

# HCM2010 Chapter 10

## Freeway Facilities

### User's Guide to FREEVAL2010



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# **FREEVAL-2010 USER GUIDE**

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## 1. INTRODUCTION

### OVERVIEW

This document is intended to provide general guidance on the use of the computational engine for HCM Chapter 10, Freeway Facilities. This document is practitioner-friendly, not developer oriented. The focus is on how to use and interpret the results of the computational engine. Detailed discussion on the procedure itself along with engine documentation guidance for software developers is provided in Chapter 25, Freeway Facilities: Supplemental.

The computational engine, FREEVAL (FREeway EVALuation) 2010 is a computerized, worksheet-based environment designed to *faithfully implement* the operational analysis computations for Undersaturated and Oversaturated Directional Freeway Facilities. Thus, FREEVAL-2010 is a faithful implementation of HCM Chapter 10, which incorporates all of the freeway segment procedures outlined in Chapters 11, 12, and 13 for basic freeway segments, weaving segments, and merge and diverge segments, respectively.

FREEVAL-2010 is executed in Microsoft Excel, with most computations embedded in Visual Basic modules. The environment allows the user to analyze a freeway facility of up to 70 analysis segments (to be defined) and for up to twenty-four 15-min time intervals (6 h). The engine can generally handle any facility that falls within these temporal and spatial constraints. However, it is highly recommended that the total facility length not exceed 9–12 mi in length to ensure consistency between demand variability over time and facility travel time. Further, the analysis spatial and temporal boundaries (i.e. first and last time intervals and first and last facility segments) should be uncongested and should allow all queues to form and clear within the facility to assure that performance measures fully account for the predicted extent of congestion and delay. These aspects are discussed in detail in Chapter 10. In conformance with the 2010 HCM, all analyses are carried out using US customary units.

FREEVAL-2010 is organized as a sequence of linked Excel worksheets, and can be used autonomously to analyze individual freeway segments or an entire directional facility. The user must define the different freeway segments and enters all necessary input data that are also required in the individual segment chapters. These include segment length, number of lanes, length of acceleration and deceleration lanes, heavy and recreational vehicle percentages, and the free-flow speed. The latter can also be calculated in FREEVAL-2010 from the segment or facility geometric attributes.

Consistent with Chapter 10, FREEVAL-2010 covers undersaturated and oversaturated conditions. For oversaturated time intervals, traffic demands, volume served and queues are tracked over time and space, as discussed in more detail in Chapter 25. In addition to characterizing oversaturated conditions, the most significant difference from the segment-based chapters is that FREEVAL carries out all calculations using 15-min flow rates (expressed in vehicles per hour). It therefore *does not* use a peak-hour factor (PHF). To replicate the example problem results found in the segment chapters, PHF-adjusted flow rates must be

entered in FREEVAL directly. Heavy vehicle adjustments (using general terrain factors or directly input for specific grade segments) are automatically handled by the methodology.

The computational engine is further designed to allow the user to revise input data following the completion of an analysis. This feature is intended to perform quick sensitivity or “what if” analyses of different demand scenarios or geometric changes to the facility. However, the user is cautioned to ensure that all prior inputs are maintained when using FREEVAL for extensive scenario evaluation. FREEVAL-2010 is not a commercial software product, and as such relies on the voluntary commitment of the TRB Committee on Highway Capacity and Quality of Service to address software bugs that may emerge in the course of its use, and incorporate methodological changes over time.

### **CHAPTER ORGANIZATION**

The next section gives a brief description of the FREEVAL-2010 structure and organization. The document then presents a series of screenshots from the computational engine, in a step-by-step –process description of input and output requirements. The document concludes with a discussion on interpreting the output for an oversaturated case, which is one of the major strengths and unique attributes of the methodology.

The software user guidance in sections 3 and 4 is based on example problems 1 and 2 of Chapter 10 and the user is encouraged to reference that discussion for further information on the interpretation of results.

## 2. ENGINE STRUCTURE AND ORGANIZATION

The FREEVAL computational engine is organized as a sequence of computational worksheets; one for each 15-min time, or analysis period. These worksheets are used both for data input and data output, with portions of the worksheets that are irrelevant to a particular segment type automatically hidden by the procedure. Additional worksheets are used for interim calculations and to present facility summary statistics. Worksheets are hidden and write-protected automatically as needed. A total of 24 time intervals can be included and up to 70 user-defined segments can be coded for a directional facility.

### INPUTS

Data input in FREEVAL takes place in three locations.

First, a *global input screen* appears when first executing the methodology. It contains basic settings for the number of time intervals and segments, as well as global settings for free-flow speed and other facility-wide parameters.

Second, most inputs regarding individual segment geometry and volumes appear in the *individual time-period worksheets*. Some variables are pre-coded with default values, but can be readily overridden by user input. Also, many inputs entered in time-period 1 are automatically copied to later time intervals. The user must enter the demand flows for each mainline segment and for each ramp in every time interval. These cells are highlighted in yellow in the engine to assist with data entry.

The third and final set of inputs is related to the weaving segment methodology. Due to the special data requirements for this methodology, inputs are handled through a *separate input dialog box* that automatically appears when a user codes a weaving segment and executes the analysis.

### OUTPUTS

Data output in FREEVAL also appears in three places.

First, every time-period worksheet contains a summary of the measures of effectiveness (MOEs) for each segment in that time interval. The worksheet also contains facility average estimates of MOEs such as overall travel-time and facility-average density, which is needed to estimate facility levels of service.

Second, a summary worksheet (labeled "Results Summary") provides overall segment performance across all time intervals.

The third type of output are 3-D contour plots and summary tables showing how a select number of MOEs vary by segment and time interval such as volume-to-capacity ratio, demand-to-capacity ratio, segment speed, segment density, and level of service (LOS) (table only). All outputs are used to evaluate the operational performance of a facility as will be described in section 4.

The next section provides a step-by-step outline of the input coding procedure.

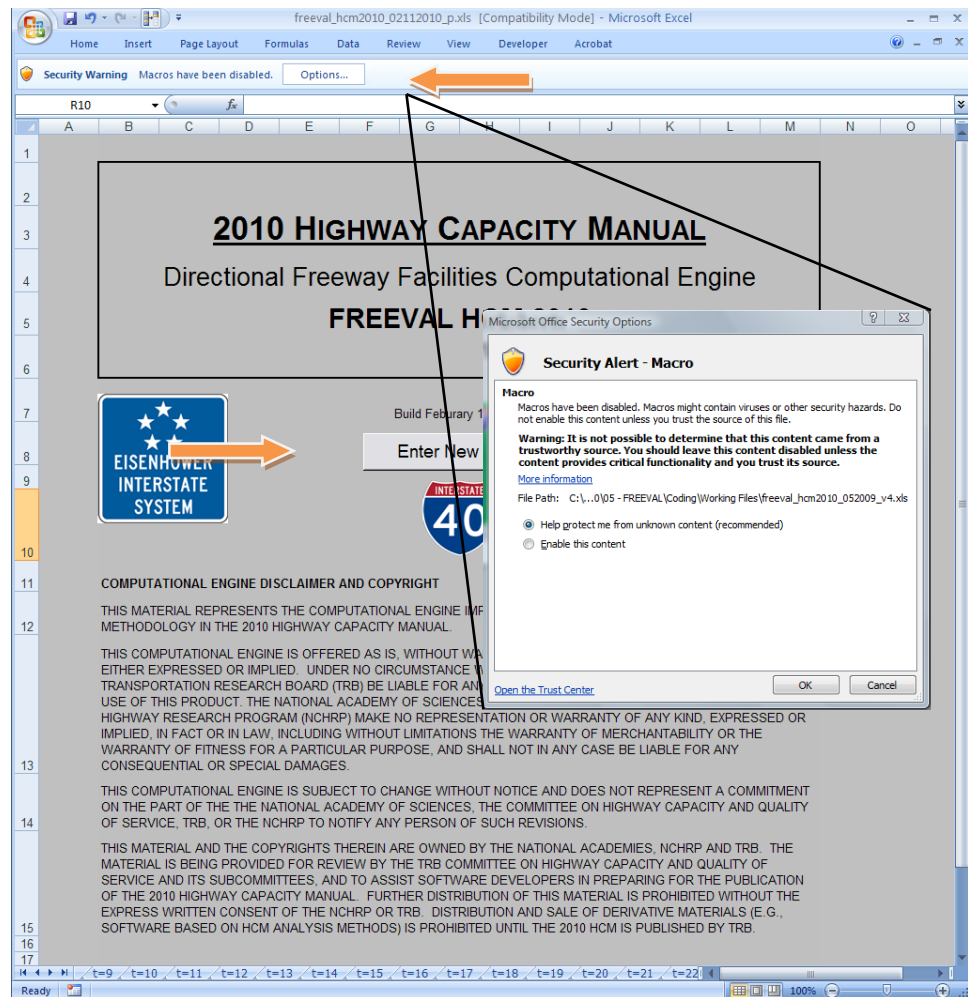
### 3. STEP-BY-STEP INPUT CODING PROCEDURE

This section presents a detailed overview of the data input process in FREEVAL through a series of screenshots. The engine is saved as an .xls file, but can also be opened and executed in Excel 2007 and 2010. The computations are performed using Visual Basic macros and macros must be enabled in order to execute the spreadsheet.

#### STEP A: WELCOME SCREEN

After opening the program, a welcome screen appears (Exhibit 1). To begin coding, the user clicks on the “Enter New Data” button in the center of the screen. If macros are disabled, a security warning will appear at the top of the screen (shown in Exhibit 1 for Office 2007). Select “Enable this content” in the dialog box that appears.

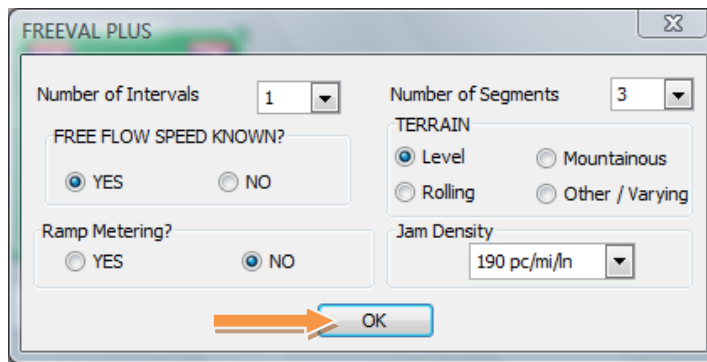
**Exhibit 1**  
FREEVAL-2010 Welcome  
Screen





**STEP B: GLOBAL INPUT PARAMETERS**

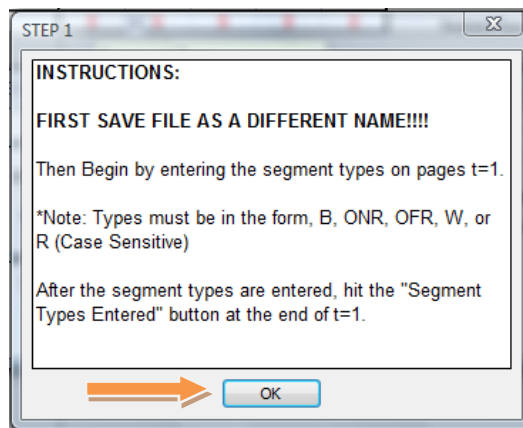
After selecting “Enter New Data” the global input dialog will appear (Exhibit 2). Here the user selects the number of time intervals and number of segments to be analyzed. Other settings include whether the facility free-flow speed is known or should be calculated, whether ramp metering is used, the type of terrain, and the jam density of the facility (used for oversaturated calculations). After completing all global settings, select “OK”. The macro will automatically delete all extra worksheets for time intervals and unused columns for segments. Output charts and tables are also updated. Depending on the computer used, this process may take a few minutes.



**Exhibit 2**  
Global Settings Dialog

**STEP C: SAVE FILE AS A DIFFERENT NAME**

A dialog box will prompt the user to save the file under a different name (Exhibit 3). This step is of critical importance, since saving using the same name will override the original macro and the code will be lost! In fact, it is strongly recommend as a first step that the user creates at least one copy of the original FREEVAL-2010 containing the code and keep it in safe storage.



**Exhibit 3**  
Save File Dialog

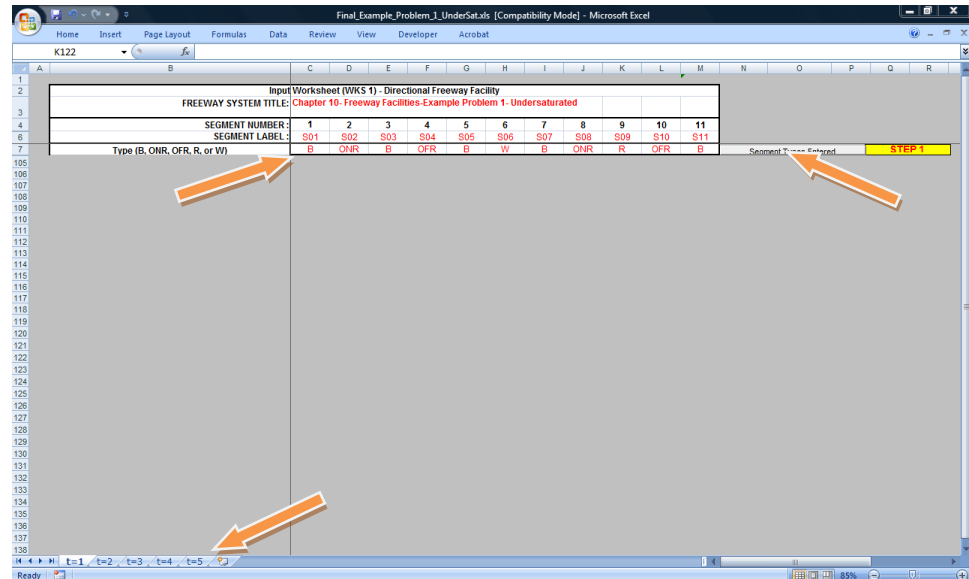
**STEP D: CODE SEGMENT TYPES**

Next, the user enters the type of each segment (Exhibit 4). Note that the number of columns has been reduced to match the number of segments defined by the user. The proper way to define the appropriate number of segment is explained in Chapter 10, including the requirement that the first and last segments of the facility should be coded as basic segments. Also, the number of

*The first and last segments of the modeled facility should be basic freeway segments.*

**Exhibit 4**  
Defining Segment Types

input worksheets generated matches the number of (15-min) time intervals selected in the global dialog box. Using drop-down menus, the user defines each segment as a basic, on-ramp, off-ramp, weaving, or overlapping ramp segment following HCM conventions (see Chapter 10). After identifying all segments, click the “Segment Types Entered” button. After that action, the macro will automatically black out all unneeded data entry cells. This process may take a few minutes.



**STEP E: SEGMENT DATA ENTRY**

Next, the user enters all segment data for each time interval in sequence (Exhibit 5). The common inputs needed for all segments are: length (ft), number of lanes, free-flow speed (mi/h), segment demand (veh/h), % trucks, and % RVs. Additionally, the user can utilize several adjustment factors that may affect the operations of the facility. These will be discussed in a later section.

For all ramp and weaving segments, the user further needs to enter the ramp demand flows and can adjust the heavy vehicle percentages as desired. Note that a time interval corresponds to a 15-min period and as a result all volume inputs should take the form of 15-min demand flow rates (in vehicles per hour). No PHF adjustment is necessary.

After entering all input for one time interval, the user opens the tab for the worksheet in the next time interval. For all subsequent time intervals, some inputs are automatically copied from the t=1 worksheet. However, the engine generally allows the user to override automatically generated input. Demand volumes always need to be entered for all time intervals. After completing all inputs for all time intervals and checking for correctness, click the “Run Entire Analysis” button shown on the worksheet in the last time interval.

*All traffic data input need to be entered in the form of demand flow rates. The method internally tracks whether these demands are processed and distinguishes in the output between demand volumes (input) and the actual volume served (output).*

SEGMENT NUMBER:	1	2	3	4	5	6	7	8	9	10	11
SEGMENT LABEL:	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11
Type (B, ONR, OFF, R, or W)	B	ONR	B	OFF	B	W	B	ONR	R	OFF	B
Length (ft)	5280	1500	2280	1500	5280	2640	5280	1140	300	1140	5280
Number of Lanes	3	3	3	3	3	4	3	3	3	3	3
FF Speed (Mph)	60	60	60	60	60	60	60	60	60	60	60
Segment Demand (vph)	4,506	4,955	4,955	4,955	4,685	5,225	4,865	5,315	5,315	5,315	5,045
Capacity Adjustment Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Origin Demand Adjustment Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Destination Demand Adjustment Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
% Trucks	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
On-Ramp Demand (vph)	0	0	0	0	0	0	0	0	0	0	0
On-Ramp % Trucks	450				540		450				
On-Ramp % RV's	5				5		5				
Off-Ramp Demand (vph)	0				0		0				
Off-Ramp % Trucks			270		360		270				
Off-Ramp % RV's			5		5		5				
Accel/Decel Lane Length (ft)	500		500		0		500			500	
Number of Lanes on Ramp	1		1		1		1			1	
Ramp on Left or Right (L / R)	Right		Right				Right			Right	
Ramp FF S (mi/hr)	40		40		40		40			40	

**Exhibit 5**  
Data Input

**STEP F: WEAVING DATA**

If the analyst coded at least one weaving segment in the facility, a weaving dialog box will appear after clicking “Run Entire Analysis” (Exhibit 6). The dialog contains all needed input variables for the new HCM2010 weaving methodology. Some variables are automatically passed through from the main input worksheets, but can be edited by selecting any of the radio buttons in the “Value Known” group. For example, weaving volumes in FREEVAL-2010 are automatically estimated assuming a common exit percentage of on-ramp and freeway mainline traffic onto the off-ramp. If the user has actual weaving counts, these should be entered instead. After editing a value, it is important to click “Update” first to ensure that the new data have been saved. Then click “OK” when done.

For guidance on estimating the weaving-specific variables, the user is referred to Chapter 11, Freeway Weaving Segments. Special attention should be paid to the distinction between weaving *segment length* and the weaving *short length*. In FREEVAL, the effective segment length is entered in the Excel worksheets and is the length to which the calculated performance measures are applied. However, the performance measures are calculated based on the short length as discussed in Chapter 12. For example, a weaving segment may have a short length of 1,500 ft, which is measured as the distances between the gores at the on and off-ramps. Following the guidance given in Chapter 12, the operational effects of the weaving segment often extend a distance of 500 ft upstream and downstream of that short length. Consequently, the weaving segment length should be entered as 2,500 ft in the time interval input worksheets.

The user can select “Use defaults for all time intervals” to skip the detailed data entry, but is required to enter data for each segment in the first time interval. After entering all data for each time interval, click “OK”. If more than one weaving segment exists or more than one time interval is used, the weaving dialog will move to the next set of inputs.

*For weaving segments, the segment length is the length over which performance measures are applied. The performance measures are calculated using the short length, which is commonly shorter than the segment length.*

**Exhibit 6**  
Weaving Dialog

To ensure that weaving segments are coded correctly, the reader is referred to Chapter 12, where definitions for weaving segment short length, the number of required lane changes, and the number of weaving lanes are provided. The user should not accept the default values in the weaving dialog before consulting Chapter 12 variable definitions and analysis conventions. The interchange density is automatically calculated from the overall facility geometry, but can also be user-adjusted. Since FREEVAL only know the number of ramps (and the facility length), but not the number of interchanges, an average of two ramps per interchange is assumed. Consequently, the interchange density is estimated as half the total ramp density.

A default value for ramp-to-ramp flow is estimated as describes above. However, the user can adjust any of the values in the flow diagram and the method will automatically calculate all remaining values when the user clicks the "Update" button. A user adjustment for ramp-to-ramp flow is especially important for two-sided weaves. This adjustment is selected using the radio button at the top of the dialog. The weaving graphic shown in Exhibit 6 automatically changes when a two-sided weave is used.

**STEP G: OUTPUTS**

The summary worksheet labeled "Results Summary" (Exhibit 7) contains aggregated results for all time intervals. It provides average speed and travel time over all time intervals and gives the maximum demand-to-capacity ratio (*d/c*) for each segment across all time intervals. Provided all segments operate below capacity (at or below a *d/c* ratio of 1.00) in all time intervals, the facility operations will be labeled as "globally undersaturated." If that is the case, all individual segment results are obtained by Chapter 11–13 methodologies. The

aggregation of performance measures is consistent with the computations presented in Chapters 10 and 25.

If any segment during any time interval operates at a *d/c* ratio > 1.0, the facility is considered to be “oversaturated” and additional output is generated. This is discussed in more detail below. From the summary worksheet, the user can select any of the individual interval worksheets for detailed results (Exhibit 8). Additionally, a set of four summary graphs is created showing four key MOEs over all segments and all time intervals (Exhibit 9).

Worksheet 3 - Facility-Level Summary												
Chapter 10- Freeway Facilities-Example Problem 1- Undersaturated												
Number of ValidTime Intervals	5											
Period Duration (min)	75											
												SECTION AND PERIOD TOTALS
SEGMENT NUMBER :	1	2	3	4	5	6	7	8	9	10	11	units
SEGMENT LABEL :	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	
Input or estimated segment type (B,W,ONR,OFB)	B	ONR	B	OFB	B	W	B	ONR	R	OFB	B	
Segment length (ft)	5280	1500	2280	1500	5280	2640	5280	1140	360	1140	5280	6.00 miles
Number of lanes	3	3	3	3	3	4	3	3	3	3	3	
Free flow speed (mi/hr)	60	60	60	60	60	60	60	60	60	60	60	
Maximum d/c ratio*	0.78	0.87	0.87	0.87	0.83	0.77	0.90	0.99	0.99	0.99	0.92	Globally Undersaturated
Time interval queueing begins												
Travel time per vehicle (min)	1.00	0.32	0.44	0.30	1.01	0.62	1.02	0.25	0.08	0.23	1.03	6.3 min
VMTD Veh-miles (Demand)	5788.8	1797.9	2732.9	1797.9	5968.8	3321.9	6238.8	1473.3	465.3	1473.3	6463.8	37,523 VMT
VMTV Veh-miles (Volume)	5788.8	1797.9	2732.9	1797.9	5968.8	3321.9	6238.8	1473.3	465.3	1473.3	6463.8	37,523 VMT
VHT travel (hrs)	96.8	33.6	46.4	32.1	100.3	69.0	106.3	28.0	8.8	26.4	111.3	659.0 VHT
VHD delay (hrs)	0.3	3.6	0.9	2.2	0.9	13.6	2.3	3.4	1.1	1.9	3.5	33.6 VHD
Space mean speed = VMTV / VHT (mph)	59.82	53.53	58.85	55.98	59.49	48.16	58.99	52.85	52.85	55.78	58.09	58.9 mph
Average density (vpmpl)	25.8	31.5	28.7	30.1	28.8	27.6	28.3	34.6	34.6	32.6	29.7	28.5 veh/miIn
Average density (pcmppl)	26.4	32.3	29.4	30.9	27.4	28.3	29.1	35.4	35.4	33.4	30.4	29.2 pc/miIn

Exhibit 7 Facility Summary Worksheet

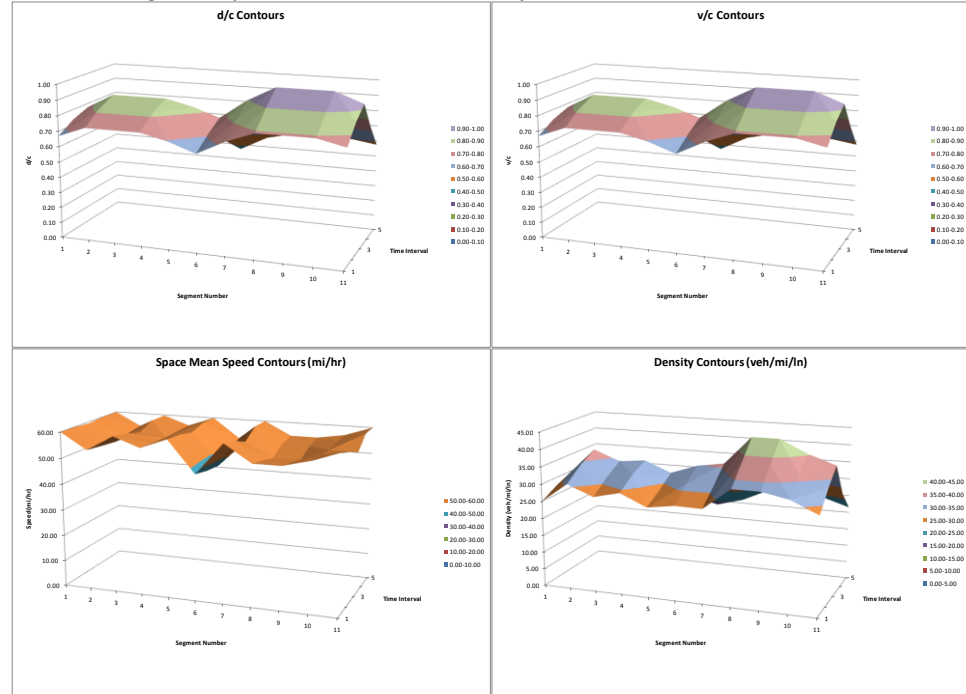
Input Worksheet (WKS 1) - Directional Freeway Facility												
FREEWAY SYSTEM TITLE: Chapter 10- Freeway Facilities-Example Problem 1- Undersaturated												
SEGMENT NUMBER :	1	2	3	4	5	6	7	8	9	10	11	
SEGMENT LABEL :	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	
Input or estimated segment type (B,W, ONR,OFB,R)	B	ONR	B	OFB	B	W	B	ONR	R	OFB	B	
Segment Length (ft)	5,280	1,500	2,280	1,500	5,280	2,640	5,280	1,140	360	1,140	5,280	6.00 miles
Number of lanes	3	3	3	3	3	4	3	3	3	3	3	
Free flow speed (mph)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	
Space mean speed (mph)	59.4	52.5	57.1	55.7	58.3	46.1	56.1	50.6	50.6	55.2	55.0	
Segment density (veh/mi/In)	29.3	37.2	34.2	35.0	31.9	34.6	35.8	43.9	43.9	40.3	37.7	34.8 veh/miIn
Segment capacity (vph)	6,732	6,732	6,732	6,732	6,732	8,303	6,732	6,732	6,732	6,732	6,732	
Segment demand (vph)	5,225	5,855	5,855	5,855	5,595	6,395	6,035	6,665	6,665	6,665	6,215	
Segment volume served (vph)	5,225	5,855	5,855	5,855	5,595	6,395	6,035	6,665	6,665	6,665	6,215	
d/c ratio	0.78	0.87	0.87	0.87	0.83	0.77	0.90	0.99	0.99	0.99	0.92	
On-Ramp demand (vph)	0	630	0	0	0	810	0	630	0	0	0	
On-Ramp capacity (vph)	0	2,000	0	0	0	2,000	0	2,000	0	0	0	
Off-Ramp demand (vph)	0	0	0	270	0	360	0	0	0	450	0	
Off-Ramp capacity (vph)	0	0	0	2,000	0	2,000	0	0	0	2,000	0	
Ramp-to-Ramp demand (vph)				150								
Travel time per vehicle (min)	1.01	0.32	0.45	0.31	1.03	0.65	1.07	0.26	0.08	0.23	1.09	6.51 min
Free-flow travel time (min)	1.00	0.28	0.43	0.28	1.00	0.50	1.00	0.22	0.07	0.22	1.00	6.00 min
Freeway mainline delay (min)	0.01	0.04	0.02	0.02	0.03	0.15	0.07	0.04	0.01	0.02	0.09	0.51 min
System delay-- includes on-ramps (min)	0.01	0.04	0.02	0.02	0.03	0.15	0.07	0.04	0.01	0.02	0.09	0.51 min
VMTD Veh-miles / interval (Demand)	1,306.3	415.8	632.1	415.8	1,396.3	799.4	1,508.8	359.8	113.6	359.8	1,553.8	8,861 veh-mi
VMTV Veh-miles / interval (Volume served)	1,306.3	415.8	632.1	415.8	1,396.3	799.4	1,508.8	359.8	113.6	359.8	1,553.8	8,861 veh-mi
VHT travel / interval (hrs)	22.00	7.92	11.07	7.46	23.96	17.32	26.88	7.12	2.25	6.52	28.24	160.74 hrs
VHD delay / interval (hrs)	0.23	0.99	0.54	0.53	0.69	4.00	1.74	1.12	0.35	0.53	2.34	13.05 hrs
Space mean speed = VMTV / VHT (mph)	59.4	52.5	57.1	55.7	58.3	46.1	56.1	50.6	50.6	55.2	55.0	55.1 mph
Segment density (pc/mi/In)*	30.1	31.8	35.0	31.5	32.7	35.5	36.7	35.8	36.9	36.9	38.6	35.6 pc/miIn
Density-based LOS on segment	D	D	D	D	D	D	E	E	E	E	E	
Demand-based LOS on segment												

Exhibit 8 Time Interval Performance

From any of the time interval sheets (Exhibit 8) the user can select “revise input data” to modify segment and time-interval specific data. However, the user cannot add or delete segments or time intervals at this stage, since the corresponding worksheets and columns have been customized in step B above. No attempt is made to characterize facility LOS across multiple time intervals

**Exhibit 9**  
Output Graphs

which may have very different operational performance and can therefore bias the resulting facility LOS value considerably.



The four graphs in Exhibit 9 show performance measures over the time-space domain. The *v/c* and *d/c* graphs in this case are identical, because the facility is globally undersaturated. The speed plot shows a slight reduction in speed in the weaving segment (segment 6) resulting from relatively high weaving volumes that still do not exceed capacity. The density plot shows elevated densities in segments 8 and 9. Note that the length axis in the graphs is categorical and the scale therefore does not reflect the different lengths of segments.

In addition to the graphical outputs, FREEVAL also gives summary tables of the same four performance measures (*v/c*, *d/c*, speed, and density), as well as LOS. Exhibit 10 shows only the LOS table, since other outputs are already represented in the previous exhibit.

**Exhibit 10**  
LOS Summary Table

DENSITY BASED Level Of Service												
	Segment											FACILITY
Time	1	2	3	4	5	6	7	8	9	10	11	LOS
1	C	C	D	C	D	C	D	D	D	D	D	D
2	D	D	D	D	D	D	D	D	D	D	D	D
3	D	D	D	D	D	E	E	E	E	E	E	E
4	D	C	D	D	D	C	D	D	D	D	D	D
5	C	C	C	C	C	B	C	C	C	C	C	C

DEMAND BASED Level Of Service											
	Segment										
Time	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3											
4											
5											

\*IF ALL CELLS BLANK, D/C<1.0 ACROSS ALL SEGMENTS AND TIME PERIODS.

A
B
C
D
E
F

Consistent with the discussion in Chapter 10, FREEVAL provides two LOS summary tables. The upper table in Exhibit 10 gives the density-based levels of service criteria, which in this case are all at LOS E or better. The bottom table gives supplemental LOS information for any segments where demand exceeds capacity. Since all segments operate below capacity, no entries are shown in the demand-based LOS table.

#### **STEP H: REVISING INPUT DATA**

Step G above concludes the freeway facility methodology outlined in Chapter 10. It is expected, however, that analysts will use the methodology to test various scenarios or to perform sensitivity analyses. The FREEVAL computational engine has been designed to allow the user to revise input data and make changes to geometry, demand patterns or other input variables to test the effect of such changes on the operations of the facility. Motivations to revise inputs include:

- Testing sensitivity of increased volumes due to traffic growth or traffic diversion to other routes;
- Testing geometric changes such as added lanes, different ramp configurations, or alternate weaving patterns in select segments; and
- Testing the operational effects of work zones and/or incidents through changes in segment capacity and/or free-flow speeds.

As stated earlier, the input revision does not allow the analyst to change the number of segments or time intervals. This limitation is due to the manner in which the engine customizes the segment columns and time interval worksheets in step B. If the analyst wishes to modify the temporal or spatial analysis domain, the facility has to be re-coded.

FREEVAL provides two types of adjustment factors that are intended to assist the user in performing basic sensitivity analyses. These are:

- Origin/Destination Demand Adjustment Factors, and
- Capacity Adjustment Factors.

The two adjustment factors are described in more detail below.

#### **Origin/Destination Demand Adjustment Factors**

The origin and destination demand adjustment factors are used to test the effect of an increase or decrease in the original demand volumes by a user-defined growth or shrinkage factor. Each segment contains one origin and one destination adjustment factor for each time interval. They act as simple multiplicative factors that adjust the entering and exiting demands in the segment. For example, an origin adjustment factor of 1.10 increases the demand of mainline or an on-ramp segment by 10%. Similarly, a destination adjustment factor of 0.85 will reduce the demand at an off-ramp by 15%. For weaving segments, the entering and exiting demands can be changed with the applicable origin and destination adjustment factors, respectively.

The origin/destination demand adjustment factors are intended to run quick sensitivity analyses or what-if analyses of demand scenarios. For example, they can be used to quickly assess the impact of ITS treatments that cause a proportion of drivers to leave the freeway at an off-ramp upstream of a freeway bottleneck. Similarly, they could be used to model a surge in on-ramp traffic. The analyst can change all origin and destination demand adjustment factors by the same value to model general background traffic growth (e.g. 1.05 for 5% traffic growth).

### Capacity Adjustment Factors

The capacity adjustment factors (CAF) are used to decrease the capacity of a segment in one or more time intervals. The HCM capacity value for the segment in the selected time interval is multiplied by the CAF. As a result, the speed-flow relationship on the segment is changed as is discussed in more detail in Chapters 10 and 25. Capacity adjustment factors can be used to model short-term incidents in a segment or to represent the effects of increased *friction* due to work zones, or simply to calibrate the basic capacity to an observed, non-HCM condition (e.g., freeway tunnel). Capacity adjustment factors should generally only be used to reduce the per-lane capacity in a segment. The speed-flow and capacity relationships in Chapters 10–13 have been calibrated and an adjustment to higher capacities (e.g. greater than 2,400 veh/h/ln) is not supported by the data. From a computational perspective, the equation used to calculate the new speed-flow relationship after applying a CAF, can further result in speeds above the free-flow if a CAF > 1.0 is used. If the user wishes to use the CAF to calibrate FREEVAL-2010 to higher field-observed speeds, a higher free-flow speed curve should be used. This speed-flow curve can then be calibrated to a lower capacity using the CAF if desired.

The effect of advanced traffic management strategies, such as temporary shoulder use, should be modeled by adding a lane in the appropriate segments and time intervals, and then reducing the capacity of the revised segment using a capacity adjustment factor (since the use of a shoulder is unlikely to result in a full lane of added capacity. For example, if the use of the shoulder on a 3-lane, 70 mi/h basic freeway segment (per-lane capacity of 2,400 veh/h/ln) results in an additional half-lane of capacity (1,200 veh/h/ln), it should be modeled as a four-lane segment with a capacity adjustment factor of 0.875 ( $= [3 \times 2,400 + 1,200] / [4 \times 2,400]$ ).

*Capacity adjustment factors should generally only be used to reduce the per-lane capacity in a segment, not to increase capacity above the calibrated HCM2010 capacity for that segment type.*



### 4. INTERPRETING OVERSATURATED RESULTS

This section discusses the interpretation of results for an oversaturated freeway facility. A freeway facility is defined as oversaturated if any segment experiences a *d/c* ratio greater than 1.0 during any analysis time interval. In the facility summary worksheet, this facility will be labeled as “oversaturated” as shown in Exhibit 11. If this is the case, the user should first ensure that whatever queues that have formed during the analysis have dissipated by the end of the last time interval and that all vehicles were able to clear the facility. To check for this, the total vehicle-miles-traveled (VMT) based on demand flow (VMTD) should exactly match the actual VMT processed (VMTV) in the Results Summary worksheet. If these two numbers match (within a rounding margin of error), a message appears indicating that “All Vehicles have cleared within the analysis period.” If not, the analysis violates the underlying assumptions of Chapter 10, which requires that all queues should be fully contained within the time-space domain. If VMT-Demand does not equal VMT-Volume, this assumption is violated in the *time-dimension*.

If a violation in the *space-dimension* occurs, an additional warning message will alert the user that “The queue in time interval X extends beyond the analysis region.” In either case, the analyst should start over and re-run the analysis with additional segments and/or time intervals as appropriate. An alternative in the case of space-dimension violation is to artificially increase the length of the first upstream segment until the spillover queue is captured within the facility confines. A congested boundary of the time-space domain means that vehicles either remain on the facility by the end of the analysis, or in the case of extended queuing upstream of the first segment, that the impact is not accounted for in the delay and travel times computed for the facility. Only if all boundaries of the time-space domain are free of queuing, can it be assured that FREEVAL-2010 represents the true extent of congestion.

The oversaturated facility shown in Exhibit 11 was generated by applying across-the-board origin/destination demand adjustment factors of 1.11 to all segments and time intervals for the undersaturated facility presented above. This represents an 11% overall growth in traffic flow.

*Only if all boundaries of the time-space domain are free of queuing, can it be assured that FREEVAL-2010 represents the true extent of congestion.*

Worksheet 3 - Facility-Level Summary												
Chapter 10: Freeway Facilities-Example Problem 2-Oversaturated												
Number of Valid Time Intervals	5											
Period Duration (min)	75											
SECTION AND PERIOD TOTALS												
units												
SEGMENT NUMBER :	1	2	3	4	5	6	7	8	9	10	11	
SEGMENT LABEL :	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	
Input or estimated segment type (B,W,ONR,OFB)	B	ONR	B	OFB	B	W	B	ONR	R	OFB	B	
Segment length (ft)	5280	1500	2280	1500	5280	2640	5280	1140	360	1140	5280	
Number of lanes	3	3	3	3	3	4	3	3	3	3	3	
Free flow speed (mi/hr)	60	60	60	60	60	60	60	60	60	60	60	
Maximum d/c ratio**	0.86	0.97	0.97	0.97	0.92	0.85	1.00	1.10	1.10	1.10	1.02	
Time interval queueing begins					3	3	3					
Travel time per vehicle (min)	1.02	0.32	0.46	0.31	1.08	0.76	1.20	0.25	0.08	0.23	1.07	
VMTD Veh.-miles (Demand)	6425.5	1995.7	3033.5	1995.7	6625.3	3687.3	6925.0	1635.4	516.4	1635.4	7174.8	
VMTV Veh.-miles (Volume)	6425.5	1995.7	3033.5	1995.7	6625.3	3687.3	6925.0	1635.4	516.4	1635.4	7174.8	
VHT travel (hrs)	109.0	38.0	53.5	35.8	119.2	93.1	138.8	31.7	10.0	29.5	128.0	
VHD delay (hrs)	1.9	4.7	3.0	2.6	8.7	32.5	23.4	4.5	1.4	2.2	8.4	
Space mean speed = VMTV / VHT (mph)	58.93	52.58	56.68	55.71	55.60	39.59	49.90	51.52	51.52	55.49	56.06	
Average density (vp/mpl)	29.1	35.6	33.1	33.6	31.8	37.2	37.0	39.2	39.2	36.4	34.1	
Average density (pc/mpl)	29.8	36.5	33.9	34.5	32.6	38.2	37.9	40.2	40.2	37.3	35.0	

**Exhibit 11**  
Summary Output for Oversaturated Facility

All entry vehicles have cleared within the analysis period.

Demand-to-Capacity (d/c) ratios greater than 1.0 without any associated queuing indicate hidden bottlenecks.

The summary output in Exhibit 11 gives insight on congestion patterns and severity. In the example, a total of 4 segments are shown to have a maximum *d/c* ratio greater than 1.0 (segments 8, 9, 10, and 11). Segments 5, 6, and 7 all have queuing starting in time interval 3, suggesting an *active bottleneck* in segment 8. The downstream segments 9 and 10 are not exhibiting a queue, suggesting that demand is metered at the segment 8 bottleneck. The *d/c* ratios greater than 1.0 without any associated queuing indicate *hidden bottlenecks*.

More insight can be obtained by looking at the output worksheet for interval 3 (the time interval with queuing), shown in Exhibit 12. The exhibit shows that the *d/c* ratio in segment 8 is 1.10 and, as a result, a queue starts forming in segment 7. Within the 15-min time interval, the queue fills up all of segments 7 and 6, and extends 1,164 ft into segment 5. Queuing also occurs on the on-ramp at segment 6, with a 270-ft queue on the ramp. The queuing occurs because the calculated capacity of segment 8 (6,732 veh/h) is less than the demand of 7,398 veh/h. The actual segment volume and throughput to the next segment (segment 9) is limited to the capacity and thus also equals 6,732 veh/h. It is important to note that FREEVAL always places the bottleneck at the upstream end of the segment.

**Exhibit 12**  
Oversaturated Output for  
Time Interval 3

Input Worksheet (WKS 1) - Directional Freeway Facility											
FREEWAY SYSTEM TITLE: Chapter 10- Freeway Facilities-Example Problem 2- Oversaturated											
SEGMENT NUMBER :	1	2	3	4	5	6	7	8	9	10	11
SEGMENT LABEL :	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11
Input or estimated segment type (B,W, ONR, OFFR)	B	ONR	B	OFFR	B	W	B	ONR	F	OFFR	B
Segment length (ft)	5,280	1,500	2,280	1,500	5,280	2,640	5,280	1,140	360	1,140	5,280
Number of lanes	3	3	3	3	3	4	3	3	3	3	3
Free flow speed (mph)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Space mean speed (mph)	57.4	51.0	53.0	55.4	53.6	28.2	34.8	50.2	50.2	55.1	54.6
Segment density (veh/mi/ln)	33.7	42.5	40.3	33.1	38.0	58.8	57.7	44.7	44.7	40.7	43.7
Segment capacity (rph)	6,732	6,732	6,732	6,732	6,732	8,303	6,732	6,732	6,732	6,732	6,732
Segment demand (rph)	5,800	6,439	6,439	6,439	6,199	7,038	6,699	7,398	7,398	7,398	6,899
Segment volume served (rph)	5,800	6,439	6,439	6,439	6,111	6,625	6,032	6,732	6,732	6,732	6,277
d/c ratio	0.86	0.97	0.97	0.97	0.92	0.85	1.00	1.10	1.10	1.10	1.02
v/c ratio	0.86	0.97	0.97	0.97	0.91	0.80	0.90	1.00	1.00	1.00	0.93
Queue length at end of time interval (ft)					1164	2640	5280				
On-Ramp demand (rph)	0	639	0	0	0	899	0	639	0	0	0
On-Ramp volume served (rph)	0	639	0	0	0	874	0	639	0	0	0
On-Ramp delay (veh-hrs)		0.0				0.8		0.0			
On-Ramp queue length (ft)						270					
On-Ramp capacity (rph)		2,000				2,000		2,000			
Off-Ramp demand (rph)	0	0	0	300	0	400	0	0	0	500	0
Off-Ramp volume served (rph)	0	0	0	300	0	393	0	0	0	455	0
Off-Ramp capacity (rph)				2,000		2,000				2,000	
Ramp-to-Ramp demand (rph)						167					
Travel time per vehicle (min)	1.05	0.33	0.49	0.31	1.12	1.07	1.72	0.26	0.08	0.24	1.10
Free-flow travel time (min)	1.00	0.28	0.43	0.28	1.00	0.50	1.00	0.22	0.07	0.22	1.00
Freeway mainline delay (min)	0.05	0.05	0.06	0.02	0.12	0.57	0.72	0.04	0.01	0.02	0.10
System delay-- includes on-ramps (min)	0.05	0.05	0.06	0.02	0.12	0.78	0.72	0.04	0.01	0.02	0.10
VMTD Veh-miles / interval (Demand)	1,443.9	461.6	701.6	461.6	1,543.8	887.3	1,674.7	399.3	126.1	399.3	1,724.7
VMTD Veh-miles / interval (Volume served)	1,443.9	461.6	701.6	461.6	1,527.7	828.1	1,508.1	363.4	114.7	363.4	1,563.3
VHT travel / interval (hrs)	25.28	3.05	13.24	8.34	28.53	29.41	43.29	7.23	2.28	6.59	28.74
VHD delay / interval (hrs)	1.11	1.35	1.54	0.64	3.06	16.40	18.15	1.18	0.37	0.54	2.58
Space mean speed = VMTD / VHT (mph)	57.4	51.0	53.0	55.4	53.6	28.2	34.8	50.2	50.2	55.1	54.6
Segment density (pc/mi/ln)*	34.5	35.0	41.9	34.3	39.0	60.3	59.2	36.5	37.4	37.4	39.3
Density-based LOS on segment	D	D	E	D	E	F	F	F	F	F	F
Demand-based LOS on segment											

In the same time interval, it is evident that segments 9–11 also have *d/c* ratios greater than 1.0, but no queuing occurs since the demand is metered by segment 8. This occurs because the capacity of segment 8 is greater than or equal to the capacities of these downstream segments. For example, the demand in segment 11 is 6,899 veh/h, which is greater than the segment capacity of 6,732 veh/h (*d/c* = 1.02). However, due to the upstream (more severe) bottleneck, the volume served in segment 11 during this time interval is only 6,277 veh/h and the served volume-to-capacity ratio is only 0.93. The bottleneck in segment 11 is therefore inactive or hidden. As a result, the downstream segments operate at capacity,

which is defined as density-based LOS E. The fact that these segments do have *d/c* ratios greater than 1.0 is reflected in the demand-based LOS, which is LOS F for segments 9 through 11. This recognizes that the segment would fail if the upstream bottleneck did not exist (or was alleviated through geometric changes to the facility at that location only).

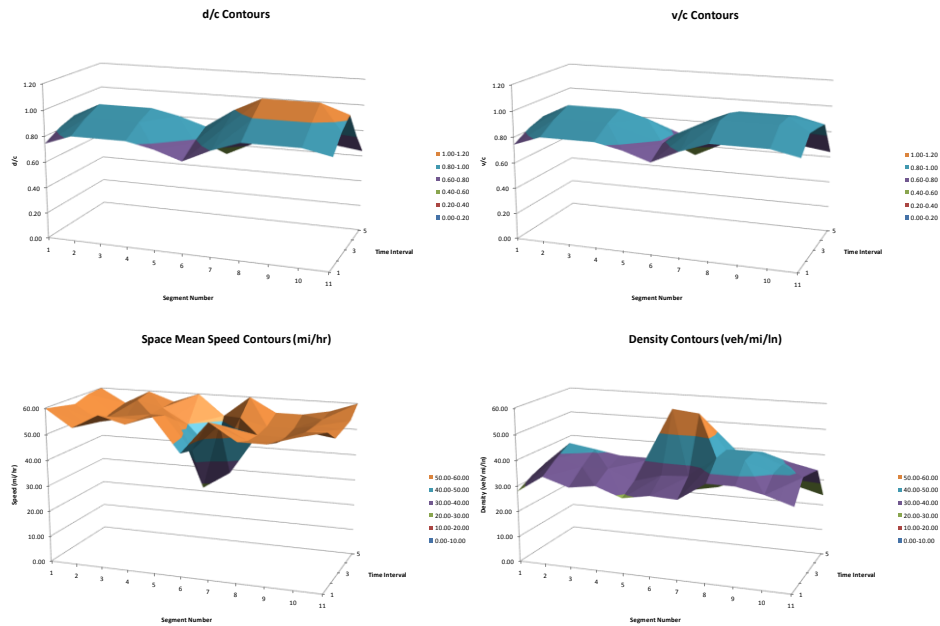
The results for time interval 3 in Exhibit 12 show that not all the forecasted demand actually reaches segment 9–11, due to congestion in segment 8. Because some vehicles were not served in time interval 3, they are now added as residual demand in time interval 4. Exhibit 13 shows this effect. While the segment 9–11 served volumes were lower than the demand in time interval 3, the volumes are greater than the demand in time interval 4. For example, segment 11 demand is 5,500 veh/h, but as the upstream queue clears, the actual served volume is 6,121 veh/h in this time interval. The output further shows that due to a drop in demand from time intervals 3 to 4, all queues have cleared at the end of the 15-min interval.

Input Worksheet (WKS 1) - Directional Freeway Facility											
FREEWAY SYSTEM TITLE: Chapter 10- Freeway Facilities-Example Problem 2- Oversaturated											
SEGMENT NUMBER :	1	2	3	4	5	6	7	8	9	10	11
SEGMENT LABEL :	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11
Input or estimated segment type (B,W, OMR,)	B	OMR	B	OFR	B	W	B	OMR	R	OFR	B
Segment Length (ft)	5,280	1,500	2,280	1,500	5,280	2,640	5,280	1,140	360	1,140	5,280
Number of lanes	3	3	3	3	3	4	3	3	3	3	3
Free flow speed (mph)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Space mean speed (mph)	59.4	53.0	58.2	55.8	49.9	39.2	53.9	51.2	51.2	55.3	55.6
Segment density (veh/mi/ln)	29.2	35.2	32.1	33.4	36.0	39.4	36.9	42.1	42.1	38.9	36.7
Segment capacity (vph)	6,732	6,732	6,732	6,732	6,732	8,382	6,732	6,732	6,732	6,732	6,732
Segment demand (vph)	5,200	5,600	5,600	5,600	5,300	5,700	5,300	5,800	5,800	5,800	5,500
Segment volume served (vph)	5,200	5,600	5,600	5,600	5,389	6,173	5,367	6,466	6,466	6,466	6,121
<i>d/c</i> ratio	0.77	0.83	0.83	0.83	0.79	0.68	0.79	0.86	0.86	0.86	0.82
<i>v/c</i> ratio	0.77	0.83	0.83	0.83	0.80	0.74	0.89	0.96	0.96	0.96	0.91
Queue length at end of time interval (ft)											
On-Ramp demand (vph)	0	400	0	0	0	400	0	500	0	0	0
On-Ramp volume served (vph)	0	400	0	0	0	425	0	500	0	0	0
On-Ramp delay (veh-hrs)		0.0				0.0		0.0			
On-Ramp queue length (ft)											
On-Ramp capacity (vph)		2,000				2,000		2,000			
Off-Ramp demand (vph)	0	0	0	300	0	400	0	0	0	300	0
Off-Ramp volume served (vph)	0	0	0	300	0	406	0	0	0	345	0
Off-Ramp capacity (vph)				2,000		2,000				2,000	
Ramp-to-Ramp demand (vph)						89					
Travel time per vehicle (min)	1.01	0.32	0.45	0.31	1.20	0.77	1.11	0.25	0.08	0.23	1.08
Free-flow travel time (min)	1.00	0.28	0.43	0.28	1.00	0.50	1.00	0.22	0.07	0.22	1.00
Freeway mainline delay (min)	0.01	0.04	0.01	0.02	0.20	0.27	0.11	0.04	0.01	0.02	0.08
System delay - includes on-ramps (min)	0.01	0.04	0.01	0.02	0.20	0.27	0.11	0.04	0.01	0.02	0.08
VMTV Veh-miles / interval (Demand)	1,300.1	397.7	604.5	397.7	1,325.1	712.5	1,325.1	313.1	38.9	313.1	1,375.0
VMTV Veh-miles / interval (Volume served)	1,000.1	397.7	604.5	397.7	1,047.2	717.1	1,491.7	349.0	110.2	349.0	1,530.4
VHT travel / interval (hrs)	21.88	7.50	10.38	7.12	27.02	19.70	27.70	6.82	2.15	6.31	27.52
VHT delay / interval (hrs)	0.21	0.87	0.31	0.50	4.57	6.85	2.84	1.00	0.32	0.43	2.01
Space mean speed = VMTV / VHT (mph)	59.4	53.0	58.2	55.8	49.9	39.2	53.9	51.2	51.2	55.3	55.6
Segment density (pc/mi/ln)	29.9	35.9	32.9	30.5	36.9	40.4	37.9	34.3	34.8	34.8	37.6
Density-based LOS on segment	D	D	D	D	E	E	E	D	D	D	E
Demand-based LOS on segment											

**Exhibit 13**  
Oversaturated Output for Time Interval 4

The effects of congestion are also evident in the graphical output provided as part of FREEVAL. The graphs in Exhibit 14 are the same as already introduced in Exhibit 9, but now show the effect of congestion. Most importantly, while the under-saturated *d/c* and *v/c* graphs in Exhibit 9 were identical, the oversaturated *v/c* graph limits the throughput of the active bottleneck in segment 8 to 1.0. It further shows the metering effect in segments 9 through 11. The speed graph shows a significant drop in speed as a result of the active bottleneck, but further shows that operating conditions downstream of segment 8 are acceptable. This point is critical, since an individual segment analysis of segments 9–11 would have predicted a much lower and congested speed. The density plot further shows areas of queuing with densities exceeding 45 veh/mi/ln in the queued segments.

**Exhibit 14**  
Graphical Output for  
Oversaturated Case



The LOS summary table for the oversaturated scenario now clearly shows the distinction between the density-based LOS that uses the actual volumes served on the facility and the demand-based LOS table that shows the presence of all segments with *d/c* ratios greater than 1.0, including all active and hidden bottlenecks (Exhibit 15).

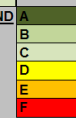
**Exhibit 15**  
LOS Summary Table for  
Oversaturated Scenario

DENSITY BASED Level Of Service												
	Segment										FACILITY	
Time	1	2	3	4	5	6	7	8	9	10	11	LOS
1	D	D	D	D	D	D	D	D	D	D	D	D
2	D	D	E	D	D	E	E	E	E	E	E	E
3	D	D	E	D	E	F	F	E	E	E	E	F
4	D	D	D	D	D	E	E	D	D	D	E	E
5	C	C	C	C	C	C	C	C	C	C	C	C

DEMAND BASED Level Of Service											
	Segment										
Time	1	2	3	4	5	6	7	8	9	10	11
1											
2											
3								F	F	F	F
4											
5											

\*IF ALL CELLS BLANK, D/C<1.0 ACROSS ALL SEGMENTS AND TIME PERIODS.



The density-based LOS table in Exhibit 15 shows that segments 6 and 7 operate at LOS F in time interval 3. In this case, Segment 8 is the active bottleneck and because FREEVAL places the bottleneck at the beginning of the segment, it operates at capacity, or LOS E. Since all downstream segments have capacities less than or equal to that of the active bottleneck, they also operate at LOS E. The bottom portion of Exhibit 15 shows the demand-based LOS, which emphasizes that segments 8–11 all have *d/c* ratios greater than 1.0 in time interval 3. The comparison between the density-based and demand-based LOS tables allows a quick and easy analysis of which bottlenecks are active and which segments are inactive or hidden bottlenecks due to an upstream metering effect of traffic demand. The overall facility LOS is F in time interval 3, since one or more individual segments have *d/c* ratios greater than 1.0.