAF the capability to simulate passing lanes, climbing lanes, and short-four-lane sections on two-lane highways.

1.3 Program structure

TWOPAS was originally developed on a mainframe computer and this original version of TWOPAS is not user friendly. An improved interface was needed to increase the user friendliness of TWOPAS and to allow it to be used effectively in the PC environment.

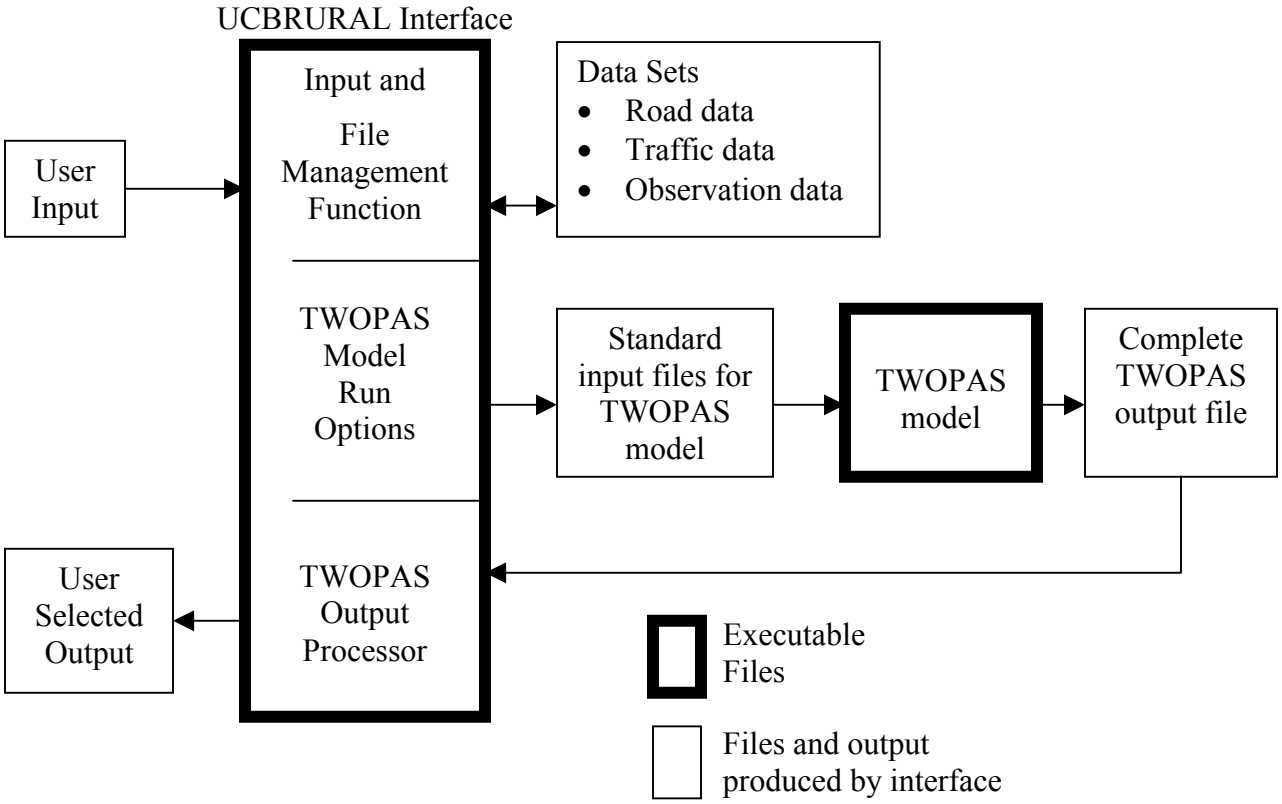


Figure 1.1 Functional framework for the UCBRURAL interface [4]

In the recent work for the California Department of Transportation, the Institute of Transportation Studies (ITS) at the University of California-Berkeley (UCB) has developed a user interface, known as UCBRURAL, for use with the TWOPAS model. The interface allows the user to input all data in a user-friendly manner and the functional framework of the interface is shown in Figure 1.1, which is also shown in the UCBRURAL software.

1.3.1 Description of each of the components in the framework

Each component of the UCBRURAL interface is discussed below, with the intention of informing the user of how the interface elements work together for operating the TWOPAS simulation. The actual implementation of UCBRURAL in conjunction with TWOPAS is discussed and demonstrated in Chapters 2 through 4.

1. User input: interface allows the user to input the data like road geometry, traffic data, type of model runs, and desired output.

2. Input and file management function: component of the interface that allows the user to create and manage data sets required to run TWOPAS.
3. Data sets: three data sets are created from the user input. The data sets are the road data set, the traffic data set and the observation data set.
    - *The Road Data Set* contains details of the barrier lines, passing lanes, curves, sight distance, and road grades at regular intervals. This set defines the geometric conditions of the highway to be studied.
    - *The Traffic Data Set* contains the volume, composition, and desired speeds of directional traffic, it also describes the platooning of the traffic entering the roadway section and the simulation.
    - *The Observation Data Set* contains the location of observing points and observing intervals along the simulated road. These points and intervals define where simulation information will be collected and the intervals over which this information will be aggregated, respectively.
4. TWOPAS model run options: component of the interface that controls the type of run being made by TWOPAS.
5. Standard input file: The UCBRURAL interface creates a standard TWOPAS input file from the current data sets and provides it to the TWOPAS model.
6. TWOPAS: executable file that processes the data sets, performs the simulation.
7. TWOPAS Output File: file generated by the simulation run.
8. TWOPAS output processor: component of the interface which processes TWOPAS output files into aggregate data and graphics.
9. User selected output: When the user requests either screen or hardcopy output from a TWOPAS run, the UCBRURAL interface extracts the necessary output variables from the output produced by the TWOPAS model and then produces the necessary graphs.

1.4 Capabilities

The model simulates traffic operations on two-lane highways by reviewing the position, speed, and acceleration of each individual vehicle on a simulated roadway at 1-second intervals and advancing those vehicles along the roadway in a realistic manner. To provide a more realistic representation of traffic operations, the model takes into account the effects of road

geometry, traffic control, driver preferences, vehicle size and performance characteristics, and the oncoming and same direction vehicles that are within sight at any given time. Specific features of the TWOPAS model are listed below [5].

- Three general vehicle types can be specified– passenger cars, recreational vehicles, and trucks.
- Roadway geometry that can be specified includes horizontal and vertical curves, sight distance, passing lanes, climbing lanes and short four-lane sections.
- Traffic controls in the form of passing and no-passing zones marked on the roadway can be specified by the user or calculated automatically based on the horizontal and vertical alignment.
- Entering traffic streams at each end of the simulated roadway are generated in response to a user-specified flow rate, traffic mix, and percent of traffic platooned, or can be entered based on field data.
- Variations in driver performance and preferences are generally default values but can be changed or updated if the data is available.
- Driver speed choices in unimpeded traffic are based on a user-specified distribution of driver desired speeds.
- Driver speed choices in impeded traffic are based on a car-following model that simulates driver preferences for following distances, based on relative leader/follower speeds, driver desired speeds, and the desire to pass the leader.
- Processing of traffic and updating of vehicle speeds, accelerations, and positions occurs at intervals of 1 second of simulated time.
- Driver decisions concerning initiating passing maneuvers in the opposing lane, continuing/aborting passing maneuvers, and returning to the normal lane, are based on default values but may be changed if data is available.
- Driver decisions concerning behavior in passing/climbing/four-lane sections, including lane choice at the beginning of the added lane, lane changing/passing within the added lanes and at lane the lane drops, are based on default values but may be changed if data available.

1.5 Limitations

As with all models, TWOPAS has its limitations. Some of them are related to the model capabilities, while others are related to data input. Listed below are some limitations that were found during the project as well as in the literature.

- Passing maneuvers in TWOPAS have been modeled based on field data collected in the 1970's [6].
- No intersection operations or turning movements are modeled [6].
- Turnout operations are not modeled [6].
- Data intense input—may be able to rectify in some cases by providing an interface between design software and the simulation software.
- The flexibility of TWOPAS and its current interface, UCBRURAL, regarding traffic characteristics is limited. Specifically, it does not allow variations in AADT, the vehicle and driver characteristics can not be changed from the user interface, and the definition of a platooned vehicle can not be modified from the user interface.
- Knowledge of the surrounding environment such as intersections, bridges, environmentally sensitive areas, earth works, roadside obstructions, etc. is not considered.
- If consideration of restricted sight distances due to roadside obstructions is necessary they must be manually entered.
- The definition of the roadway is entered in subsections, which limits the detail and accuracy of input.

2 CREATING TWOPAS FILES

2.1 Operating UCBRURAL

UCBRURAL uses a format similar to windows. Like windows, it has a horizontal menu with pull downs. Also, it allows for use of the mouse in the Road data file and after a file has been created or edited. To initially activate the menu press F10, and then use the arrow keys to toggle to your desired option. Pressing the enter key activates the highlighted option.

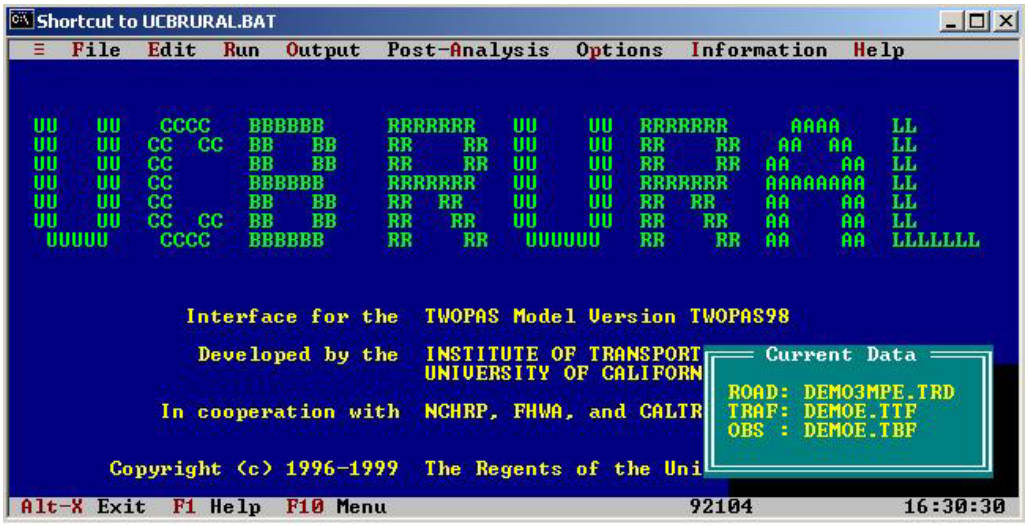


Figure 2.1 Main View UCBRURAL.

There are three types of data input files created in the UCBRURAL interface: 1) Road Data, 2) Traffic Data, and 3) Observation data. When these files are open their names are shown in the "Current Data" box in the lower right hand corner of the UCBRURAL main view, as shown in Figure 2.1. A new Road data file must be created, or an existing file opened, before either a traffic or observation data file can be created or a traffic file opened (an observation file can be opened before a traffic data file). To complete a TWOPAS simulation, all three files must be opened and compatible and the terms of compatibility are discussed later. UCBRURAL creates a text file, "twopas.inp", based on the input in these three data files and this is the text file that TWOPAS actually reads.

Another option for creating an input file is to by-pass the interface and directly create, or modify a "twopas.inp" file in the correct format for TWOPAS. This option is much more involved and is not addressed in this project.

2.2 Basic Navigation in UCBRURAL

The tab and arrow keys are most useful for movement when working in a data file. In both the Observation data and Traffic data files, the tab key must be used to move throughout the screen. UCBRURAL breaks the section of highway being analyzed into equal length subsections, which are organized into rows on the data input screen.

Movement in the Road data file is accomplished with the mouse, arrow keys for movement of one row at a time, or page up or down keys for movement of ten rows at a time. Each row contains information of a discrete subsection of the entire highway section being analyzed. The mouse only allows horizontal movement, the arrow keys allow for both horizontal and vertical movement through the file, and the page up or down keys allow vertical movement. Also, the home key will move the curser to the first row while the end key moves it to the last row.

2.3 Creating a UCBRURAL Road Data File

The road data file is created first and is created using a series of subsections, which have a uniform, user defined length. There are two ways to create this file: using zones or sections. The default method is zones, but this can be changed by selecting Options on the main menu and then selecting Environment. The Road data entry heading under Environment allows the user to switch between entering data by zones or road section.

2.3.1 Zones

Under the zone method, the interface asks the user for the uniform length of each subsection and the number of subsections in the road data set. All subsections are then created using default values. The user modifies the subsections to match the correct data. Modifications are only needed at the beginning of each change in roadway characteristic (called a zone). The interface will automatically modify all consecutively similar subsections to the new inputted value. For example, say subsections one through five have a grade of 0% but the sixth

subsection has a grade of 5%, as shown in black characters in Figure 2.2. The user would like to modify this grade data so that sections three, four, and five have 2% grades. Typically, the user would change each value individually. Fortunately, if the user has selected the zones method for entering road data, then all that needs to be changed is the grade for the third subsection. The gray characters in Figure 2.2 represent the changes in the road data that occurred due to the change in the third subsection. When 2% was entered for the third subsection, subsections four and five were modified to 2% with no additional input from the user. No other subsections changed and this rule will apply whenever editing the road data.

Subsection	Grade (%)
1	0
2	0
3	0 → 2%
4	0 → 2%
5	0 → 2%
6	5
7	5

Figure 2.2 Example of Zone Road Data Entry.

2.3.2 Sections

The section entry method asks the user for the uniform length of the subsections. Once the subsection length is entered, press the down key to begin entering data. The user then creates one subsection at a time. Once the correct values are inputted for the first section, press the add button to create the next subsection. This new subsection will have the same values as the previous subsection. Continue this process until the desired road length is achieved. In the section entry method, the interface will not make any automatic changes in either entry or editing.

In both the zone and section methods of entering data, subsections maybe added, inserted, or deleted. This is done by choosing the corresponding button at the bottom of the screen with the mouse. Adding a subsection places a new subsection at the end of roadway. The new subsection has the exact same values as the previous subsection. The insert button places a new subsection directly after the subsection which is highlighted at the time. The new subsection has

the same values as the highlighted subsection. The delete button deletes the highlighted subsection and subsequently shortens the road way by one subsection.

Subsection length is an important variable in the road data set, because data can only be inputted at the beginning of each subsection and the quality of the model of the roadway is directly proportional to the length of the subsections. Also, the number of observation points made by TWOPAS is determined by subsection length, because the smallest allowable increment between observed points is a subsection. In summary, when choosing subsection length keep the following in mind:

- TWOPAS can handle up to 30 miles of roadway.
- The minimum number of subsections is 4 and the maximum is 1200.
- All subsections have a uniform length.
- The default value for a subsection length is 528 ft (.1 miles) and can vary from 52.8 ft (.01 miles) to 5280 ft (1 mile).
- Advantages to smaller subsections:
  - More detail can be added.
  - The model roadway can more closely represent the actual roadway.
- Disadvantages to smaller subsection:
  - They can shorten the possible length of the roadway because TWOPAS can only allow 1200 subsections.
  - It may require more time to input the data.

2.3.3 Steps in Creating a new Road Data File

1. In the main menu, select File.
2. Under File, select the New option.
3. Enter length and number of subsections if using the zone method.
4. If using the section method, enter the subsection length and press the down arrow.
5. Enter the roadway data.

6. Using the mouse, press the exit key.
7. Name and Save the Road data file.
8. To edit the road data file after exiting, chose the Edit option in the main menu and select Road data.

2.3.4 Inputting Road Data

Once a new Road Data File has been created, the user must input the correct field data. There are nine types of field data and they are as follows:

1. Barrier Lines
2. Auxiliary Lanes
3. Sight Distance
4. Lane Width
5. Shoulder Width
6. Grade
7. Horizontal Curve Radius
8. Sections of Mandatory Reduced Speed
9. Direction of Roadway

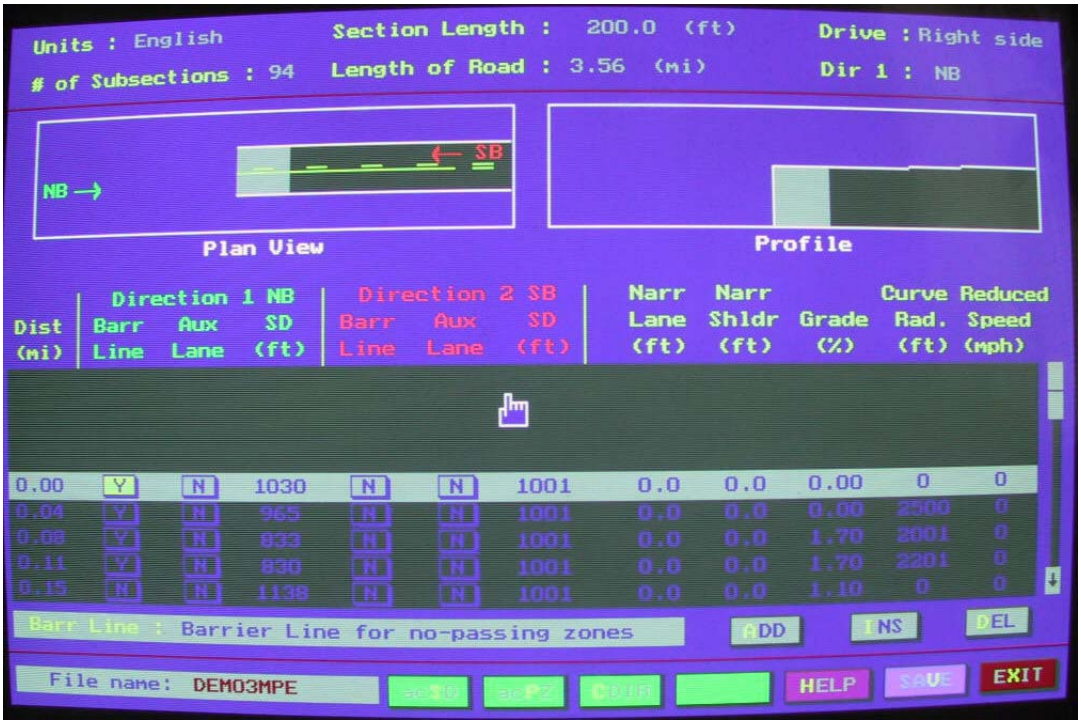


Figure 2.3 Road Data Input Screen.

Figure 2.3 shows the screen in which the road data is input to UCBRURAL. To enter data, use the arrow keys to select the desired subsection. Then use the mouse or arrow keys to select the desired field data, and enter the correct data. There is no need to delete; the interface will automatically overwrite any existing data.

2.3.5 Sight Distance

Sight distance is the distance along the roadway that is visible to a driver. This is calculated from the eye height of the driver, and may be determined in two ways: 1) the user may calculate their own sight distance for each subsection and input that and 2) the interface will automatically calculate sight distance based on horizontal and vertical alignment. The automatic calculation done by UCBRURAL does not take into account any sight obstructions other than road geometry and roadside clearance. For trees, hills, or structures that obstruct a driver's view, the sight distance must be modified manually and entered as part of the road data.

To activate the automatic calculation, select the AcSD button in the road data file. Enter the offset in each direction, which is the distance from the centerline to the outermost edge of the right-of-way, and click okay.

In the automatic calculation, sight distance is calculated up to ten times per subsection but no closer than ten feet apart. A total of 600 sight distance zones per direction of roadway can be calculated. The smallest sight distance value calculated in a subsection will be adopted as the sight distance for that subsection. Calculations are rounded to the nearest hundred. If the calculated sight distance is greater than 2000 feet, the interface will enter 2000 feet as the sight distance.

2.3.6 Barrier Lines

This alerts UCBRURAL to the existence of passing and no passing zones. The user enters either Y or N. Y means a barrier line is present in that direction (passing is not allowed). N means no barrier line is present in that direction (passing is allowed).

An option is available in the road data file for UCBRURAL to calculate the placement of barrier lines based on sight distance due to road geometry. To activate this, using the mouse, press the button labeled AcPZ. The user must then enter the minimum length of roadway and the minimum sight distance to complete a pass. Note: If using the automatic sight distance calculations, barrier lines should be calculated after sight distance is calculated.

UCBRURAL has another barrier line feature. In the main menu, under Options and then Environment, is an option named ACPZ Barr Opp Pass Lane. There are two selections under this heading: Forced-no-passing and Based-on-sight distance. Forced-no-passing creates a double barrier line whenever there is a passing lane, including the tapers. The “based-on-sight distance” option calculates the barrier lines in the opposing direction based on the sight distance. This option must be changed prior to running ACPZ to reflect the changes in the barrier lines.

2.3.7 Auxiliary Lanes (Passing/Climbing Lanes)

The user selects Y or N for each subsection. The Y indicates the presence of an auxiliary lane in that direction. A N means there is no auxiliary lane in that direction. Auxiliary lanes include climbing lanes and passing lanes.

2.3.8 Narrow Lanes and Narrow Shoulders

The effect of narrow lanes and shoulders can be entered in feet. In this software, it is assumed that operational effects of narrow shoulders occur at widths less than or equal to six feet. However, at this point the effects of narrow lanes have not been implemented in this software.

2.3.9 Grade

Enter the average grade for each subsection, entering the percent form of the grade. For vertical curves, enter code 99, by typing a 99 in the grade field of the appropriate subsection. The interface allows for 600 grade zones. The user must decide whether to assume a vertical curve, depending on its significance in the vertical alignment of the section in which it resides. If the vertical alignment in the section is primarily composed of tangents then it would be best to emphasize the most prominent grade.

2.3.10 Horizontal Curves

For horizontal curves, enter the radius of the curve in the appropriate subsection or subsections. A positive radius creates a curve to the right while a negative radius indicates a curve to the left. A zero place in a horizontal curve field means there is no curve. UCBRURAL allows up to 150 curves per roadway.

2.3.11 Sections of Mandatory Reduced Speed

These are sections in a roadway where the speeds are mandated to be lower than the desired travel speed. An example of this is a sharp curve where the speed limit is reduced temporarily. If such a section does exist, enter the average reduced speed in the appropriate subsections. The maximum speed in this field is 70 mph and the minimum is 10 mph. A zero place in this field means the speed is not reduced.

2.3.12 Direction of Roadway

This option allows the user to select the compass direction of the roadway. The default is set so that direction one is north bound and direction two is south bound. This can be altered by selecting the CDIR button in the road data file. Then select the desired roadway direction and

press OK In the road data file, the abbreviation for the compass direction should appear in the heading of each road direction.

2.3.13 Creating a Warm up Distance

It is desirable to have a warm up distance for each direction of roadway so the traffic simulation can normalize before TWOPAS starts collecting data, as shown in Figure 2.4. There are two main types of warm up zones and each is recommended to be approximately one mile [6]. The first type is the use of a fabricated roadway for the warm up distance and the second type is to use actual roadway for the warm up distance [7].

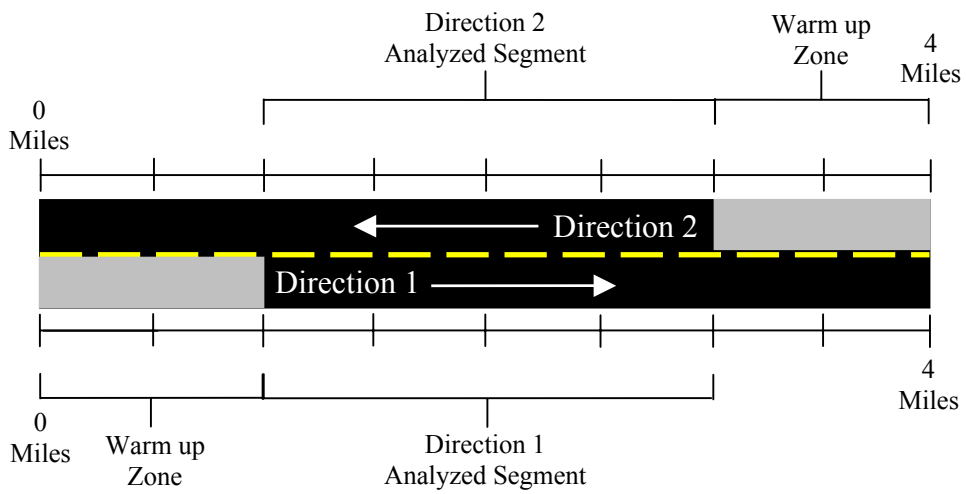


Figure 2.4 Warm-Up Zones.

For the fabricated warm up distance, add the desired length to the beginning and end of each roadway, and use the interface field defaults. In the observation data, change the first and end observation points to 0.1 of a mile plus the warm up distance. So if your warm up distance was 1 mile than the beginning point for observations would be 1.1 miles. This is explained again later when observation data is discussed.

When using the actual roadway as the warm up distance, input a longer roadway by extending the desired test roadway on both ends. The locations of the first and last observation points would be a distance equal to the warm up distance plus the length of a subsection from the beginning and end of the highway section.

2.4 Creating a UCBRURAL Traffic Data File

To create a new traffic data file, select the File option on the main menu then choose "New" and then select "Traffic data". When the data entry is complete save and name the file. It is sometimes helpful to use the same naming convention for the three corresponding data files to show that they are related. Five types of traffic data are required for each direction. The data are listed below and the traffic data input window is shown in Figure 2.5:

1. Traffic Volume
2. Percent Traffic in Platoons
3. Percent Traffic by Vehicle Type
4. Mean Speeds by Vehicle Type
5. Standard Deviation of Mean Speeds by Vehicle Type

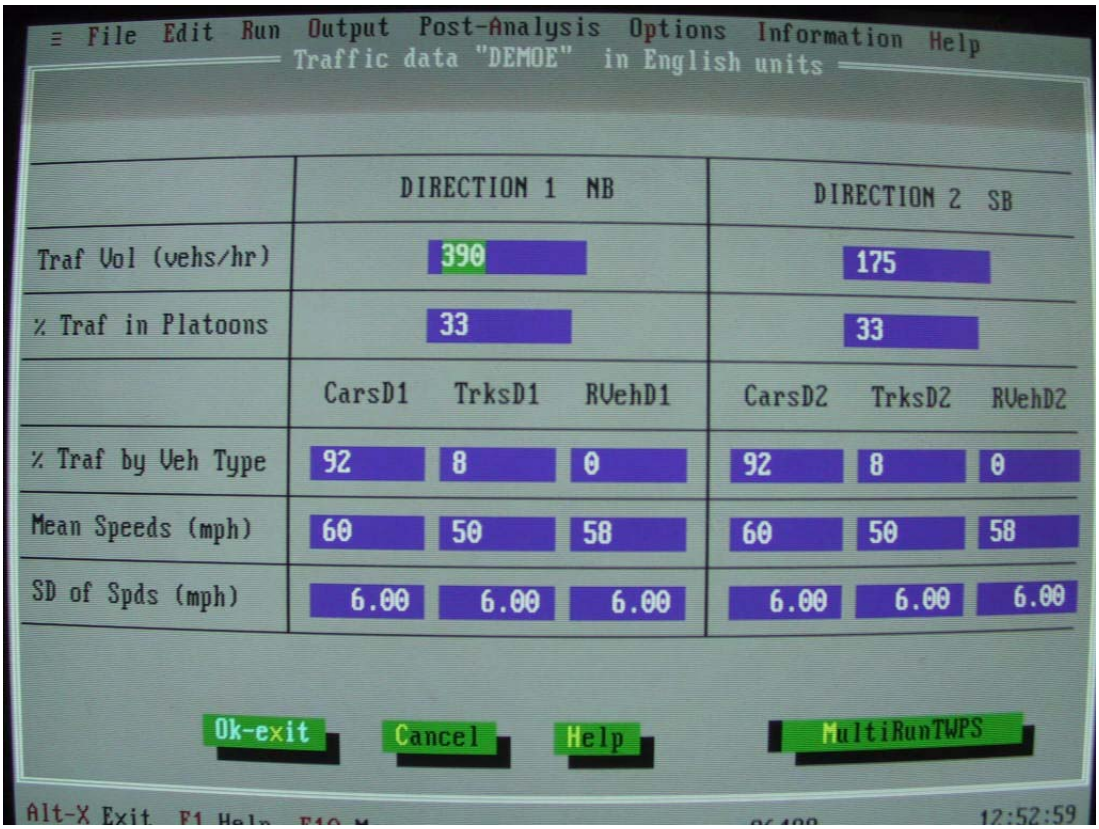


Figure 2.5 Traffic Data Input Window.

2.4.1 Traffic Volume

Traffic volume is calculated as vehicles per hour and must be entered for both

directions of traffic. The interface allows input to be between 10-2000 vehicles per hour, although 2000 is usually too large for the simulation and can result in incomplete output.

2.4.2 Percent Traffic in Platoons

Percent traffic in platoons is the percent of vehicles in platoons entering the study area. This is based on user collected field data. If such data is not available, a zero can be entered and the interface will calculate percent platoons based on flow as in figure 8-1 in the 1985 Highway Capacity Manual, as shown in Figure 2.6.

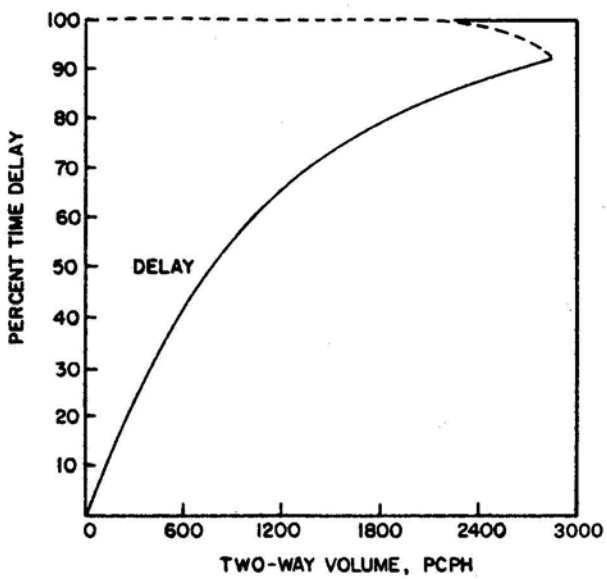


Figure 2.6 HCM Figure 8-1.

2.4.3 Percent Traffic by Vehicle Type

Percent Traffic by vehicle type is based on vehicles types that are categorized into three main types: cars, trucks, and RVs. UCBRURAL allows the user to enter the percentages of cars, trucks, and RVs. For more accurate representation of traffic streams, these percentages are further classified into thirteen vehicles types: 4 truck types, four RV types, and five passenger car types. The percentages used to split up the three vehicle categories into the four or five respective vehicle types are contained in the file, “twpsuser.tdf”.

2.4.4 Mean Speed by Vehicle Type

Mean speed is the desired speed of traffic calculated in miles per hour [6]. The interface allows for input ranges from 10-80 mph. This is the mean speed driven by vehicles if unimpeded by other traffic or roadway geometry.

2.4.5 Standard Deviation of Speed by Vehicle Type

Standard deviation of speeds defines the distribution of desired speeds by vehicle type. It must be entered for each of the three UCBRURAL vehicle categories within the allowed range of 0.1-15 mph.

2.5 Creating a UCBRURAL Observation Data File

The observation data file defines how data will be collected and, to some degree, how it will be processed by TWOPAS. To create a new observation data file, choose the File option on the main menu and select New and then select Obs data. There are two ways that TWOPAS collects data: Observation points and Intervals.

2.5.1 Observation Points

TWOPAS will collect data at user specified observation points. The user must specify in the observation data file the beginning and ending observation points for each direction of traffic. In Figure 2.7 these points would be one mile and three miles, respectively. The beginning and the ending observation points for each direction of traffic must correspond by beginning and ending at the same section. It is also important to make these observation points start after the warm-up area created in the road data file, where the warm up zone in Figure 2.7 would be one mile for both directions. (See Creating a UCBRURAL Road Data File.) This allows the simulation to stabilize before data is observed. Next the user must input the desired number of sections between observation points. The minimum distance is one section, as is shown in Figure 2.7, and it is measured in increments of sections. For example, if the user inputs a five, data will be collected every five sections between the beginning and ending observation points. The interface allows up to 100 observation points per direction of traffic. Output that is calculated from the data collected at observation points includes: number of passes initiated, average speed, and percent vehicles that are following.

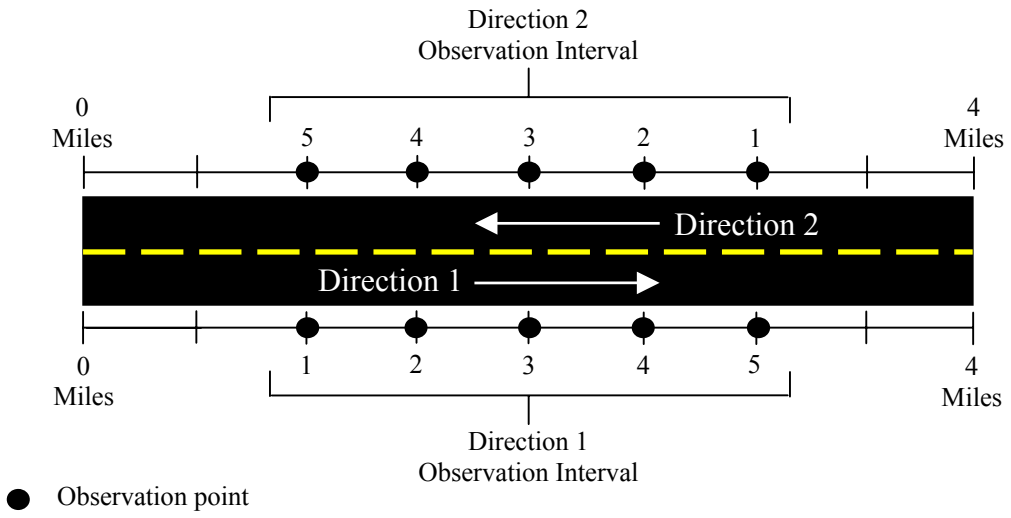


Figure 2.7 Illustration of Observation Points and Intervals.

2.5.2 Intervals

TWOPAS also collects data based on intervals. There are two intervals upon which data is collected. The first is controlled by the interface and begins at the first observation point and ends at the last observation point. This is fixed and both directions of traffic have the same interval length and location. The second type of interval is user supplied and the beginning and endpoints for each direction are inputted in the observation data file. The interval length in each direction does not have to be uniform. They must however, begin and end within the previously specified beginning and ending observation points. Average percent time following, total number of passes, and average mean speed are based on data collected in these intervals.

2.6 Making Runs

When making a run, the user must enter or accept three variables: simulation time, settling down time, and random number seed. Simulation time is the time duration that is modeled, with a default length is 60 minutes. Settling down time is the number of minutes the simulation runs before collecting data. Settling down time allows time for the simulation to load the road section and time for traffic to stabilize before data is collected. The default value is five minutes plus the time it would take a vehicle to travel the entire roadway at a rate of 30 mph.

Lastly, a random number seed must be generated or accepted. By default, the random number seed generated in UCBRURAL is used to create five random number seeds needed to run a TWOPAS simulation. These seed numbers are used to initialize a stochastic sequence of traffic characteristics such as entering headways, vehicle types, desired speed of entering vehicles, and driver types. The UCBRURAL random number seed can range from 2 to 999,999. UCBRURAL does allow the user to directly select the five TWOPAS random number seeds using the interface.

2.6.1 Single Run

When TWOPAS runs a single run, it simulates the roadway and traffic one time and collects data on that one simulation. The output includes screen graphs, a TWOPAS file, and TWOSUM output. To make a single run:

1. Open or create new road, traffic and observation data files. All three files must be opened and be compatible in terms of the roadway length.
2. In the main menu, select the run option.
3. Choose single run.
4. Input or accept simulation time, settling down time, and random number seed.
5. Press OK or enter.
6. The interface will alert the user when the run is complete.

If the user desires to input their own random number seeds they can do so by selecting "options" then "environment" and toggling the random number seeds item "entered by user" on after step one and prior to step 2 in the list above.

2.6.2 Multiple Run

The multiple run option commands TWOPAS to run several consecutive simulations. Each simulation is run independent of the others but the output is compiled into an optional spread sheet as well as the normal individual, single run outputs. For each run in a multiple run, a new UCBRURAL random seed number should be selected, since using the same random seed number will produce identical output in each run. To make a multi run, the settings for each run need to be specified from the traffic data window as opposed to specifying them as part of the run sequence. This is done by executing the following steps:

1. Open or create new road, traffic and observation data files. All three files must be open and compatible in terms of roadway length.
2. Select Edit in the main menu.
3. Choose Traffic data.
4. Select the multi run option.
5. Enter the run number you would like the first run to be labeled.
6. Enter or accept simulation time, settling down time and random seed number.
7. Press okay or enter. You have just created one run. Repeat steps 4-6 for as many runs as desired. The interface will keep track of and number the runs.
8. When the number of runs desired in the multiple run have been created, exit the traffic data file.
9. In the main menu, select Run and then Multiple run.
10. TWOPAS will now run each of the runs created and the interface will alert the user when it is complete.

To specify the random number seeds then between steps one and two the user needs to change the TWOPAS environment by selecting "options" then "environment" and then toggling on the "entered by user" feature. To make a multi run with this feature toggled on, follow the same steps with the exception that in step six the user needs to enter five random number seeds.

2.7 Multiple Run Statistics

The number of runs needed in a multiple run, to create a 95% confidence interval within +/- 10% of the mean, were calculated. They were based on travel time and percent time spent following output. The following steps were used to calculate the number of runs needed to obtain the desired confidence interval:

1. Make n_o runs with different random number seeds;
2. Calculate the sample average of model output x (such as percent time spent following) ($\bar{x}$);
3. Calculate the sample standard deviation (s);

$$s = \sqrt{\frac{n_o \sum x^2 - \left(\sum x\right)^2}{n_o\left(n_o - 1\right)}}$$

4. Calculate the required range of the confidence interval (ε), also known as tolerance;

$\varepsilon = 0.1 \times \bar{x}$

5. Look up the t-statistic t for a level of confidence of 0.05 given a degree of freedom ($df = n_o - 1$);
6. Calculate the required sample size (n_r);

$$n_r = \left(\frac{s \times t}{\varepsilon} \right)^2$$

7. Repeat steps 5 and 6 until the change in n_r is less than one sample;
8. If n_r is larger than the existing sample size n_o then do n_r - n_o additional runs and set $n_o = n_r$;
9. Repeat steps 2 through 8 until n_o is equal to or greater than n_r.

Based on our research, six was the appropriate number of runs for a 95% CI of +/- 10% of the mean. However, this may vary depending on the site conditions and length of warm up time.

3 OUTPUT DATA

The purpose of this chapter is to illustrate to the reader the methods of accessing output data. There are several types of data in different locations. So guidance is given to help determine what type of data is needed, where it is found, and how it can be accessed.

3.1 Types of Output Data

A large quantity of data are output when running the TWOPAS simulation model. However, this chapter will focus on those output data that are used as measures of effectiveness (MOE) in the year 2000 release of the Highway Capacity Manual and these are percent-time-spent-following (PTSF) and average travel speed (ATS). These MOE are defined below followed by a discussion of the context in which they can be presented, spot or space data.

3.1.1 Percent-Time-Spent-Following (PTSF)

PTSF is defined as the average percentage of travel time that vehicles must travel in platoons behind slower vehicles due to the inability to pass. Practically speaking, this is very difficult to measure in the field so a surrogate measure is used based on a headway threshold. A vehicle is defined as following if it is traveling at a headway of 3.0 seconds or less. The proportion of vehicles traveling with a headway equal to or less than the threshold is then used as the surrogate measure of PTSF and is referred to as the percent of vehicles following (PF).

TWOPAS outputs both PF and PTSF based on simulation and these values are measured in two ways: 1) for each vehicle continually as they traverse the facility and 2) at discrete points, or spots, along the facility.

One of the primary reasons for using PTSF as an MOE is that traffic speeds are not very sensitive to traffic volume but PTSF is. It also serves as a consistent indicator of the quality of service because it is not directly related to the free flow speed of a facility like average travel speed

3.1.2 Average Travel Speed (ATS)

Another measure of effectiveness used to analyze the performance of two-lane highways is average travel speed (ATS). Conceptually, this is a measure of vehicle average speeds across the facility in question. It is difficult to measure the average speed of a vehicle as it traverses a

facility continuously so point measurements are taken along the facility and then averaged. TWOPAS output data is extracted in the same way, in that the simulated facility is observed at specific locations during the simulation, at which the travel speeds are measured.

While average travel speed is not very sensitive to traffic volumes, it does indicate the effectiveness of a particular facility, especially for higher functional classifications [8]. It is also much easier to quantify the economic benefits of a design because it can be related to travel time savings and hence to dollar savings.

3.2 Locating the Output data

Output data for PTSF and ATS can be located in a variety of locations. There are two types of locations one is within the UCBRURAL interface and the other is in a text file. In UCBRURAL, select "Output" from the menu bar. There a number of options presented in the resulting menu and they are as follows:

1. Hardcopy Graphs,
2. *Screen,
3. Print Summary,
4. Print Detail,
5. Print TWOSUM.OUT,
6. MultiRun Spreadsheet File,
7. *Hardcopy Comparisons, and
8. Animation.

It should be noted that most of these options are not available in UCBRURAL at this time. Those options that are available are indicated with an asterisk. Those options that are not indicated with an asterisk are not available either do to limited printer configuration options or do to unfinished programming of UCBRURAL.

The text files that contain output data are as follows: TWOSUM.OUT, TWOPAS.OUT, and MULTIRUN.TSS. All of these files can be opened by any text file editor and are found in the directory from which TWOPAS is being run. The matrix below presents the different options for locating the desired type of output data with a brief description of how it is presented in UCBRURAL and in the text files.

Table 3.1 Matrix of Output Data Location and Form of Presentation.

	PTSF		ATS	
Data Location	**Spot Data**	**Directional Average**	**Spot Data**	**Directional Average**
UCBRURAL Screen	Graphed by direction of travel	By corner of graphs, color coded by direction	Graphed by direction of travel	By corner of graphs, color coded by direction
UCBRURAL MultiRun Spreadsheet File	Not Available	Under column labeled AVG TM DLYST	Not Available	Under column labeled AVG SPEED
UCBRURAL Hardcopy Comparisons*	Printed graph comparing two graphs	**No?**	Printed graph comparing two graphs	**No?**
TWOSUM.OUT	Text form in the %IMP column**	Text form; Bottom of text under PTD	Text form; in the SPALL column	Text form; Bottom of text under SPEED
TWOPAS.OUT	Text form; % unimpeded; in summary output table**	Text form; in summary of data for user specified section; Percent of time unimpeded**	Text form; MEAN; in spot speeds table	Text form; in summary of data for user specified section; Overall speeds

*current printer configuration does not work.

**%IMP = 100 - % UNIMPEDED and PTSF = %IMP

3.3 Accessing Output Data

3.3.1 UCBRURAL options

Currently, two reliable options are available for accessing output data in UCBRURAL. These options are Screen Data and MultiRun Spreadsheet file and they are described in the following subsections.

3.3.1.1 Accessing screen data

Screen data can be accessed by selecting "Output" from the menu bar in the main UCBRURAL screen and then selecting "Screen" from the pull down menu. At this point a menu should appear similar to what is shown in Figure 3.1.

```
•••••••••••••••••••••••• Pick Graphs for View ••••••••••••••••••••••••
•            Graph 1                                Graph 2            •
•     (•) Percent Following                 ( ) Percent Following       •
•     ( ) Number of Passes                  ( ) Number of Passes        •
•     ( ) Mean Speed                        (•) Mean Speed              •
•                                                                       •
•                                                                       •
•        Scale for Graph 1                     Scale for Graph 2        •
•     (•) Fixed                             (•) Fixed                   •
•     ( ) Set by user                       ( ) Set by user             •
•                                                                       •
•                 Ok   •        Help  •        Exit  •                  •
•               ••••••••      ••••••••      ••••••••                   •
•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
```

Figure 3.1 Screen Output Options.

Notice that in this menu you specify the information that will be included in two graphs (Graph 1 and Graph 2). Three different types of simulation output can be selected to help assess the quality of operations along the roadway: 1) Percent Following (PF), which is based on a preset headway threshold, 2) number of passes, and 3) mean speed, which is the average travel speed (ATS).

Scale of the Y-axis for the graphs is also an option. If the option of "fixed" is selected then UCBRURAL will automatically fix the Y-axis scale. Select "OK" in the screen shown in Figure 3.1 and the screen should appear as Figure 3.2.

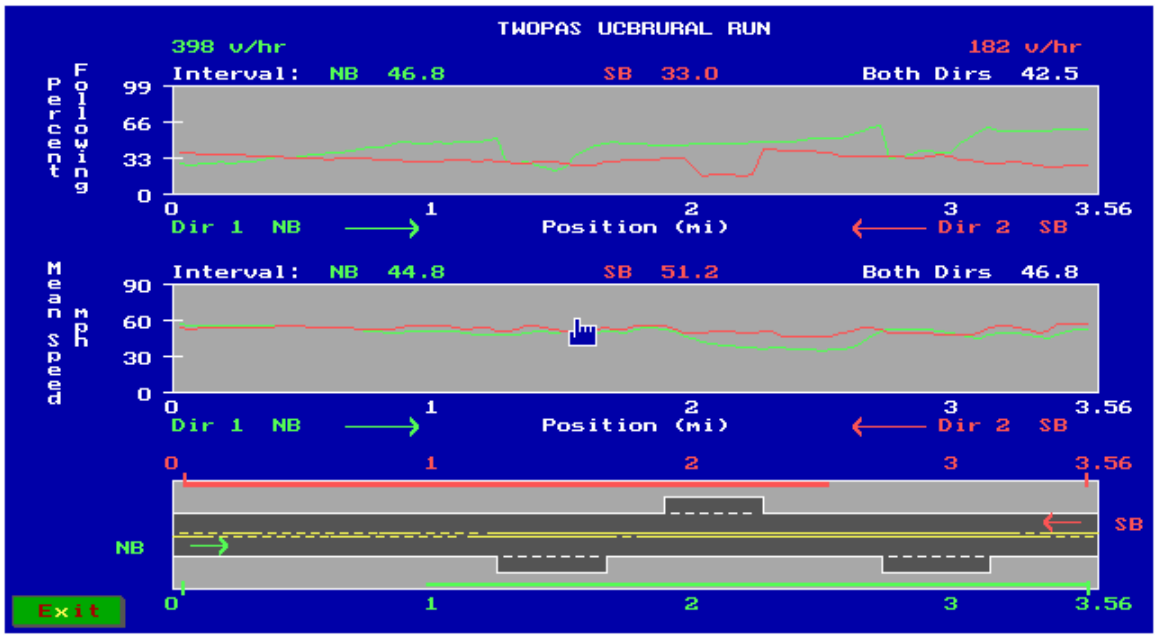


Figure 3.2 Screen Output with Fixed Y-Axis Scale.

Press "Exit", change the scale option for Graph 1 to "set by user" and select "Ok". The screen should appear similar to Figure 3.3, where the user specifies the range of values to be included on the Y-axis of a graph in the two fields provided on the left side. The upper field is the upper range of the scale and the lower field is the lower range of the scale. Change the upper and lower ranges to 65 and 17, respectively then press "OK". Notice the difference in the scales of Graph 1 shown in Figure 3.2 and on your screen.

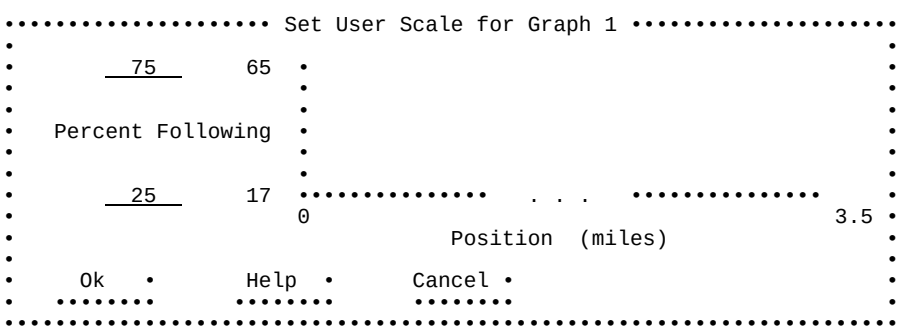


Figure 3.3 Setting the Scale for the Y-Axis.

3.3.1.2 Accessing multirun spreadsheet file

When running simulation models of traffic, it is much more useful to run six or more simulation runs with different random number seeds so that a statistically significant average can be calculated for the various output. When this is done, output data for all six runs can be accessed simultaneously by creating a multirun spreadsheet file. You can view this file by selecting "output" from the menu bar and then selecting "MultiRun Spreadsheet File". A window similar to that shown in Figure 3.4 should now be on the screen.

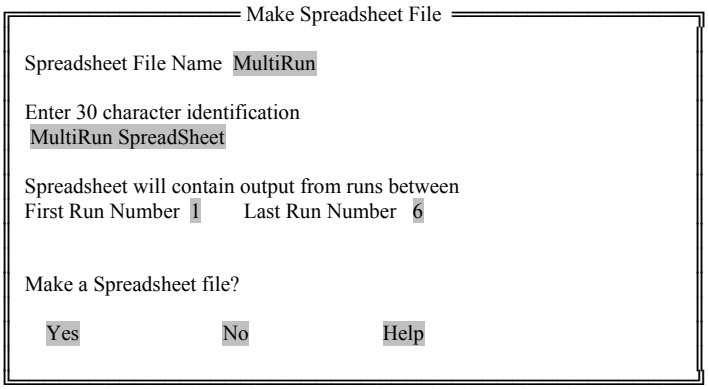


Figure 3.4 Spreadsheet for Multiple Runs.

A name can be specified in the first field for each multirun file that is created and then the file can be characterized or defined in the next field. In the next two fields, the range of runs to be included in the multirun file is specified, however it is unlikely that this feature will be needed so the first and last run numbers will be sufficient. Finally, if the fields are completed select "yes" and answer the following prompts as is appropriate.

Now that a file containing output from the runs has been created, it is ready to be viewed. Go to the directory in which the TWOPAS and UCBRURAL programs are stored and find the file labeled "MULTIRUN.TSS". This is a text file and may be viewed using a text editor. Open the file MULTIRUN.TSS and view the output data. Some of the output data labels are easily understood, however some of them are not and require additional explanation. Table 3.2 below lists the column labels and provides a brief explanation of the data in each column. Because of the quantity of the output (88 columns), the data that is most relevant to the operational analysis of a two lane highway are included in the table.

Table 3.2 Summary of Data in Multirun Spreadsheet File.

Column Label	Column Number	Data description
AVG TM FOLLNG	DIR 1: 47 DIR 2: 48 COMB: 49	This is a measure of the percent of vehicles following based on a headway criteria (referred to as PF in the text). This measure is provided by direction and across directions.
AVG TM DLYST1	DIR 1: 50 DIR 2: 51 COMB: 52	This is a measure of the percent of vehicles following based on driver characteristics (referred to as PTSF in the text). If the driver is determined to be impeded, based on the simulated driver characteristics, then they are classified as following (not in state1). This measure is provided by direction and combined across directions.
AVG SPEED	DIR 1: 53 DIR 2: 54 COMB: 55	This is a measure of average vehicle speeds across the facility by direction and combined across directions.

The primary shortfall of the UCBRURAL interface is that when a multirun is made the only information that can be graphed is that of the last run made in the series of multiruns. If a plot of the average multirun PTSF or average speed verses distance along the facility is desired then other options for accessing output data are needed. Output data measured at regular intervals along the simulated highway can be accessed for each run in text files discussed in section 3.3.2.

3.3.2 Other options

If more detailed output is required than what is available from the UCBRURAL interface then the text output files, “twosum.out” or “twopas.out” are needed.

3.3.2.1 Accessing Twosum.out

The “twosum.out” file is a summary output file created based on data extracted from the “twopas.out” file. This “twopas.out” file contains a large amount of information that can be quite difficult to access so the program TWOSUM was created to extract the information and organize it in a more useful fashion in the file “twosum.out”, as shown in Figure 3.5. It should

be noted that if you use the multiruns function to execute your TWOPAS runs, a summary output file will be created for each run. However these output files will use a different naming convention, where the TWOSUM generated output files are named “twsm0001.out” instead of “twosum.out”. Note that the number in the file name corresponds to the number of the corresponding run made by the UCBRURAL multiruns function.

After a run has been completed, the “twosum.out” file is found in the same directory as the UCBRURAL and TWOPAS program files. See Figure 3.5 for a sample printout of the “twosum.out” file. The following discussion describes the output data and their respective locations in this file, where locations are specified in lines and, when applicable, in columns.

```
1                    ***** PROGRAM TWOPAS:  RURAL TRAFFIC SIMULATION;  OUTPUT SUMMARY *****

 1RUN NO.    1      sensitivity test1
   ROAD:TEST1     TRAF:TEST1     OBS:TEST1     DATE: 9/27/01  TIME:11:17 NB SB
   RANDOM NUMBERS:    313255    741279    124073    763253    262453
 0      WARM TIME= 25.000 MINUTES        TEST TIME= 60.000 MINUTES        TOTAL TIME= 85.000 MINUTES
 OVERALL TRAVEL TIME=   63.5 SEC, S.D.=   2.7 SEC
 OVERALL % TIME NOT IN STATE 1:  DIR1=  62.4 DIR2=  60.7 COMB=  61.5
 LENGTH=    52800.
 DIR1 FLOW RATE=  600. ENTERING % FOLL.=  33.    DIR2 FLOW RATE=  600. ENTERING % FOLL.=  33.
 TRAF COMPOSITION    DIR 1 TRUCKS=   4.0 RVS=   0.0 CARS=  96.0  DIR 2 TRUCKS=   4.0 RVS=   0.0 CARS=  96.0
 STANDARD DEVIATION  DIR 1 TRUCKS=  3.50 RVS=  3.00 CARS=  4.00  DIR 2 TRUCKS=  3.50 RVS=  3.00 CARS=  4.00
 SPEEDS              DIR 1 TRUCKS=  60.0 RVS=  60.0 CARS=  62.0  DIR 2 TRUCKS=  60.0 RVS=  60.0 CARS=  62.0


                            *** SUMMARY SPOT CHARACTERISTICS ***
 STN         LOCATION            DIRN  NL  FLOW  %UNIMP  %DESSP  PSIZE  NFOLL  SPTRK   SPRV  SPCAR  SPALL   %IMP  PFOLL  #PASS
  1  MILEPOST   0.100               1   1  586.0   82.0   84.0    2.9  201.0   59.3    0.0   61.0   60.9   18.0   34.3    0.0
  2  MILEPOST   0.200               1   1  587.0   77.0   80.0    2.9  214.0   59.5    0.0   60.6   60.6   23.0   36.5    1.0
  3  MILEPOST   0.300               1   1  587.0   75.0   77.0    3.0  230.0   59.7    0.0   60.3   60.3   25.0   39.2    3.0
…
 97  MILEPOST   9.700               1   1  585.0   22.0   20.0    7.1  481.0   54.9    0.0   54.9   54.9   78.0   82.2    0.0
 98  MILEPOST   9.800               1   1  585.0   20.0   21.0    7.3  483.0   54.8    0.0   54.9   54.9   80.0   82.6    0.0
 99  MILEPOST   9.900               1   1  586.0   22.0   21.0    7.2  482.0   55.1    0.0   55.3   55.3   78.0   82.3    0.0
…
301  OPPOSING DIR - MP   9.900      2   1  608.0   82.0   85.0    3.0  222.0   59.5    0.0   61.4   61.3   18.0   36.5    0.0
302  OPPOSING DIR - MP   9.800      2   1  608.0   77.0   81.0    2.9  241.0   59.7    0.0   61.1   61.0   23.0   39.6    1.0
303  OPPOSING DIR - MP   9.700      2   1  608.0   74.0   78.0    2.9  253.0   59.7    0.0   60.9   60.8   26.0   41.6    3.0
…
397  OPPOSING DIR - MP   0.300      2   1  590.0   24.0   23.0    6.9  480.0   55.5    0.0   56.0   56.0   76.0   81.4    0.0
398  OPPOSING DIR - MP   0.200      2   1  590.0   22.0   22.0    6.9  480.0   55.6    0.0   56.0   56.0   78.0   81.4    0.0
399  OPPOSING DIR - MP   0.100      2   1  590.0   24.0   23.0    7.0  481.0   55.8    0.0   56.4   56.3   76.0   81.5    0.0


                            *** SUMMARY INTERVAL INFORMATION ***
 DIRN  FROM  TO   DIST  SPEED   TTIME   MTIME  TFDLY    PTD  %UNIMP  PR1   PR2   VTIME    VPH   PASS1L  PASS2L VEH-MILES  GEDLY
    1    1   99  51744.  56.7  367220.   63.5    5.1   70.2   37.6  0.02  0.00   622.4    590.     136       0   5785.56    0.0
    2    1   99  51744.  57.4  370284.   62.5    4.2   69.4   39.3  0.03  0.00   613.0    604.     162       0   5900.89    0.0
    1   10   99  46992.  56.4  335306.   63.8    5.4   72.5   34.7  0.02  0.00   567.9    590.     108       0   5257.14    0.0
    2   10   99  46992.  57.1  337536.   62.8    4.4   71.5   36.5  0.02  0.00   559.3    604.     127       0   5353.97    0.0

  COMPUTER TIME FOR THIS RUN WAS:     7.25 SEC.
```

Figure 3.5 Sample TWOSUM.OUT File.

A large amount of data is presented in the TWOSUM.OUT file, so this description of the file will focus on those elements that are of primary importance to the operational analysis of two lane highways. In the HCM 2000 procedures, the measures of effectiveness that are used are average travel speed and percent time spent following. The TWOSUM.OUT file contains measures for both of these in a variety of forms.

In row 5 of the first area of output, is the measure, OVERALL % TIME IN STATE 1. This is the direct measure of PTSF output by TWOPAS. Notice that there are three values reported, where two values are for directions one and two and the other is a combination of the two.

In the second area of output, labeled "Summary Spot Characteristics", there is a row of information for each observation point specified in the observation file. First the information for direction one is presented for each observation point. Then the information for direction two is presented. Notice that the location of each observation station is given in terms of ascending mileposts in direction one.

Average travel speed for the traffic stream is reported in the column labeled "SPALL", where the average travel speed for trucks, RVs, and cars precede it. The spot measure of PTSF is given in the column labeled "%IMP" and the spot measure of PF is given in the column labeled %FOLL

Finally, in the last area of output labeled "Summary Interval Information" is given data summarized over the facility. The first two rows are for data summarized over all of the observation stations, where the first row is for direction one and the second is for direction 2. If an observation interval is set up other than the entire length of the facility then a third and a fourth row will be output as well, one row for each direction (as is the case for the file shown in Figure 3.5).

Average travel speed for a given direction is given in the column labeled "SPEED". The measure of PF is given in the column labeled PTD and %UNIMP is given in another column, where PTSF = 100 - %UNIMP.

4 CASE STUDIES

Three case studies considering two lane rural highway segments in different parts of the state of Idaho were completed as a part of this project. The first case study was done at US 12 considering a segment of road running between Kamiah and Kooskie. The second case study was at US 30, and the third at US 26. The primary purpose of these case studies was to develop realistic scenarios to use in developing TWOPAS training material.

4.1 Methodology

4.1.1 Input Data

The primary input data required to run the TWOPAS simulation are road data, traffic data, and observation data. Table 4.1 explains about different input parameters required and where the respective data can be obtained.

Table. 4.1 Input data files and parameters

Input data file	Input data parameter	Source of Input data
Road Data	• Lane widths	Plan sheets provided by ITD
	• Segment length	
	• Curves (horizontal and vertical)	
	• Sight distance (ft)	Video logs
	• Barrier lines	Barrier logs provided by ITD
Traffic Data	• Volume in both directions	ITD traffic volume report
	• % Trucks	Calculated from truck factor given by ITD report
	• % RV's *	% RV's is taken as zero
	• Portion of volume in platoon	Percent volume in platoon and average speeds are evaluated from field studies
	• Average speeds of trucks, passenger cars and RV's	
Observation Data	• Road units (mi)	Road units and number of observation points are user-defined values.
	• Number of observation points in both directions	
	• Start and end point on the segment	

* Percent RV's is included in percentage of trucks.

Observation points were specified every 0.05 to 0.10 miles and start and end points were specified to leave 1.0mile buffer zones. While entering values for the number of observation points and the segment length, a suitable length of segment should be considered for a warm up zone as shown in the Figure 4.1. Generally, a length of 1.0 mile is considered a sufficient length for the warm up zone. [6]

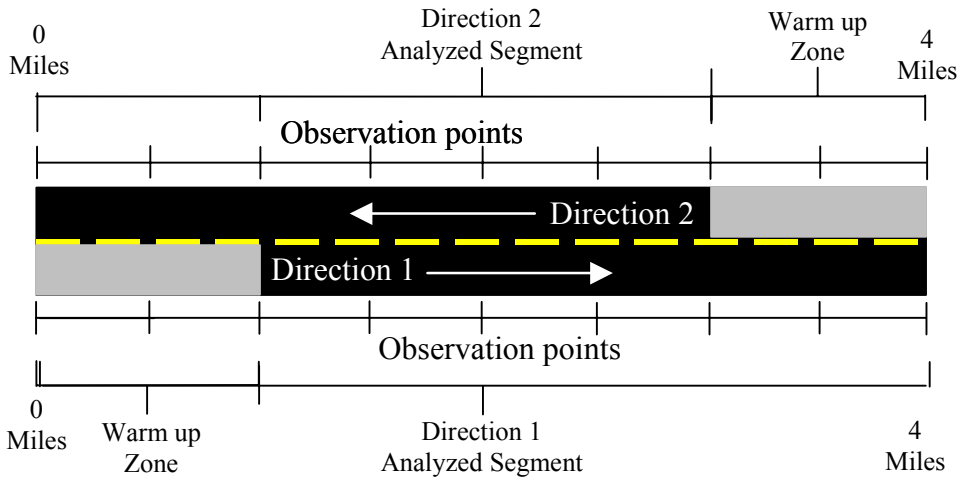


Figure 4.1 Different segments of road length for analysis

The road data file should be created first and then the traffic data file and observation data file can be created. Refer to chapter 2 to create a new file and to open and edit old input data files.

4.1.2 Scenarios

To illustrate the importance of the TWOPASS model and to explain the analysis procedure, different scenarios were considered in each case study. The analysis of these scenarios shows the feasibility of a passing lane and how to maximize the benefits by reducing percent time spent following and increasing average travel speed. The typical scenarios considered are the following:

1. Existing conditions,
2. A passing lane was considered on both lanes,

3. A passing lane included only in the north bound direction, and
4. A passing lane included only in the south bound direction

A passing lane was included in the above mentioned scenarios to determine the importance of a passing lane in reducing the percent time spent following and in increasing the average travel speed. To derive more precise results, traffic splits of 60/40 and 40/60 (NB/SB) are considered in each scenario. The percent time spent following for each scenario was calculated from the TWOPAS simulation model and was tabulated in each case study.

4.1.3 Simulation

To run UCBRURAL, all three input data files should be opened. There are two options to run the model.

a) Single run
b) Multiple runs

Multiple runs should be performed when statistically valid results are desired. Generally 4 to 6 runs are sufficient to get valid results. Statistical analysis (mean and, standard deviation of parameters) can be carried out with the TWOPAS multiple run results.
Refer to chapter 2 to learn more about how to perform multiple simulation runs.

4.1.4 Analysis of results

Traffic parameters such as percent time spent following and average travel speed can be analyzed for the existing road section by using output from simulation runs. The terminology for percent time spent following is different in different out put files from TWOPAS simulations runs. It is referred to as "%imp" in TWOSUM.out files when considering point-by-point observations on the segment. At the end of the TWOSUM.out file, percent time spent following should be evaluated by subtracting "%unimp" from 100. Percent time spent following was referred to as "USRINTATDST1" when considering "MULTIRUN.TSS" file. The percent spent following value for each run from a multiple run was obtained from "MULTIRUN.TSS". Refer to chapter 3, section 3.3.1.2, to access percent impeded and average travel speed. Each run performed gives output in the form of a text file. Chapter 3 gives a detailed description of how to access output data from simulation runs.

4.2 Case Study I – US 12

A road segment of 7.5 miles was considered on US 12 between Kamiah and Kooskie for Case Study I. The road segment is level terrain with many large radii horizontal curves. The Clearwater River runs along one side of the road for most of the 7.5 miles and there are some historical sites located at several points on both sides of the road. The profile of the road segment is shown in Appendix A with the help of plan sheets provided by ITD.

4.2.1 Input Data for US 12

1) Road Data file

Lane width = 12 ft

Shoulder width = 3.3 ft

Barrier lines, sight distance and radii of curves are shown below in a snap shot taken from UCBRURAL. Refer to Appendix for full details of road data set.

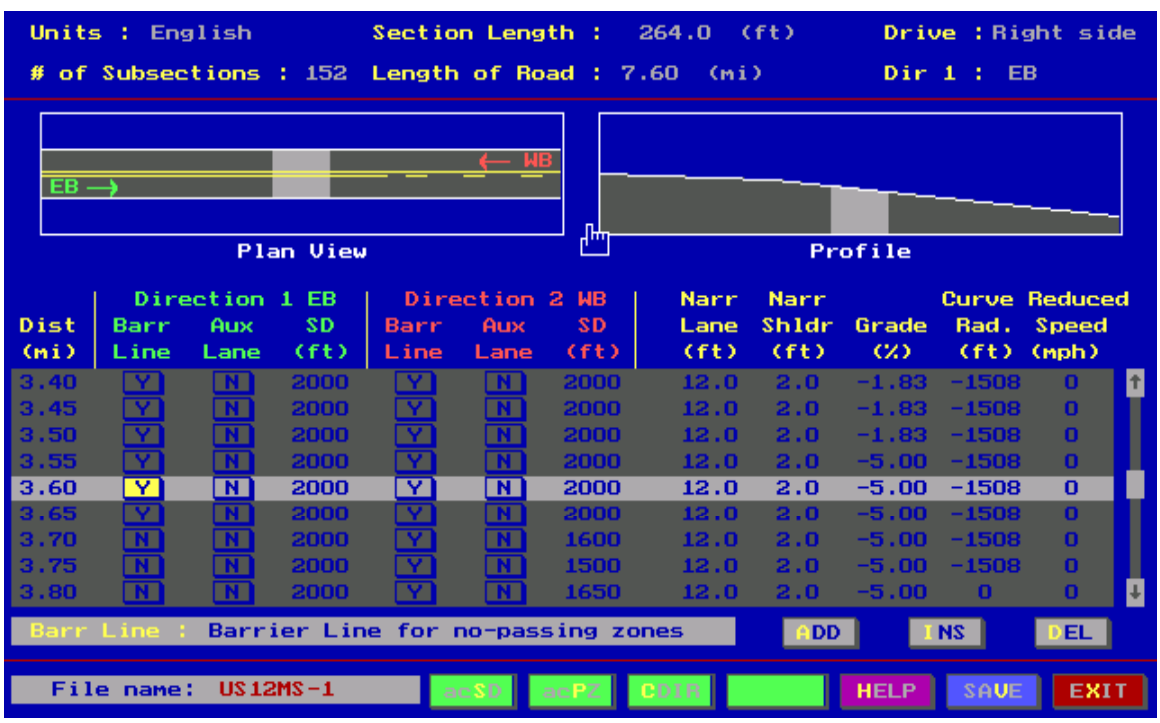


Figure 4.2 Snapshot of road data file from TWOPAS model

2) **Traffic Data file**

Design Hour Volume (DHV) = 545 veh/hr

Directional split = 60/40 and 40/60 (WB/EB)

Percentage of trucks = 7

Percentage of passenger cars = 93

Percentage of RV's = included in trucks

% Traffic in platoon= 0—The built-in function in UCBRURAL computes this value for the user, assuming random arrivals.

Table 4.1 Average speed and standard deviation for speed

	Passenger Cars	Trucks
Average speed	62 mph	60 mph
Standard Deviation	5.0	4.0

3) **Observation Data file**

This file shows the observation data points along the road section of analysis. It consists of the length of the road section, the road unit, the number of sections, the start and end interval of the study section, and the first and last observation points. A graphic similar to the one shown in Figure 4.3 will be displayed in this file.

Section length = 7.6 miles

Road unit = 0.05 mi

Number of road units = 152

Westbound direction:

First observation point: 7.55

Last observation point: 0.05

Start interval: 6.55

End interval: 0.05

Eastbound direction:

First observation point: 0.05

Last observation point: 7.55

Start interval: 1.0

End interval: 7.55

All observation data points are shown below in a snapshot taken from UCBRURAL model.

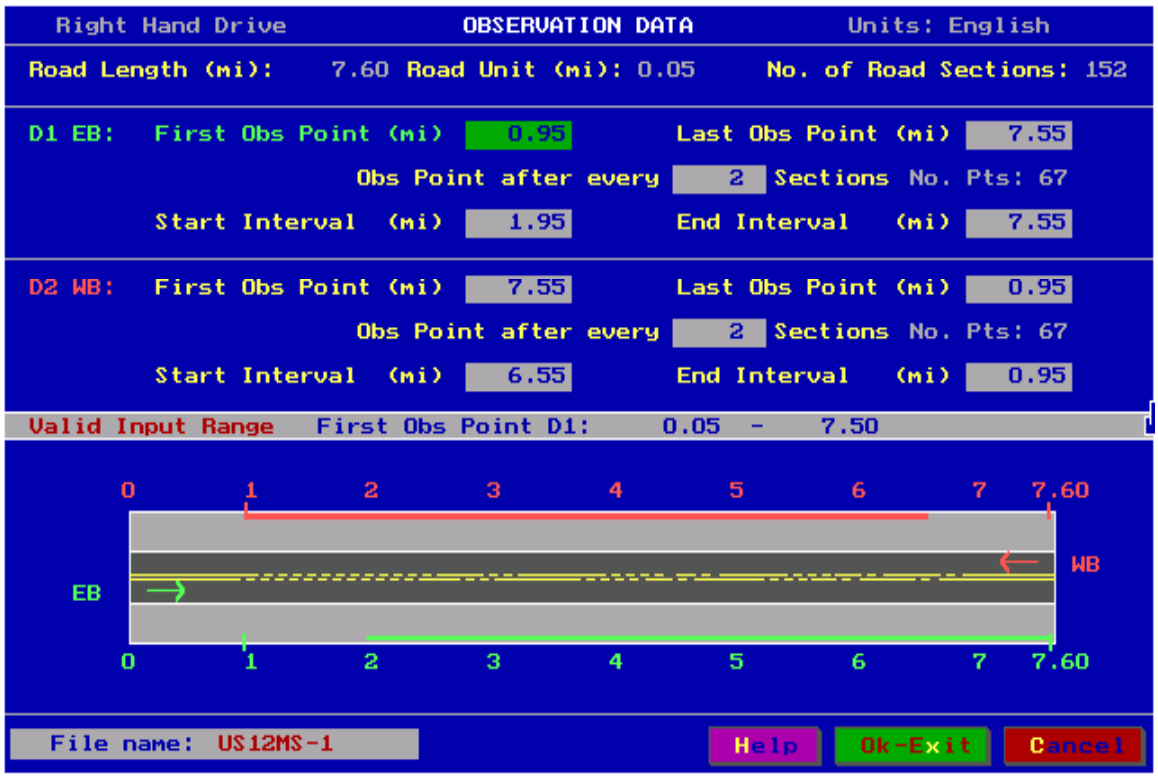


Figure 4.3 Snapshot of observation data file from TWOPAS model

4.2.2 Scenario 1

In this scenario, the existing conditions on US12 are analyzed with the above-mentioned input values. There are no passing lanes in either the westbound or eastbound directions for existing conditions. The description of the road segment passing zones and the setup for observation data is given above in Figure 4.3.

4.2.3 Simulation Results

All three input data files should be opened before executing the simulation runs. In chapter 2, a detailed description is given about how to perform simulation runs. To obtain statistically significant results, six runs were performed with varying random numbers and the results from these runs are shown in Table 4.2. Only the percent time spent following values are be reported here. However, average travel speed results are presented in the discussion of results in section 4.2.7. The values were calculated taking the average of both cases of traffic split: 60/40 and 40/60, across all of the replicate simulation runs. The mean and variation of these values about the mean are shown Table 4.3, where the variation is shown in terms of the standard deviation. A discussion of these results is given in section 4.2.7.

Table 4.2 PTSF values from different runs

Directional Split	Runs											
	1		2		3		4		5		6	
	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB
60/40	64.8	57.3	68.3	57.0	66.6	55.4	67.4	61.3	66.0	55.2	65.9	58.1
40/60	49.8	68.6	56.3	68.4	53.9	69.1	52.7	66.5	52.7	65.4	54.3	69.1

Table 4.3 PTSF values for scenario 1

Directional split	Average PTSF		Average standard deviation	
	WB	EB	WB	EB
60/40	66.50	57.38	1.23	2.22
40/60	53.28	67.85	2.16	1.54

4.2.4 Scenario 2

The input values for volume, % trucks, % passenger cars, % RV's and standard deviation of speed for different vehicles are the same as mentioned in scenario 1. In scenario 2, a passing lane is added on both directions. A passing lane of 0.95 miles is included in the westbound direction from milepost 72.02 to 71.07 and in the eastbound direction a passing lane of length 0.75 miles from milepost 68.62 to 69.37 is included. The location of these passing lanes was determined by considering the physical constraints on the US 12 alignment. The most

significant physical constraint is the Clearwater River, which runs along the edge of the eastbound lane for most of the 7.6 mile section being analyzed.

The traffic file and observation file is the same as that which was used in scenario 1. The road data file was changed, by adding passing lanes in the westbound and eastbound directions. Multiple runs were executed using the TWOPAS model and a summary of results is tabulated below for this scenario. An analysis of these results in given in section 4.2.7.

Table 4.4 PTSF values for scenario 2

Directional split	Average PTSF		Average standard deviation	
	WB	EB	WB	EB
60/40	53.35	44.10	2.73	1.72
40/60	41.93	57.75	1.43	0.99

4.2.5 Scenario 3

In this scenario, a passing lane is added only in the westbound direction, in the same location as described in scenario 2. The traffic data is the same as was used for the other two scenarios. Multiple simulation runs were executed and the summary of results is tabulated below. An analysis of the results is given in section 4.2.7.

Table 4.5 PTSF values for scenario 3

Directional split	Average PTSF		Average standard deviation	
	WB	EB	WB	EB
60/40	52.75	57.77	3.30	1.76
40/60	40.30	69.37	1.83	3.36

4.2.6 Scenario 4

In this scenario, a passing lane is added only in the eastbound direction with all other input values being the same as those in the other scenarios. Multiple runs were executed and the summary of results is tabulated below. An analysis of the results is given in section 4.2.7.

Table 4.6 PTSF values for scenario 4

Directional split	Average PTSF		Average standard deviation	
	WB	EB	WB	EB
60/40	65.37	44.92	2.72	3.79
40/60	55.73	58.42	2.98	2.01

4.2.7 Comparison between different scenarios

Four different scenarios were developed to determine the benefit of a passing lane on a section of US 12 between Kamiah and Kooskia. In all of the scenarios, the addition of a passing lane reduces the percentage of time spent following in the direction of travel of the passing lane. Table 4.7 below shows the average values of percent time spent following (PTSF) for the four different scenarios. Several points can be made regarding this graph and they are as follows:

- For existing conditions, the PTSF value in the westbound is slightly more than the eastbound direction of travel.
- When a passing lane is included in both directions of travel, the PTSF values were reduced in both directions.
- When a passing lane is included only in a particular direction of travel, the PTSF value is reduced considerably in that direction of travel, while it remained the same as in scenario 1 for the other direction.

Table 4.7 PTSF values for different scenarios

Direction	Scenario 1 (Existing)	Scenario 2 (PL WB and EB)	Scenario 3 (PL WB)	Scenario 4 (PL EB)
WB	59.54	40.48	40.73	59.93
EB	57.97	41.74	59.70	41.47

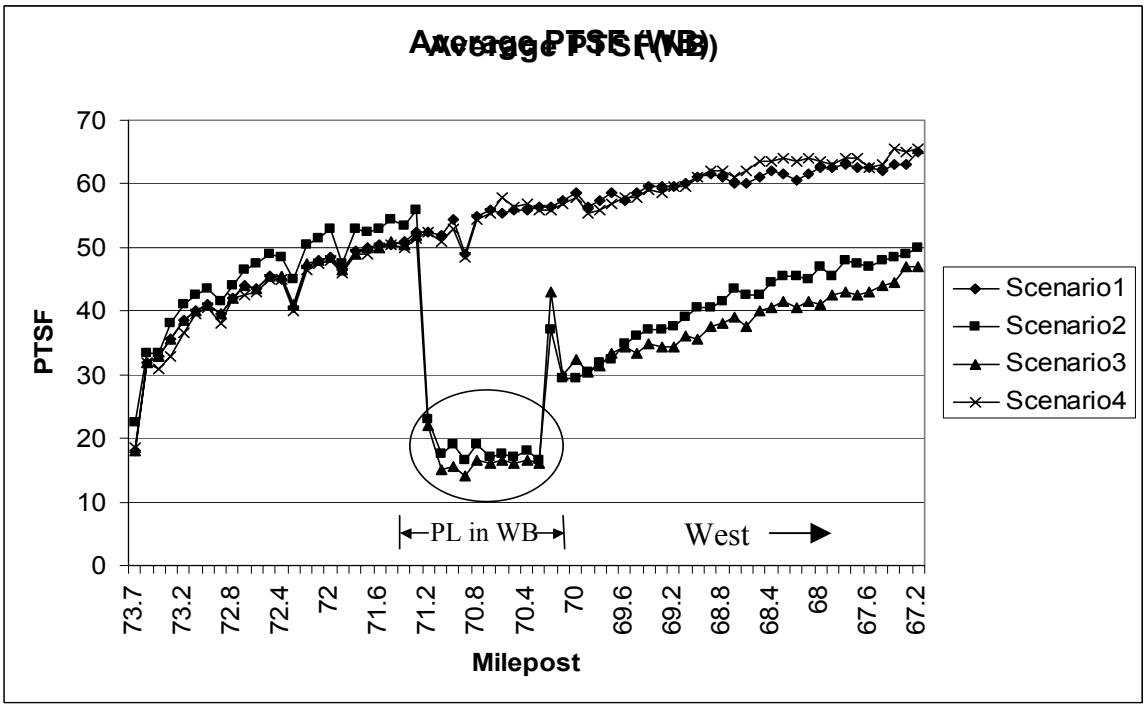


Figure 4.4 PTSF values from different scenarios for US12

In Figure 4.4, it can be seen that, in scenarios 2 and 4 the PTSF value decreased when a passing lane was added in the westbound direction. The westbound traffic had high PTSF values before the passing lane and then PTSF decreases when in the passing lane zone. Also, the PTSF value is much lower downstream of the passing lane. This suggests that the benefit of the passing lane is experienced downstream of the passing lane as well as at the passing lane its self.

The study road section of US12 consists of many large radii curves with negative and positive grades. The results from a single run were plotted to observe the variation of the average travel speed (ATS) along the section. As can be seen from Figure 4.5, there is some variation in speed along the section. The run result shows an increase in ATS where passing lanes were provided and the abrupt reductions in ATS represent the effects of reduced speed curves.

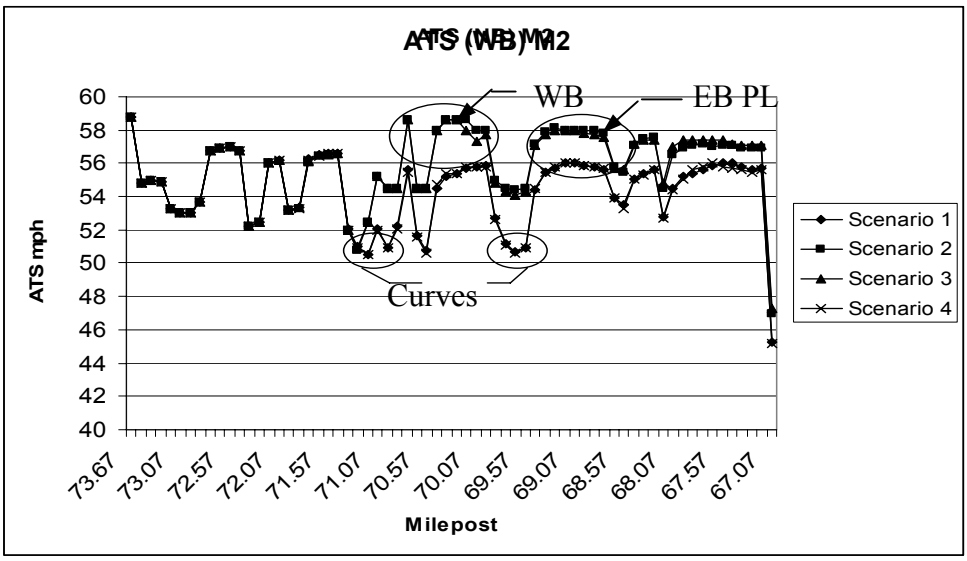


Figure 4.5 Variation of speed along the section on WB for US12

Several trends were observed from the output data and they are as follows:

- The addition of a passing lane in any direction of travel increases the average travel speed in that particular direction of travel.
- The comparison of four different scenarios is shown in the graph below. The average travel speed in both directions is approximately the same for the existing conditions and also for scenario 2.
- Table 4.8 also shows that the average travel speed increases in the direction of travel in which a passing lane is added.
- The travel speed remained approximately the same in the other direction of travel.

Table 4.8 Table showing ATS values

Direction	Scenario 1 (Existing)	Scenario 2 (PL WB and EB)	Scenario 3 (PL WB)	Scenario 4 (PL EB)
WB	52.02	54.08	54.05	51.93
EB	51.57	53.31	51.33	53.33

4.3 Case Study 2 – US 26

This case study was performed in the same manner as case study 1, where scenario 1 is existing conditions, scenario 2 has passing lanes in both directions of travel, etc. The second case study was done for US 26 between milepost 338.63 and 347.62. The road segment is 9.0 miles long with many driveways and small intersections in the segment. There is a variation of volume along the segment and the alignment is level with very few horizontal curves.

4.3.1 Input Data

The input data for this case study was gathered in a manner similar to that used for case study 1. Data were derived from video logs, barrier logs, plan sheets and the traffic volume report file, which were provided by ITD. Video logs and plan sheets were used to complete the road data file and the traffic report was used to complete the traffic data file for the TWOPAS model.

1) **Road Data file**

   Lane width = 12 ft

   Shoulder width = 5 ft

   The road segment is level with no significant horizontal or vertical curves.

2) **Traffic data file**

   Traffic volume varies along the segment due to the presence of small intersections. The weighted average ADT, DHV and percentage of trucks were calculated from the traffic report.

   Design Hour Volume (DHV) = 512 vph

   Percentage of trucks = 11

   Percentage of passenger cars = 89

   Percentage of R.V's was included in percentage of trucks.

3) **Observation data file**

   Road length = 8.95 miles

   Road unit = 0.05 mi

Number of road units = 179

Eastbound direction:

First observation point: 0.05

Last observation point: 8.90

Start interval: 1.00

End interval: 8.90

Westbound direction:

First observation point: 8.90

Last observation point: 0.05

Start interval: 7.90

End interval: 0.05

4.3.2 Scenarios

The scenarios used in this case study are fashioned after those used in case study 1. A description of the case study 1 scenarios is provided in sections: 4.2.2, 4.2.4, 4.2.5, and 4.2.6.

The major problem encountered in providing a passing lane in this section is the number of intersections along the road segment. The TWOPAS simulation model does not model intersections so the effect of turning traffic will not be represented in this analysis.

A westbound passing lane was considered between mileposts 345.69 and 344.74, whereas in the eastbound direction a passing lane was considered between mileposts 343.49 and 344.59. Minor intersections were present in both passing lane sections, but their effects on operational performance was assumed to be minor.

4.3.3 Simulation results

A comparison study between the four scenarios is described below with the help of tables 4.9 to 4.12. TWOPAS simulation runs were executed in the same way as in case study 1, using traffic splits of 60/40 and 40/60. The averages for percent time spent following (PTSF) and average travel speed (ATS) for all four scenarios are shown in Table 4.9 below.

Table 4.9 PTSF values for different scenarios

Direction	Scenario 1 (Existing)	Scenario 2 (PL EB and WB)	Scenario 3 (PL EB)	Scenario 4 (PL WB)
EB	54.84	42.90	42.96	54.74
WB	55.53	42.32	54.94	41.75

The PTSF value reduced in the direction of travel in which a passing lane was added, similar to case study 1, and the PTSF value remained approximately equal to the existing conditions in the direction of travel for which no passing lane was added. Figure 4.6 shows the variation of PTSF for eastbound traffic along the length of the highway section being modeled, showing trends and patterns that are similar to those pointed out for case study 1.

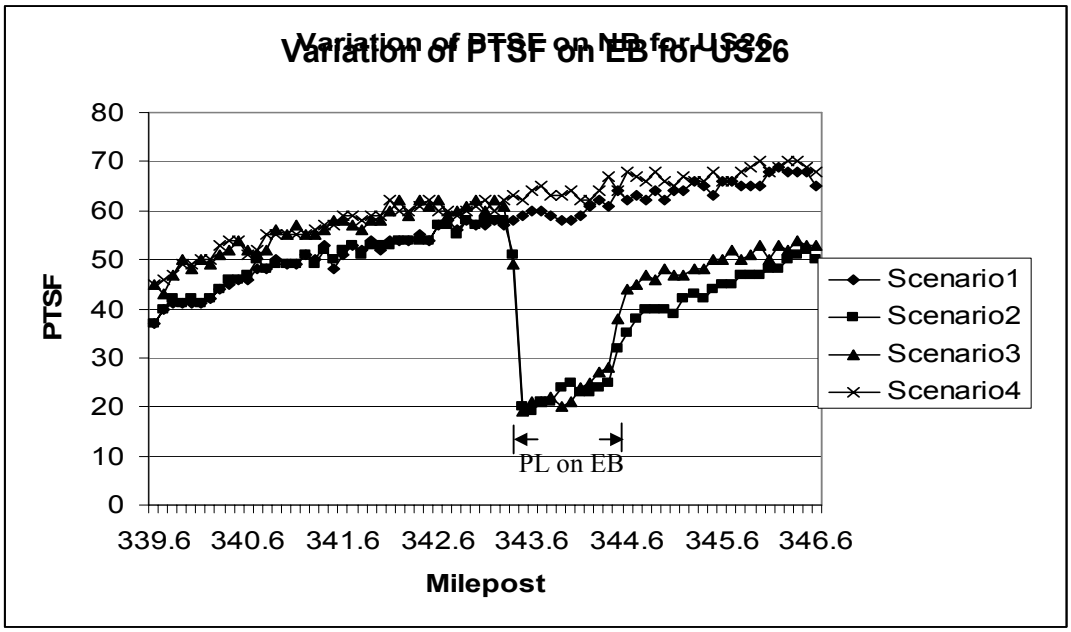


Figure 4.6 Variation of PTSF on EB along the section for US26

Trends and patterns for ATS of case study 2 are similar to those found in case study 1. The primary trends are clearly seen in Table 4.10 and are as follows:

- The eastbound and westbound travel speeds are very similar to each other for scenarios 1 and 2. The similarity occurs because the traffic streams and grades of the two directions are essentially the same.
- The average travel speed increased slightly in the direction of travel, in which a passing lane was added.

Table 4.10 ATS values for different scenarios for US26

Direction	Scenario 1 (Existing)	Scenario 2 (PL EB and WB)	Scenario 3 (PL EB)	Scenario 4 (PL WB)
EB	56.74	57.61	57.64	56.41
WB	56.52	57.60	56.40	57.74

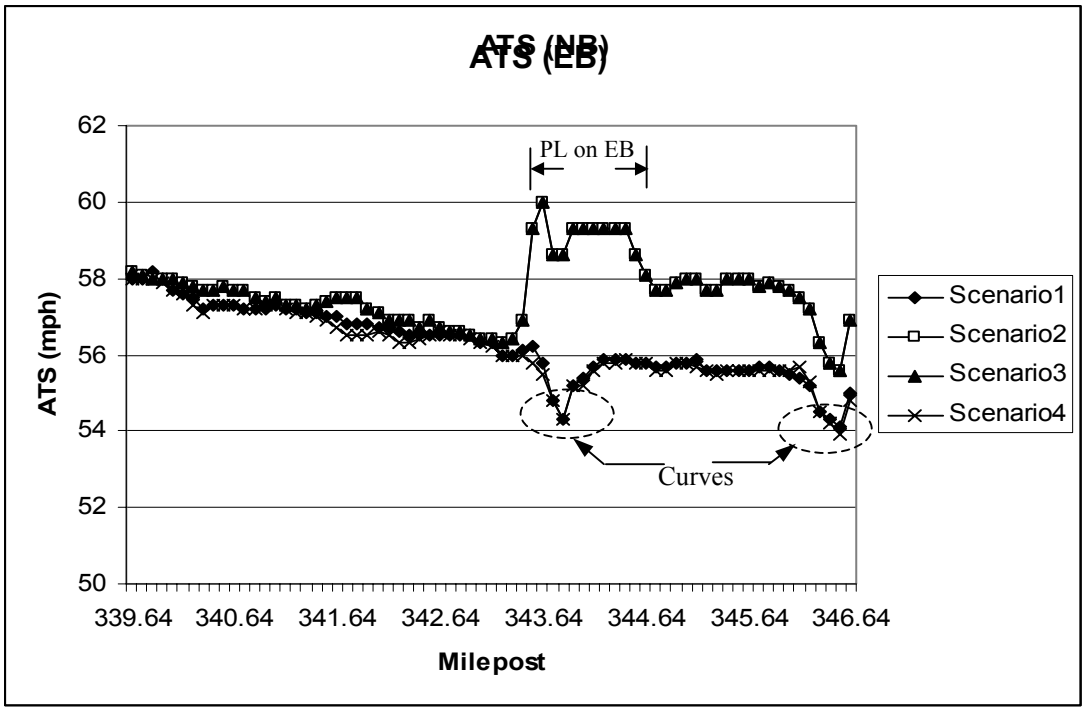


Figure 4.7 Variation of ATS value on EB from different scenarios for US26

Several trends can be seen for the eastbound directions of travel from Figure 4.7 and they are listed below. Trends for the westbound direction of travel were very similar.

- It can be seen that the ATS in all scenarios is less than 60 mph at the beginning of the section and reduced gradually till the vehicles reached the passing lane section.
- In scenario 2 and 3, the ATS values increased to nearly 60 mph between mileposts 343.49 and 344.59 because of the presence of a passing lane. Vehicles passed slow moving vehicles at the passing lane section and maintained their desired speed in the downstream segment of the study section.

4.4 Case Study 3 – US30

The third case study was done at US30 between mileposts 359.7 and 369.0. This section is located between McCammon and Lava Hot springs in southern Idaho. A study was done for ITD by UMA Engineering, in which another two-lane highway simulation model, TRARR, was used. Information roadway data that was used by the UMA study as input was also used as input for this case study.

4.4.1 Input Data

The input for this case study was derived from a report prepared by UMA Engineering, Inc, Irvine, California for ITD in 1995.

1) Road Data file

The input data defining the roadway alignment and other roadway characteristics was obtained from the report provided by UMA Engineering.

Study section length = 9.3 miles

Lane width = 12 ft

Shoulder width = 5 ft

2) Traffic data file

The weighted average DHV and percentage of trucks were taken from an ITD traffic report.

Design Hour Volume (DHV) = 340 vph

Percentage of trucks = 25

Percentage of passenger cars = 75

Percentage of RV's was included in the percentage of trucks.

3) Observation data file

Road length = 9.3 miles

Road unit = 0.05 mi

Number of road units = 179

Northbound direction:

First observation point: 0.05

Last observation point: 8.90

Start interval: 1.00

End interval: 8.90

Southbound direction:

First observation point: 8.90

Last observation point: 0.05

Start interval: 7.90

End interval: 0.05

4.4.2 Scenarios

In this case study four scenarios were developed in the same way similar to what was done in previous case studies. However, in this case study the locations for the passing lanes were based on the passing lane locations evaluated in the UMA study. In scenario 1, the analysis was done for the existing conditions without passing lanes. In scenario 2, two passing lanes were included in the eastbound direction and one passing lane was included in the westbound direction. In scenario 3, two passing lanes were included in the eastbound direction and no passing lane was included in westbound direction. In scenario 4, one passing lane was added only in the westbound direction.

The first passing lane in the eastbound direction was included between mileposts 363.1 and 363.8 and the second passing lane between 365.9 and 366.6. In the westbound direction a passing lane was included between mileposts 363.4 and 364.1. The above information was taken from the input data files of the report prepared by UMA Engineering Inc.

4.4.3 Simulation results

As before, the traffic split was taken as 60/40 and 40/60. The results in the form of average PTSF and ATS values for the various scenarios are discussed below.

Table 4.11 PTSF values of different scenarios for US30

Direction	Scenario 1 (Existing)	Scenario 2 (PL 2 EB 1 WB)	Scenario 3 (PL 2 EB)	Scenario 4 (PL WB)
EB	60.68	36.90	36.93	60.94
WB	60.90	47.33	61.33	47.04

The following observations can be made based on the values shown in Table 4.11:

- Again, the PTSF values for the different directions of travel are similar for scenario 1 because the conditions of the two directions are similar.
- The PTSF value in the eastbound direction is less than that of the westbound direction in scenario 2 and 3 because of the greater number of passing lanes in the eastbound direction, providing vehicles traveling in the eastbound direction with more passing opportunities and thus reducing the PTSF.

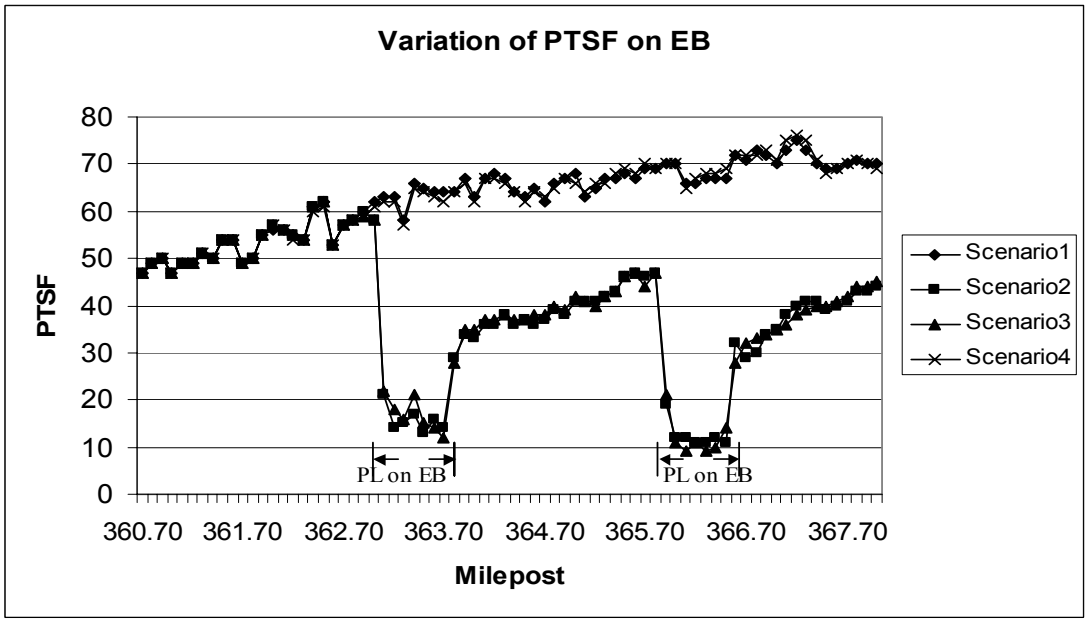


Figure 4.8 Variation of PTSF on EB along the section for US30

This case study differs from the other cases studies because two passing lanes were added in one direction. The following observations can be made based on Figure 4.8:

- It can be seen that the PTSF values increased gradually in scenarios 1 and 4 because there ware no passing lanes.
- In scenarios 2 and 3, the PTSF value decreased substantially at the passing lane sections, resulting in a PTSF value that was much lower compared to scenarios 1 and 4.

Table 4.12 ATS values of different scenarios for US30

Direction	Scenario 1 (Existing)	Scenario 2 (PL 2 EB 1 WB)	Scenario 3 (PL 2 EB)	Scenario 4 (PL WB)
EB	50.40	53.60	53.62	50.35
WB	50.96	53.03	50.90	53.02

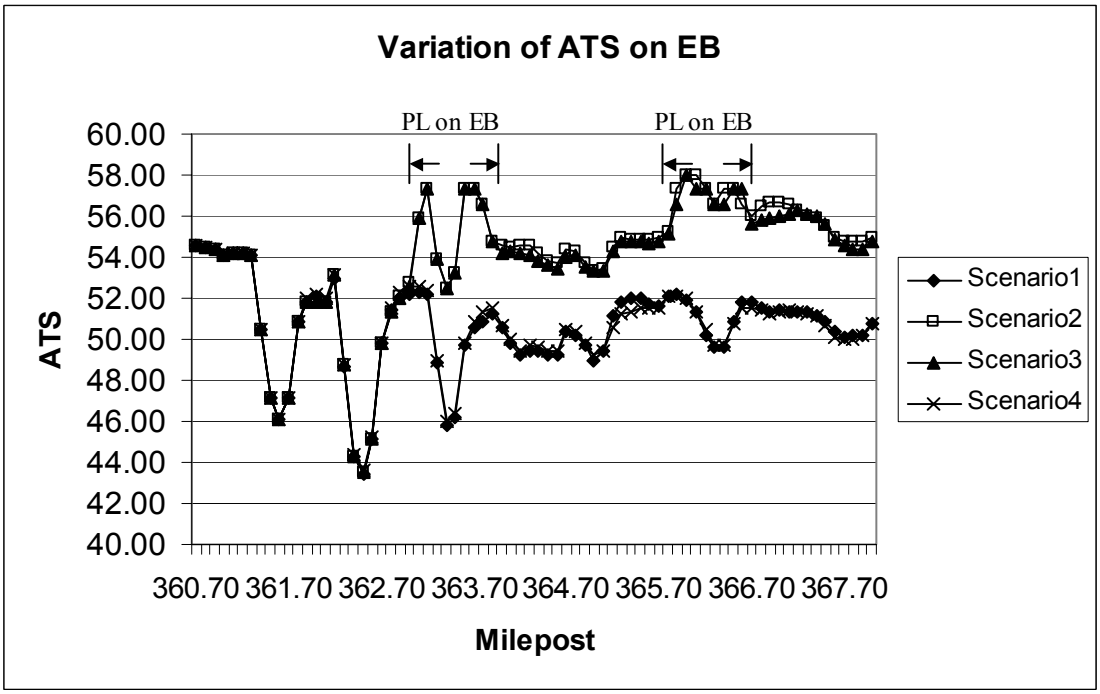


Figure 4.9 Variation of ATS on EB along the section for US30

Table 4.12 illustrates similar trends to those found in the other case studies, where the ATS value increased with the addition of passing lanes. The following observations can be made from Figure 4.9 for the EB direction of travel:

- The ATS value decreased at horizontal curves. This is seen by the dips in the ATS values.
- In scenarios 2 and 3, the ATS values increased by approximately 4 mph.

5 SENSITIVITY ANALYSIS

In chapter five, a sensitivity analysis of common design variables related to two lane highways will be presented. Design variables included in this analysis are horizontal curvature, passing lane length, shoulder width, lane width, and grade. Multiple runs were not made because the analysis was based on trends observed from tables comparing performance measures such as percent time spent following against a design variable. However, because traffic characteristics may vary from project to project, volume and vehicle mix was varied between runs. Tables 5.1 and 5.2 describe the runs made as part of the sensitivity analysis.

5.1 Passing lane length and location

When insufficient passing opportunities exist on a section of highway, a popular improvement is to add a passing lane, where the slower traffic can move to the right lane and let the faster traffic pass them in the passing lane. It is clear that adding a passing lane would tend to improve traffic operations, but the desired passing lane length and how much improvement would be obtained from this length relative to shorter and longer alternatives is not known. TWOPAS does have the capability of modeling passing lanes and does offer some valuable insights on the subject. Several runs were made in TWOPAS to determine the effects of different passing lane lengths on traffic operations and they are defined in Table 5.1.

The results reported in Table 5.1 illustrate that as the length of the passing lane increases the performance of the facility improves. This can be seen by comparing the PTSF and ATS values for runs 2, 5 , 8, and 11 for a passing lane that begins 3.11 miles downstream of the beginning of the highway section. The reductions in PTSF and ATS relative to a no-passing lane situation (run 2) were as follows:

1) PTSF for run 2 – PTSF for run 5 = 1.63
2) PTSF for run 2 – PTSF for run 8 = 5.0
3) PTSF for run 2 – PTSF for run 11 = 9.93
4) ATS for run 2 – ATS for run 5 = -0.10 mph
5) ATS for run 2 – ATS for run 8 = -0.40 mph

6) ATS for run 2 – ATS for run 11 = -0.76 mph

Based on these differences in PTSF and ATS it can be seen that passing lane length does have an effect on the improvement in operations. It can also be seen that placing a passing lane further downstream from the beginning of the highway section tends to improve the overall highway operations. This is because by locating the passing lane further downstream vehicles have a greater likelihood of catching up to a slower vehicle and thus a higher likelihood of demanding a passing opportunity before they arrive at the passing lane. It is also important to remember that if a passing lane begins too close to the end of the highway section then the length of highway downstream of the passing lane on which vehicles will benefit from the passing lane is reduced. This phenomenon is discussed in more detail in chapter 6 of this report.

Table 5.1 Sensitivity Analysis Runs for Passing Lane Length.

Run	Volume (vph)	Passing Lane Length (miles)	Grade (%)	% No-passing[b]	PL at 0.62 miles		PL at 3.11 miles		PL at 5.59 miles	
					PTSF	ATS (mph)	PTSF	ATS (mph)	PTSF	ATS (mph)
1	200	0.0	0	100	57.53	57.95	57.53	57.95	57.53	57.95
2	400	0.0	0	100	72.73	56.68	72.73	56.68	72.73	56.68
3	600	0.0	0	100	80.23	55.51	80.23	55.51	80.23	55.51
4	200	0.31	0	100	55.00	58.18	54.33	58.22	54.27	58.18
5	400	0.31	0	100	71.57	56.74	71.10	56.78	71.23	56.74
6	600	0.31	0	100	79.23	55.58	78.97	55.58	78.90	55.58
7	200	0.62	0	100	52.57	58.38	49.40	58.61	49.53	58.61
8	400	0.62	0	100	68.47	56.98	67.73	57.08	67.53	57.04
9	600	0.62	0	100	76.87	55.85	76.23	55.85	76.10	55.81
10	200	1.24	0	100	48.07	58.74	45.23	58.92	43.73	59.14
11	400	1.24	0	100	64.33	57.28	62.80	57.45	62.40	57.51
12	600	1.24	0	100	73.97	56.08	72.40	56.22	72.57	56.22
13	200	1.86	0	100	45.7	58.88	42.23	59.25	41.20	59.31
14	400	1.86	0	100	61.43	57.55	59.53	57.64	58.67	57.88
15	600	1.86	0	100	71.23	56.35	70.27	56.44	70.13	56.44

5.2 Shoulder and lane width

The effects of shoulder and lane widths is intuitive, where roadways that feel more restrictive or less forgiving of driver maneuvering errors tend to have lower speeds. However,

the effect on PTSF is not quite as clear. Twelve runs were made to ascertain the effects of shoulder and lane widths on PTSF and ATS and the results are shown in Table 5.2.

The results show that having a shoulder width of 6 ft will result in a slight decrease of PTSF of approximately 2. Lane width has no discernible effect. Similarly, having a shoulder width of 6 ft will increase average travel speed by approximately 3 to 4 miles per hour relative to a shoulder width of 1 ft. Again, according to the TWOPAS simulation, lane width has no discernible effect on ATS.

Based on these results it appears that the TWOPAS model is not very reliable for predicting PTSF and ATS when attempting to determine the effects of lane and shoulder widths on traffic operations.

Table 5.2 Sensitivity Analysis Runs for Shoulder and Lane Width.

Run	Volume (vph)	% Trucks	Lane Width (ft)	Shoulder Width (ft)	Curve Radius (ft)[a]	Passing Lane Length (miles)	Grade (%)	% no-passing[b]	PTSF	ATS
1	200	10	12	6	None	0	0	0	57.53	57.95
2	400	10	12	6	None	0	0	0	72.92	56.56
3	600	10	12	6	None	0	0	0	80.03	55.51
4	200	10	10	6	None	0	0	0	57.53	57.95
5	400	10	10	6	None	0	0	0	73.07	56.54
6	600	10	10	6	None	0	0	0	79.90	55.61
7	200	10	12	1	None	0	0	0	60.13	54.08
8	400	10	12	1	None	0	0	0	75.50	52.78
9	600	10	12	1	None	0	0	0	82.17	51.91
10	200	10	10	1	None	0	0	0	60.13	54.08
11	400	10	10	1	None	0	0	0	75.50	52.78
12	600	10	10	1	None	0	0	0	82.17	51.91

6 HIGHWAY CAPACITY MANUAL PROCEDURE COMPARISONS

To procure funds for two-lane rural highway improvements, agencies need to justify the expense and this is usually accomplished through a two-lane highway planning/operations analysis procedure. Two analysis procedures for two-lane highways are TWOPAS and the rural two-lane highway procedure from the, HCM 2000 [8]. Historically, HCM procedures for two-lane highway analysis have been used more frequently than TWOPAS. However, the HCM 2000 procedures have not been validated under conditions observed in the US [6]. In response to this need for validation, the purpose of this paper is to present an evaluation of the 2000 release of the HCM 2000 two-lane highway procedures for two-way, directional, and passing lane analysis using field data collected in Idaho.

In the second section of this paper a brief background on the analysis of two-lane rural highways is presented. Then in the third section the subject of two-way analysis for two-lane highways is addressed with emphasis given to the estimation of percent-time-spent-following using the two-way analysis and directional analysis procedures. A field study was performed, where detailed data were collected at multiple locations and TWOPAS was used to gain additional insights. Then in the fourth section the subject of passing lane analysis is discussed, emphasizing the estimation of percent-time-spent-following. A field study was performed on a highway section containing passing lanes, where data were recorded at regular intervals through the section. TWOPAS was used to provide further insights into the development of the HCM 2000 procedure for passing lanes. Finally, in the fifth section a summary of results are given as well as some guidance on future directions that should be taken.

Note that TWOPAS played a significant role in the development of the HCM 2000 two-lane highway procedures, where model parameters and adjustment factors were derived based on its output. It seemed logical that one of the first steps to validate the HCM 2000 two-lane highway procedures would be to see if they agree with TWOPAS simulation output for an actual facility (i.e., not part of a standard set of scenarios used to develop the procedures). It stands to

reason that, when analyzing a given highway section, that TWOPAS and the HCM 2000 would tend to agree. However, this may not always be the case as will be shown in this paper.

6.1 Background

An HCM procedure for two-lane highway analysis has been available since 1950 and has undergone several revisions and modifications since then. A history of these revisions and modifications can be found elsewhere [9, 10]. The most recent revisions to the procedure were made as part of the HCM 2000. One of the primary revisions was the addition of the procedure for directional analysis and the procedure for analyzing passing lanes. Revisions were also made to the two-way and specific grade analysis procedures. These procedures use Percent Time Spent Following (PTSF) and Average Travel Speed (ATS) as performance measures for determining Level of Service (LOS). PTSF is defined as the average percentage of travel time that vehicles must travel in platoons behind slower vehicles due to the inability to pass. Unfortunately, PTSF is difficult to measure in the field. As a result, a surrogate field measure of the percentage of vehicles traveling with headways of less than three seconds at specific points is recommended by the HCM 2000 [8] and is referred to in this paper as percent following (PF). In the past it has been found that PF results in values that are comparable to PTSF [6].

Luttinen has examined the revised two-way and directional analysis procedures in the context of Finnish two-lane highway operations, concentrating on PTSF. Luttinen [10] found that the HCM 2000 procedures tend to overestimate PTSF for Finnish highways, similar to findings cited by Krummins [11] for the HCM 1985 procedure. Luttinen concluded that the HCM 2000 procedure should be calibrated to local conditions. He also found that there seems to be a discrepancy between the directional and two-way analysis procedure results [10]. However, no guidance was given as to which analysis is more correct, and hence which should be held in higher confidence. Luttinen did not evaluate the passing lane analysis procedure, but did suggest a methodology whereby it could be calibrated to local conditions [12].

Procedures set forth in the HCM 2000 were developed based primarily on output from the TWOPAS simulation model. TWOPAS was calibrated by performing a series of simulation

runs while systematically varying factors. The traffic performance measures provided by the model were then checked to ensure that they responded to the changes in a reasonable fashion. TWOPAS was then validated using data collected on two highway sections.

Calibration can be performed by adjusting the desired travel speed parameters and a car following parameter. For the sake of consistency, the parameter values used to develop the HCM 2000 two-lane highway procedures were also used for the TWOPAS runs in this paper. Desired travel speed parameters are comprised of means and standard deviations for passenger cars, trucks, and recreation vehicles. Mean desired travel speeds that were used in TWOPAS were 61, 60, and 60 mph for passenger cars, trucks, and recreation vehicles respectively. Desired travel speed standard deviations were set at 5.0, 4.0, and 3.5 mph for passenger cars, trucks, and recreation vehicles respectively. Finally, the car following sensitivity factor was set to 0.8 [6]. This factor helps characterize the distribution of headways at which motorists prefer to drive while following another vehicle and it is a ratio of the average time gap of platooned vehicles observed in the field and the default average gap of platooned vehicles used in TWOPAS. More information regarding this factor can be found elsewhere [3].

6.2 TWO-Way and directional Analysis

Two-way analysis of a two-lane highway can be performed using two methods presented in the HCM 2000. The first method is the two-way analysis procedure, where a two-lane highway section is analyzed using a two-way volume and a directional split. Equation 6.1 is used to estimate PTSF for a two-way analysis.

$$PTSF = 100 \times \left(1 - e^{-0.000879 v_p}\right) + f_{np/d} \qquad (6.1)$$

where

PTSF = estimate of two-way percent time spent following,

v_p = two-way volume, pcph,

$f_{np/d}$ = adjustment for the combined effect of the directional distribution of traffic and of the percentage of no-passing zones.

The second method is the directional analysis procedure where the analysis is performed for each direction and then aggregated to get a two-way result. Equation 6.2 is used to estimate the PTSF for a directional analysis and the PTSF estimate combining directions one and two can be derived through Equation 6.3. The parameters, a and b, vary depending on the level of opposing traffic volume and are specified in the HCM 2000 (*1*).

$$PTSF_d = 100 \times \left(1 - e^{a v_d^{\,b}}\right) + f_{np} \qquad (6.2)$$

where

$PTSF_d$ = percent time spent following in the analysis direction, d,

v_d = volume in the analysis direction, pcph,

a = coefficient for estimating base percent time spent following,

b = coefficient for estimating base percent time spent following,

f_{np} = adjustment to account for the effect of percentage of no-passing zones.

$$PTSF = \frac{TT_1 \times PTSF_1 + TT_2 \times PTSF_2}{TT_1 + TT_2} \qquad (6.3)$$

where

TT_1, TT_2 = total travel time in analysis direction 1 and 2, respectively (veh-h).

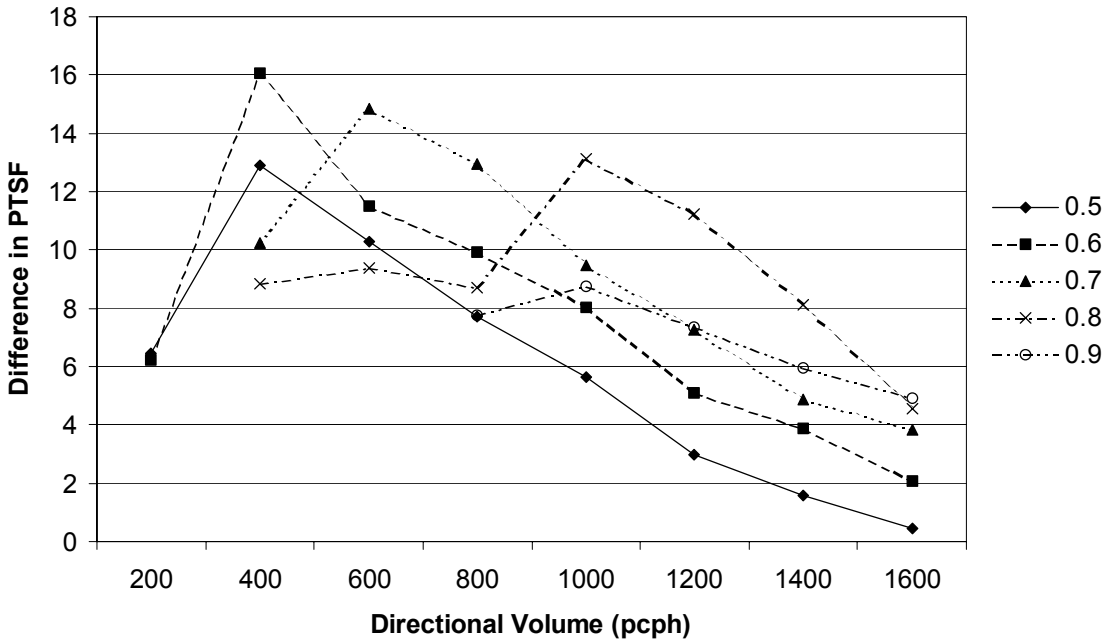


Figure 6.1 Discrepancy Between Two-Way and Aggregated Directional Analysis.

While the results of the two methods should be similar, our analysis shows that this is not the case. Thirty five test cases were run using both Equation 6.1, 6.2, and 6.3 with zero percent no-passing, level terrain, 3.6 m lanes, 1.8 m shoulders, no access points, one hundred percent passenger cars, and at volumes ranging from 200 to 1600 vph in 200 vph increments. Figure 6.1 shows the difference in PTSF values over the range of volumes, where the difference is between the estimate resulting from using Equation 6.3 and the two-way analysis estimate.

As shown in Figure 6.1, Equation 6.3 results are consistently higher. The discrepancy can be quite large, with differences in PTSF that would likely result in a change in level of service, which are defined in increments of 15 after the level of service A, which ends at 35 PTSF. This discrepancy has been pointed out in previous work by Luttinen (*3*), but was left unresolved in that no guidance was given as to which method should be used for a two-way analysis. It can be assumed that the HCM 2000 recommends the use of the two-way analysis procedure because the two-way analysis procedure exists and it states that the directional analysis is appropriate for steep grades and for passing lanes. However, neither one of these

preclude the use of Equation 6.3 to aggregate directional analysis results in an effort to arrive at a two-way analysis result.

The question of which method to use was explored by determining which analysis approach was more accurate, where the accuracy of an analysis procedure was determined by a field test. Field tests were performed on US 12, a rural two-lane highway in northern Idaho and simulations were performed using TWOPAS. Using TWOPAS in this evaluation helped determine the accuracy of the procedures as well as the approximate cause of the discrepancy.

6.2.1 US 12 Data Set and Test Bed

US 12 is a highway serving local traffic, recreational traffic, and long distance freight traffic. The 6.55 miles section of US 12 on which data were collected follows a river in a north/south alignment and is bordered at both ends by small communities. The general terrain characteristics of the highway section range from level to rolling including horizontal curves that are not severe enough to require reductions in speed. Access points are frequent on one part of the facility but are scarce on the other. Due to traffic entering and exiting at the access points, volumes are not uniform along the facility, with higher traffic volumes occurring at the north end of the facility.

Data collected for this facility included the following: traffic volumes, vehicle classification, vehicle speeds, and vehicle gaps. Data were collected at five different locations to provide a section wide view of traffic characteristics. These data were collected via tube counters, with one located at each end of the highway section and three located at various points in the middle. Data were collected for a 24-hour period, where specific 15-minute periods were chosen for analysis based on data quality and volume levels.

Recall that the surrogate field measure for PTSF is PF, the percentage of headways less than 3.0 seconds. Unfortunately, only one counter collected headway data, with the remainder collecting gap data. However, the difference between a time gap and a time headway can be expressed as $h - g = \Delta$; where headway, gap, and the difference between them is represented by

h, g, and Δ, respectively. This difference can be calculated directly if given the vehicle length and the travel speed. Vehicle lengths were not available from this set of data, so in order for this gap data to be useful for gaining insight into PF, and hence PTSF, the difference between the cumulative distributions of gaps and headways must be understood in the context of PF.

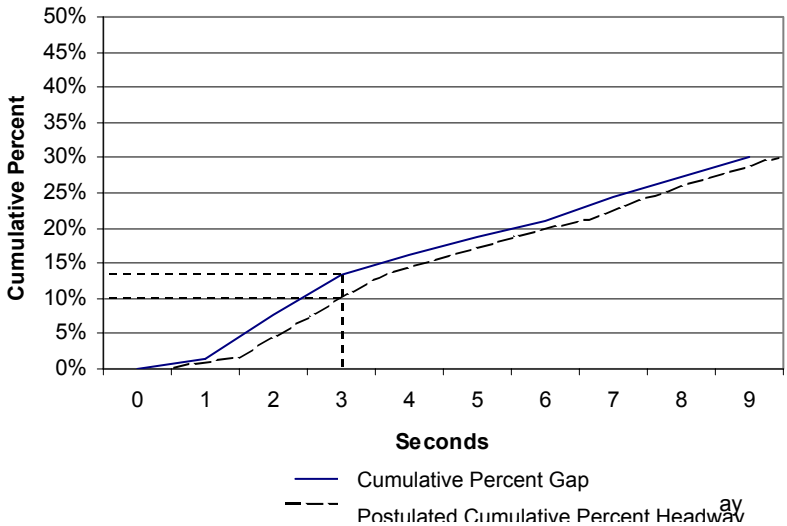


Figure 6.2 Comparison of Gap and Headway Cumulative Distributions.

The cumulative gap distribution for data collected from US 12 is shown in Figure 6.2 together with a postulated cumulative headway distribution. Note that the postulated distribution is the gap distribution shifted 0.5 seconds toward the y-axis to reflect an average Δ of 0.5 seconds. A vertical line was drawn at 3.0 seconds on the x-axis to represent the threshold for determining PF recommended in the HCM 2000. Two horizontal lines were drawn from the points where the vertical line at 3.0 seconds intersected the distributions such that the y-intercept of these lines is the corresponding cumulative frequency at 3.0 seconds. The three-second cumulative frequencies shown on Figure 6.2 are 10 percent and 13 percent, approximately. This suggests that, given the traffic conditions on US 12, there would be little difference between the gap and headway cumulative frequencies, indicating that the cumulative frequency of gaps less than or equal to 3.0 seconds might be used for a measure of PF. As a result, it was decided that using the cumulative frequency of gaps, instead of headways, would be adequate under the circumstances sited for US 12

To verify the assumption that PF based on three-second gaps would be similar to its value if based on three-second headways, PF values from the one counter that collected headway data were compared to those of the closest counter, at a distance of 0.93 miles. It was found that the average percent error was less than one percent with a maximum absolute difference of 10 PF. Obviously the two data sources do not agree perfectly, but based on the average percent error the bias seems to be minimal.

6.2.2 HCM, TWOPAS, and Field Data Comparison

It would seem that the directional analysis procedure should be more accurate than the two-way procedure because it is more disaggregate. However, the US 12 field results show that the opposite is true. Four time intervals were analyzed with two-way volumes ranging from 213 vph to 355 vph.

From Table 6.1 it can be concluded that the HCM directional and TWOPAS PTSF estimates are too high. This is illustrated by comparing the northbound field PF value of 15.4 for the first time interval to the corresponding HCM and TWOPAS PTSF values of 46.0 and 36.2, respectively.

In Table 6.2 it can be seen that on average the two-way analysis is substantially less than the directional analysis and that the two-way analysis more closely approximates the field data for all of the time intervals shown. For example, for the time interval beginning at 13:30, the difference between the HCM 2000 two-way analysis PTSF and the field PF is 20.0. This difference is smaller than that of the PTSF resulting from the use of Equation 6.3, which is 28.3.

Table 6.1 US 12 Evaluation of Directional Estimates.

Time Interval	Field PF		HCM Directional Analysis, PTSF		TWOPAS PTSF	
	NB	SB	NB	SB	NB	SB
10:15-10:30	15.4	11.0	46.0	43.9	36.2	30.2
13:30-13:45	24.1	21.8	52.1	50.7	40.6	40.8
13:45-14:00	19.4	20.8	51.9	53.2	40.0	44.9
15:45-16:00	19.7	28.3	55.4	57.0	43.5	49.1

Table 6.2 US 12 Evaluation of Two-way Estimates.

Time Interval (1)	Field PF [a] (2)	HCM Directional Analysis [b], PTSF (3)	HCM Two-way Analysis, PTSF (4)	TWOPAS PF (5)	TWOPAS PTSF (6)
10:15-10:30	13.6	45.0	36.9	36.3	33.6
13:30-13:45	23.1	51.4	43.1	43.7	40.7
13:45-14:00	20.1	52.5	44.2	45.6	42.6
15:45-16:00	24.1	56.2	48.0	49.9	46.5

a. weighted average of northbound and southbound observed PF values.

b. weighted average of northbound and southbound estimated PTSF values.

It can also be seen in both Table 6.1 and Table 6.2 that both the directional and the two-way procedures overestimate PTSF for all of the time intervals. It could be suggested that the difference between the field data and the HCM PTSF estimates are due to the bias that exists between PF derived from headways and PF derived from gaps. However, as illustrated in Figure 6.2 and the comparisons with headway data, this bias is small and does not explain the large differences shown in Tables 1 and 2. It may also be suggested that the difference is due to the bias that exists between PTSF and PF values that are based on the three-second headway criteria. Based on previous work, this bias is quite small in comparison to the differences between the observed PF and the HCM PTSF estimates (*2*). To help gain some insight into this bias, TWOPAS runs were made and the results are shown in Table 6.2. Based on the TWOPAS estimates of PTSF and PF it can be seen that this bias is small.

Based on these results, we can conclude that, for the two-way analysis, the HCM two-way analysis procedure is more accurate than the HCM directional analysis procedure, for the

cases investigated. Still, the large difference between the field measured PF and the HCM estimates is unresolved and will be a subject of further investigation in the next section.

6.3 Passing Lane Analysis

One of the major improvements of the HCM 2000 two-lane highway procedure is the added capability to analyze passing lanes, a feature not included in the 1985 HCM. First, a directional analysis for the highway section in question is completed. Then, the performance values are adjusted with a ratio as shown in Equation 6.4 for PTSF. Equation 6.4 is only to be used if the length, L_t, is greater than or equal to the length, $L_u + L_{pl} + L_{de}$ as shown in Figure 6.3. If this is not the case than Equation 6.5 must be used (*1*).

$$PTSF_{pl} = \frac{PTSF_d \left[L_u + L_d + f_{pl} L_{pl} + \left(\frac{1 + f_{pl}}{2} L_{de} \right) \right]}{L_t} \tag{6.4}$$

where

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

$PTSF_d$ = percent-time-spent-following for the entire segment without the passing lane,

f_{pl} = factor for the effect of a passing lane on percent-time-spent-following,

L_u = length of two-lane highway upstream of the passing lane (miles),

L_d = length of two-lane highway downstream of the passing lane and beyond its effective length (miles),

L_{pl} = length of the passing lane including tapers (miles),

L_{de} = downstream length of two-lane highway within the effective length of the passing lane (miles), and

L_t = total length of analysis segment (miles).

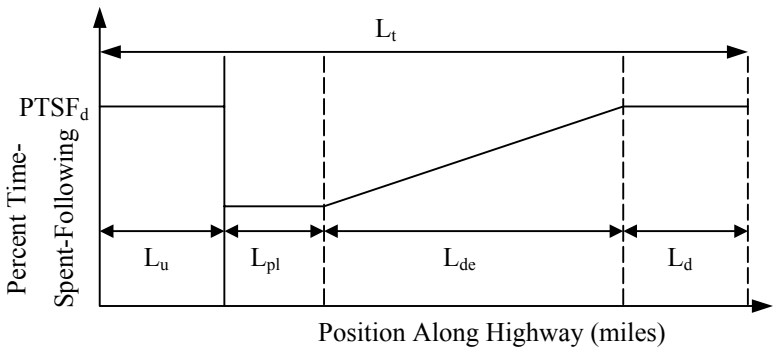


Figure 6.3 Effect of Passing Lane on Percent Time Spent Following.

$$PTSF_{pl} = \frac{PTSF_d\left[L_u + f_{pl}L_{pl} + f_{pl}L'_{de} + \left(\frac{1-f_{pl}}{2}\right)\left(\frac{(L'_{de})^2}{L_{de}}\right)\right]}{L_t} \qquad (6.5)$$

where

L'_{de} = actual distance from end of passing lane to end of analysis segment (miles); L'_{de} must be less than or equal to the value of L_{de}.

To date no field evaluations have been made of the passing lane procedure and validation of the procedure was not performed as part of the NCHRP project due to limited data and resource constraints [6]. In response, a field evaluation of the HCM 2000 passing lane analysis procedure was performed on a section of highway US 95, in northern Idaho.

In addition to the field study, a model of US 95 was developed in TWOPAS to gain insight into the effects of the passing lane on highway operations. Furthermore, including TWOPAS in this evaluation helped determine where some of the sources of error might lie with regards to the HCM 2000 two-lane highway procedures.

It should be noted that the HCM 2000 states that some passing lanes may be too complex to analyze due to interactions. It may be clear that two passing lanes in series would be interacting if the downstream passing lane was within the downstream effective length of the upstream passing lane. However, it may not be clear that interaction also occurs between adjacent passing lanes serving opposing traffic. The US 95 highway section shown in Figure 6.4 fits the latter category and it was analyzed using the HCM 2000 procedures to gain additional insight into the HCM passing lane analysis procedure using field data. Also, comparison of the HCM 2000 PTSF estimates to field PF and simulated PTSF would be useful to verify the results found for US 12. To support the use of the HCM 2000 passing lane procedure for a passing lane configuration where interaction might occur, an additional analysis was performed on output from a series of TWOPAS runs.

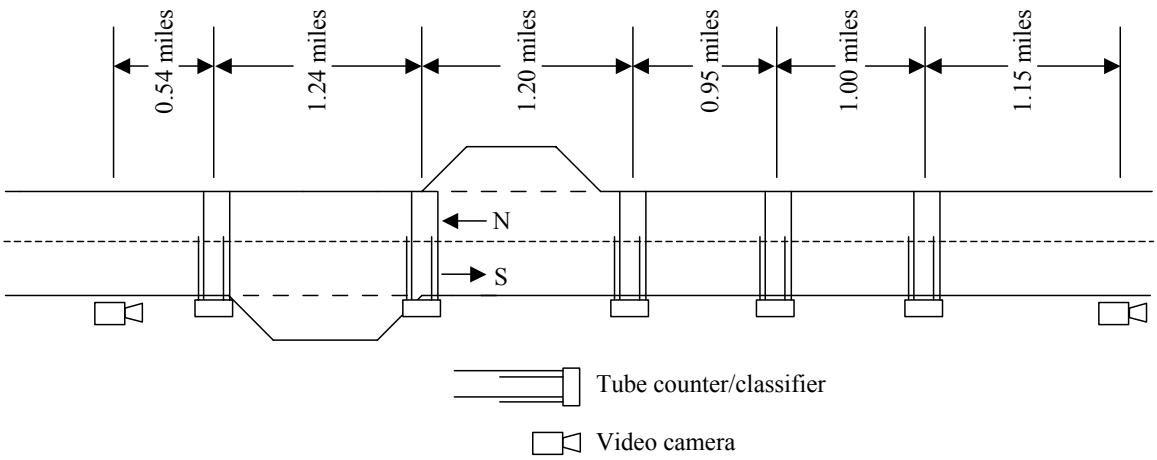


Figure 6.4 US 95 Highway Section.

6.3.1 US 95 Data Set and Test Bed

Data were collected on a 6.1 miles section of US 95. This highway carries a significant volume of freight traffic for the northern Idaho region as well as some commuter traffic. The section of highway under analysis spans gently rolling terrain with infrequent access points to adjacent farming establishments, hence volume levels are uniform across the highway section.

Tube traffic counters and video cameras were used to collect traffic counts, vehicle classifications, speed, headways, and travel times in fifteen-minute intervals. Seven data collection points were selected, two of which were covered by the two cameras located at the ends of the section, as shown in Figure 6.4. The remaining five data collection points were covered by tube counters, which were located at various points within the highway section. Two passing lanes are located in the section, one for each direction of travel, and were located toward the northern end of the highway section (see Figure 6.4).

An analysis was performed to validate the traffic counter based method for collecting headway data. This was done by comparing headway data extracted from video tapes at the same time and comparing the resulting percent following values. All four analysis periods were included in this analysis and the video based PF values of the southern video camera were compared with those of the nearest traffic counter, which was 1.15 miles to the north, as shown in Figure 6.4. It was found that the average absolute percent difference between the video based PF and the counter based PF was 15%. This verifies that although there are some differences, the counters were producing headway data that were sound.

6.3.2 US 95 TWOPAS Simulation

The TWOPAS models for US 95 were varied by volume and by the inclusion of passing lanes, where the length of the passing lanes were specified to include the taper lengths. Highway characteristics were represented in discrete intervals of 0.05 miles and were extracted from plan sheets and barrier logs provided by the Idaho Transportation Department. Warm-up zones were set at 1.00 miles and the warm up times and run times were set to twenty minutes and sixty minutes, respectively [6]. Four fifteen-minute time intervals were chosen and reflect the full range of traffic conditions that were observed at the US 95 site. For each fifteen-minute interval that was simulated, six replicate runs were made.

6.3.3 Passing Lane Effects

The first portion of the analysis of the results for passing lanes was performed with the objective of determining the effect of the passing lanes on highway operations. Table 6.3 gives the PTSF estimates taken from the HCM 2000 passing lane analysis procedure and from TWOPAS. Also included in the tables are the field measured PF values.

Table 6.3 Passing Lane Effects.

			HCM			TWOPAS		
Time Interval	Direction	Field PF	$PTSF_d$	$PTSF_{pl}$	Ratio	$PTSF_d$	$PTSF_{pl}$	Ratio
10:00-10:15	NB	19.9	53.2	43.3	0.814	41.5	24.1	0.582
10:30-10:45	NB	10.9	50.6	41.1	0.812	41.7	24.9	0.598
15:30-15:45	NB	18.9	57.6	47.1	0.818	48.1	29.7	0.618
16:30-16:45	NB	18.6	70.5	57.6	0.817	49.4	31.5	0.639
10:00-10:15	SB	17.0	57.3	38.2	0.667	42.7	26.6	0.623
10:30-10:45	SB	13.0	49.3	32.9	0.667	29.1	17.5	0.600
15:30-15:45	SB	30.8	61.2	42.7	0.698	43.9	27.9	0.636
16:30-16:45	SB	34.2	73.9	53.1	0.719	58.2	41.2	0.708

In Table 6.3, simulation results show the effect of passing lanes on NB and SB traffic operations, respectively. This effect is quantified by calculating the ratio of the PTSF estimates, $PTSF_{pl}/PTSF_d$, which can be calculated using HCM estimates or TWOPAS estimates, where the resulting ratios are given in Table 6.3.

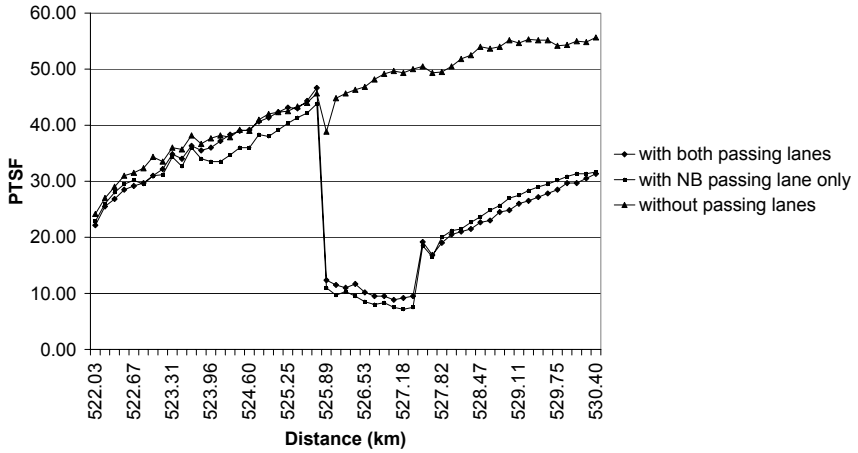
This section of US 95 is bordered by a four lane highway section on the southern end and by a high volume unsignalized intersection on the northern end, as a result it was deemed more appropriate to use Equation 6.5 to estimate the HCM PTSF adjusted for a passing lane, $PTSF_{pl}$. This is because the effective length, L_{de}, extends beyond the highway section being analyzed in both the northbound and southbound direction.

The HCM ratios for the northbound traffic are about thirty four percent larger than the TWOPAS ratios, suggesting that the HCM estimate for passing lane benefits is more conservative than TWOPAS for this highway section. However, the HCM ratios for the southbound traffic are quite close, with an average percent difference of seven percent. One

reason for this pattern in the ratios may be that the HCM procedure does not consider the interaction of passing lanes with opposing traffic, while TWOPAS does.

Figure 6.5 is a plot of the average PTSF values from six replicate runs sampled at regular intervals along the simulated facility. In Figure 6.5, it can be seen that there are differences leading to the conclusion that there is some interaction. This can be seen by referring to Figure 6.5a, a plot of the northbound PTSF. It can be seen that there are some differences between the curve "with both passing lanes" and the curve "with NB passing only". For example, from the beginning of the highway section to the end of the northbound passing lane it can be seen that the PTSF is, on average, less. This is due to reduced southbound platooning that results from the southbound passing lane, which results in fewer passing opportunities and hence a higher PTSF.

a) Northbound PTSF



b) Southbound PTSF

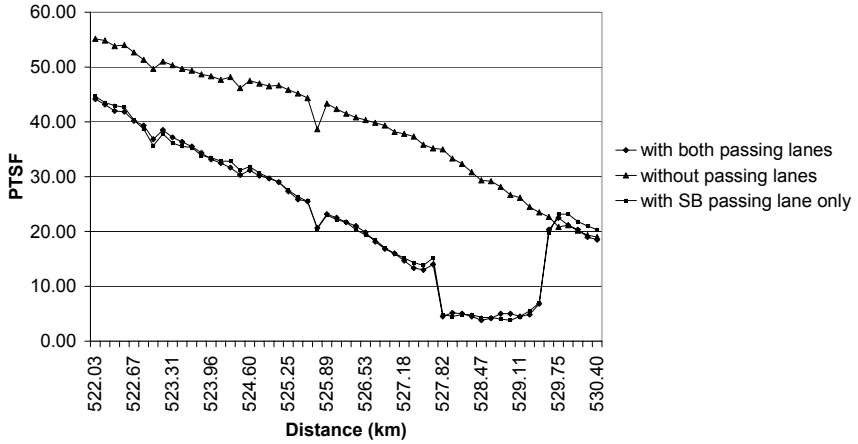


Figure 6.5 Passing Lane Interaction and PTSF.

Interaction between passing lanes was investigated further by simulating the US 95 highway section using four scenarios listed below for each of the time intervals shown in Table 6.3.

1. passing lanes in both directions,
2. passing lane in northbound direction,

3. passing lane in southbound direction, and
4. no passing lane in either direction.

An analysis of variance was performed using the northbound and southbound directions as separate experimental units. The experimental design consisted of one treatment with four levels and blocking by direction and time interval. The four treatment levels that were used on the experimental units were 1) no passing lanes, 2) one passing lane in the direction of travel, 3) one passing lane not in the direction of travel, and 4) passing lanes in both directions.

There were two important findings from this statistical analysis. One is that there is no significant difference between treatment levels one and three, with mean PTSF of 44.3 and 44.8, respectively. This suggests that traffic traveling in a direction of travel without a passing lane is essentially unaffected by a passing lane added in the opposing direction of travel. The second finding is that there is no significant difference between treatment levels two and four, with mean PTSF of 27.5 and 27.9, respectively, indicating that the interaction between passing lanes configured as they are for this highway section is insignificant. Transportation engineers may be reluctant to use the HCM 2000 passing lane analysis procedure for situations similar to what is shown in Figure 6.4. However, based on this statistical analysis and the results shown in Figure 6.5, it can be concluded that the interaction between the passing lanes does exist but has little effect on overall highway section operations.

There are three other trends in Table 6.3 that need to be addressed and they are as follows: 1) northbound and southbound HCM ratios are different, 2) northbound and southbound TWOPAS ratios are similar, and 3) northbound HCM and TWOPAS ratios are different. The first trend is easily explained by the fact that the northbound downstream effective length, L'_{de}, is cut much shorter than that of the southbound directions, with effective lengths of 1.78 and 4.30 miles, respectively. This difference in effective length reduces the effect of the northbound passing lane. The second trend conflicts with the first trend and indicates that, according to TWOPAS simulations, the relative benefits of the northbound and southbound passing lanes are similar for this highway section. This is because the northbound passing lane

causes a much larger decrease in PTSF, relative to the decrease in PTSF for the southbound, as can be seen in Figure 6.5 a and b, respectively. The third trend occurs because of this same large decrease in PTSF for northbound traffic. It is hypothesized that this third trend is due to a possible relationship between traffic volume, PTSF prior to the passing lane, and the reduction in PTSF, which is not reflected in the HCM 2000 factor for the effect of a passing lane, f_{pl}.

6.3.4 General Field Test and Simulation Results

The third portion of the analysis of the results for passing lanes was performed with the objective of determining the source of the bias in the HCM 2000 procedures that was found when analyzing the US 12 highway section. Field data were averaged across all the data collection locations to obtain an overall estimate of PF for the highway section. HCM estimates were calculated using the directional analysis procedure, which was then adjusted through the passing lane analysis procedure. The results are compared in Table 6.4 for four time intervals that reflect the full range of traffic conditions observed on the highway section.

Two important trends can be seen in the data presented in Table 6.4. One is that HCM estimates are consistently high when compared to the field PF, with errors ranging from 11.1 to 39.0 PTSF. The other trend is that the TWOPAS PTSF estimates on the average are higher than the field PF values, with errors ranging from -2.9 to 14.0, but are much closer than the HCM estimates. These trends indicate two possible sources of error. One is that the level terrain TWOPAS models used in developing the HCM procedures may not adequately represent operations on specific highway sections. Another source of error is that the calibration of the mathematical models shown in Equations 6.1 and 6.2 was done in a way that did not adequately represent traffic conditions as represented in the four time periods shown in Table 6.4.

Table 6.4 US 95 Analysis and Comparison with Field Data.

	NB				SB			
Time Interval	Volume (vph)	Field PF	HCM	TWOPAS PTSF	Volume (vph)	Field PF	HCM	TWOPAS PTSF
10:00-10:15	152	19.9	43.3	24.1	185	17.0	38.2	26.6
10:30-10:45	155	10.9	41.1	24.9	125	13.0	32.9	17.5
15:30-15:45	197	18.9	47.1	29.7	217	30.8	42.7	27.9
16:30-16:45	216	18.6	57.6	31.5	297	34.2	53.1	41.2

6.4 Evaluation Summary

Two field studies were used for evaluating the HCM 2000 two-lane highway analysis procedure. Results from these evaluations do not constitute a global evaluation of the procedure for all cases or situations, but they do give insight into the kind of results that can be expected and limitations of the HCM 2000 procedures.

Discrepancies between the directional and two-way analysis procedure PTSF estimates were verified and it was found that the two-way analysis procedure is more accurate, although both procedures produce estimates that are substantially higher than observed field conditions. The problem of consistently high HCM estimates, regardless of the analysis procedure, appears to be unresolved in the HCM 2000 two-lane highway analysis procedures. It is hypothesized that the overestimation stems from two possible sources: 1) inconsistency between the level terrain highway alignment used in TWOPAS to generate the HCM 2000 analysis procedures and the two highway alignments used in this study and 2) inaccurate mathematical modeling of traffic conditions represented in the field studies discussed here.

The passing lane analysis procedure seems to be adequate. Furthermore, based on the findings reported in this paper, it can be concluded that the HCM 2000 passing lane procedure may be used to model PTSF for adjacent passing lanes in opposite directions. When doing so, it should be noted that interactions do occur and that the HCM 2000 passing lane procedure does not take them into account. This results in a PTSF estimate that is more approximate than a situation with no interaction.

Recommendations for future research include the following:

- two-way analysis using a simplification of the directional analysis equations should be considered to ensure a certain degree of consistency,
- other factors affecting passing lane operations, such as PTSF prior to the passing lane and the existence of other passing lanes, need to be addressed, and
- relationships between two-lane highway operations and outside factors such as upstream four lane sections and intersections need to be understood in greater detail.

7 CONCLUSIONS AND RECOMMENDATIONS

This report contains a tutorial for the use of TWOPAS by way of the UCBRURAL interface develop at UC Berkeley. Step-by-step instructions are provided to help the user develop successful simulation models of two-lane highways. Also, instructions are provided for accessing the results of these simulations. Three case studies were completed as examples of how TWOPAS could be applied to the analysis of two-lane highways and their improvement through the addition of passing lanes. The case studies included highway section from US 12, US 95, and US 26. A sensitivity analysis was performed for TWOPAS to ascertain its suitability to model the effects of passing lane length, passing lane location, lane width, and shoulder width. It was found that lane width has no effect on TWOPAS results. However, passing lane location and length do have affect highway operations and appear to be modeled reasonably by TWOPAS. A field evaluation of the HCM two-lane highway procedures and TWOPAS was performed. It was found that TWOPAS represents the highway conditions much more closely. It was also found that the HCM directional analysis procedure produces PTSF estimates that are inconsistent with the two-way analysis procedure.

A training workshop was conducted and attended by ITD traffic engineers. The purpose of the workshop was to demonstrate the capabilities of TWOPAS and the UCBRURAL interface. Feedback from the workshop indicated that the engineers were very interested in what TWOPAS could do but were somewhat disappointed in UCBRURAL because of its instability on Windows machines and DOS application limitations.

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