Suggested Procedures for Analyzing Freeway Weaving Sections

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Most speed-oriented methodologies have proved unsatisfactory in describing the behavior of freeway weaving sections. Research done at the Institute of Transportation Studies at the Berkeley campus of the University of California, with the support of the California Department of Transportation, has investigated several types of simple weaves using point flow estimation. For major weaves, a type of simple weave, an analysis method was developed using point flow estimates based on movement percentages. This methodology estimates point flows within 10 percent of the actual observations for 70 percent of the cases within empirical limits. For ramp weaves a regression-based set of equations to estimate total point flow directly has proven more effective. The equations predict total point flow within 10 percent of the empirical values for 90 percent of the data. The methodology developed for major weaves has been implemented in an interactive menu-driven computer program, FREWEV. This is the first step towards an integrated freeway model, FRELANE, which currently includes major weaves and ramp weaves.

Weaving sections on freeways are one of the greatest areas of conflict in normal freeway operations. They are also the most difficult sections of the freeway to analyze satisfactorily. Various approaches and measures of effectiveness have been used during the last half century. Studies to validate the weaving methodology presented in the 1985 *Highway Capacity Manual* (HCM) have shown speed to be a very poor predictor of weaving operations (*1–3*). Ongoing research in California is exploring the use of point flow estimation and using density as a measure of effectiveness.

HISTORICAL REVIEW

The 1950 HCM presented the first method for predicting the capacity and operating speeds of freeway weaving sections (*4*). The 1965 HCM contained a revised version of this 1950 HCM graphical method with added emphasis on quality of flow (*5*). *Interim Materials on Highway Capacity*, published in 1981 by Polytechnic Institute of New York (PINY) (*6*), contained a new method for estimating weaving and nonweaving speeds for simple weaving sections (*7*) and a modification of the earlier 1965 HCM method (*8*). The 1985 HCM chapter on weaving analysis was based on the JHK algorithm, which predicted weaving and nonweaving speeds (*9*).

In 1987, on the basis of recognized needs for additional research on freeway weaving in California and encouraged by national recognition for similar research, the Institute of Transportation Studies at the Berkeley campus of the University of California (ITS-UCB), with support from the California Department of Transportation (Caltrans), began a 5-year research program.

ONGOING RESEARCH

The first phase of the research at ITS-UCB was to evaluate major weaves using existing methods. The methods evaluated included those of HCM, 1965 (*5*); Leisch (*10*); PINY (*7*); JHK (*11*); HCM, 1985 (*9*); and Fazio (*12*). These speed-based predictive methodologies produced estimates with errors of more than 10 percent for weaving and nonweaving speeds. In modeling the section as an overall unit, the speed-based methods were perceived to overlook the importance of the interactions within and between lanes. The speed predictions were also poor when a similar analysis was done with ramp weave sections (*1,2*). The Caltrans Traffic Bulletin 4 method (Level D), an alternative lane flow method for ramp weaves, was also evaluated (*13*). When applied to the same data set as the speed prediction methods, Level D predicted volumes that were within 10 percent of ramp movement volumes along the weaving section. Based on this information, a lane flow approach such as the Level D method appeared to be more promising than the speed-based methodologies for analyzing major weaves (*3*).

The second phase of the research was directed toward improving methods to analyze and design major weaving sections. Comprehensive field data was collected for 10 major weaving sections in California. Using these data sets and applying the INTRAS simulation model (*14*), a new analytical approach, point flow by movement, was developed. The proposed procedure predicts vehicle lane flow rates at frequent intervals within the weaving section as a function of prevailing traffic flow and geometric conditions. This work has been discussed in previous publications (*3,15*).

The third phase of the research program, just being completed, is concerned with developing point flow methodologies for other types of freeway weaving and ramp configurations. The models suggested predict total point flows at frequent intervals along the freeway (*16*).

Data sets for ramp weaving sites were provided by Caltrans from its own extensive study of ramp weaving sections (*1,2*). Using this data, a total point flow method was developed for analyzing ramp weaving sections (*17*).

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DEFINITION OF WEAVING SECTIONS

A weaving section exists when at least one movement must make at least one lane change to enter or exit the freeway. Only simple weaving sections are considered in this discussion.

A simple weave has only one on-ramp and one off-ramp connected by one or more auxiliary lanes. It is isolated from the influence of other ramps. Simple weaves include ramp weaves and major weaves. A ramp weave is a one-lane on-ramp connected to a one-lane off-ramp by an auxiliary lane. A major weave has an on-ramp connected to an off-ramp by one or more auxiliary lanes; at least one of the ramps must have two lanes and the other ramp may have one or two lanes. Examples of the weaving sections that are included in this discussion are shown in Figure 1.

ALTERNATIVE METHODOLOGIES

All of the methodologies described in the following are used to predict the flows at a set of points within the critical area of the weaving section. The critical area includes all lanes beginning, ending, or beginning and ending at ramps and the right-most through freeway lane. The critical areas for selected weaving sections are shaded in Figure 1. The points at which the analysis is done include the merge, the diverge, 76.2 m (250 ft) downstream of the merge, and at 152.4-m (500-ft) increments from the merge to the end of the section. The use of multiple analysis points comes from the Level D methodology. The inclusion of the 76.2-m (250-ft) point comes from empirical analysis of data collected during the research. The analysis at this point is important because it can be shown that the majority of the lane changing takes place within 152.4 m (500 ft) of the ramp of interest (*3*).

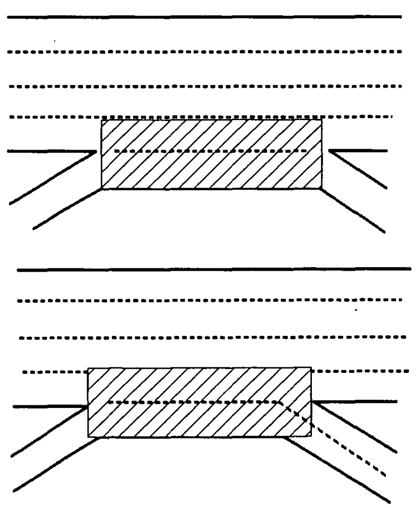

FIGURE 1 Simple weaving sections: *top*, ramp weave; *bottom*, major weave.

Level D Method

The Level D method was developed by Caltrans in the early 1960s (*13*). It is intended to evaluate ramps and ramp weave sections. The Level D method is only appropriate for a ramp weaving section operating under high or near capacity traffic flow conditions. Given the section length and volumes in the weaving section, Level D predicts the distribution of traffic in the two right-most lanes of the freeway weaving section. The distribution of each ramp movement is solely a function of section length. The amount of through traffic in the right-most through freeway lane is a function of the total freeway flow. The method allows the analyst to calculate estimates of the point flows for individual movements throughout a section. The results are highly sensitive to the estimate of non-weaving traffic in the right-most through freeway lane. Errors in estimation of total volumes at points in this lane can be attributed to failure to correctly predict freeway to freeway volumes (*17*).

Point Flow by Movement Method

Point flow by movement has its origins in the Level D method. The point flow by movement method models the distribution of movements and the amount of lane changing within the analysis area. It predicts the distribution of each movement throughout the section and estimates the total volume at a point as a sum of the individual movements. Unlike the Level D methodology, the point flow by movement method uses ramp movement percentages, which are dependent on volumes, or on weaving section length or on both volumes and weaving section length. Freeway-to-freeway percentages are not necessarily constant along the section and may be functions of volume or site geometry. The point flow by movement method for major weaves uses average percentages obtained from field data and simulation of longer sections under observed volume conditions. With a fairly wide range of values for most observed percentages, the use of an average represents the best fit.

The many equations required to produce point flows with this method and an example can be found in the initial research report (*3*).

Total Point Flow Method

Total point flow is a regression-based methodology that directly predicts the total flow at an analysis point within a weaving section (*16*). The equations, estimated separately for each analysis location, may generally be expressed as

$$\text{flow in Lane N at XX ft} = \Theta_0 + \Theta_1 FF + \Theta_2 FR + \Theta_3 RF + \Theta_4 RR$$

where

Θ_i = coefficients,
FF = freeway-to-freeway movement,
FR = freeway-to-off-ramp movement,
RF = on-ramp-to-freeway movement, and
RR = on-ramp-to-off-ramp movement.

The coefficients in the equations can provide information on the influence of the component flows within a conflict area, but the coefficients do not represent the percentages of each movement at a specific analysis point.

Movement flows can be estimated using some very strong assumptions about the behavior of individual movements and net lane changing. Net lane changing is calculated using the difference in total volume between two points across one or more lanes.

PROPOSED ALTERNATIVE METHODOLOGY FOR SELECTED WEAVES

Major Weaves

Before the research conducted at ITS-UCB, there was no analysis methodology that addressed major weaves. A major weave with at least one two-lane ramp has not been reliably analyzed by methods based on speed or the Caltrans Traffic Bulletin 4. ITS-UCB proposed a point flow by movement methodology for analyzing this type of section. The validity of the model was investigated in the initial research (*3*). The predictive ability of the method was investigated with a simple random sample of empirical data. Approximately 70 percent of the point totals are within 10 percent of observed values (*18*), as shown in Figure 2.

The total point flow methodology was also applied to major weaving sections. It was no better at predicting the total point flows than the point flow by movement method (*18*). The point flow by movement methodology allows for separate predictions of each movement. It permits the analyst to investigate individual movements without assumptions about their behavior. It also provides a secondary check on the existence of under capacity conditions. With these advantages, the point flow by movement methodology was selected for analyzing major weaves.

Ramp Weaves

The three alternative methodologies were investigated for analyzing a ramp weave section: Level D, point flow by movement, and total point flow (*17*). A subset of the Caltrans data (*1,2*), which contained information on all of the movements throughout the entire length of the weaving section, was used for the evaluation of the three methodologies when applied to ramp weaves.

Using a set of sites for which all three methods could be applied, it was determined that Level D produced estimates of total point flows within 10 percent for 40 percent of the analysis points. Seventy percent of the errors occurred in the right-most through lane because of incorrect estimates of freeway-to-freeway volumes. The point totals calculated using point flow movement estimates were better than those calculated by Level D, primarily through improved freeway-to-freeway volume estimates (*17*).

A set of total point flow equations was developed on the basis of data from three sections of similar length. The resulting total point flow estimates were an improvement over the point flow by movement method. The regression equations predicted total volumes within 10 percent of the observed volumes for 90 percent of the analysis points (*17*). A comparison of the predictions made with the total point flow equations and the predictions from the Level D method is shown in Figure 3. The Level D method and the total point flow method both continue to be evaluated for analyzing ramp weaves.

IMPLEMENTATION OF ALTERNATIVE METHODOLOGY FOR MAJOR WEAVES

An interactive menu driven computer program, FREWEV, has been developed for designing and analyzing major freeway weaving sections (*18,19*). The analysis method imple-

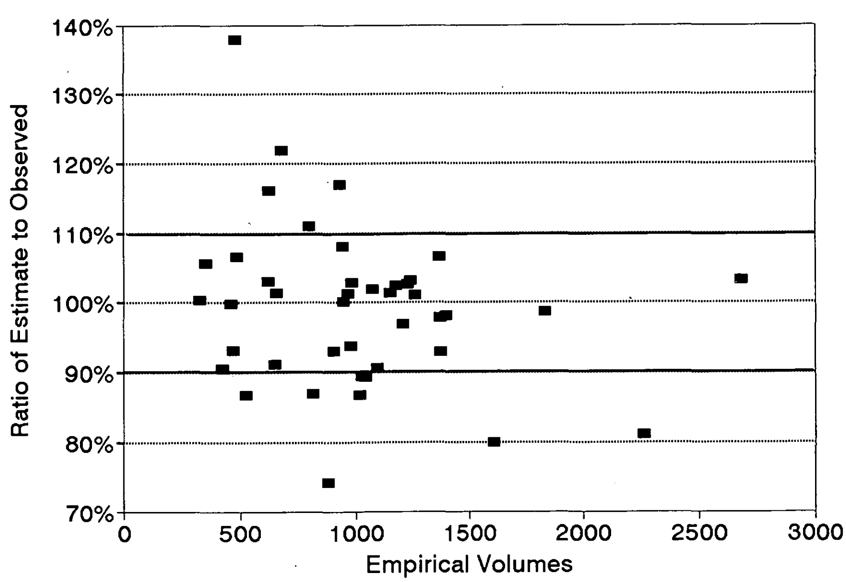

FIGURE 2 Accuracy of major weave estimates.

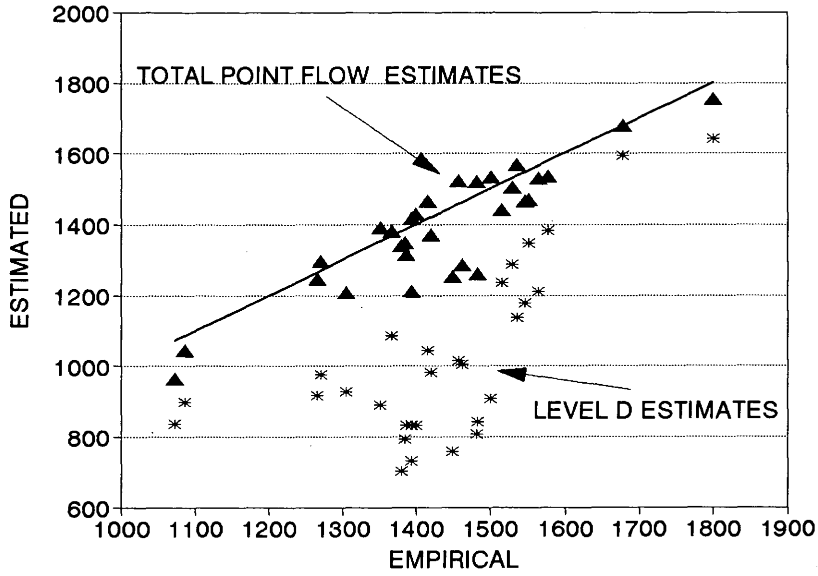

FIGURE 3 Comparison of total point flow and Level D estimates.

mented within FREWEV is the point flow by movement method described in the Alternative Methodologies section of this paper and discussed in detail in the initial research report (*3*).

Overview of FREWEV Model

The FREWEV model can analyze the five types of major freeway weaving sections that are shown in Figure 4. These weaving sections can be classified as Type B or C according to the HCM (*9*). The model evaluates only those lanes that are actually influenced by weaving movements. Those lanes define the critical area and are shaded in Figure 4. Note that the model on which the FREWEV program is based assumes that the freeway is not congested and that the weaving section is not influenced by ramps located upstream or downstream of the waving section.

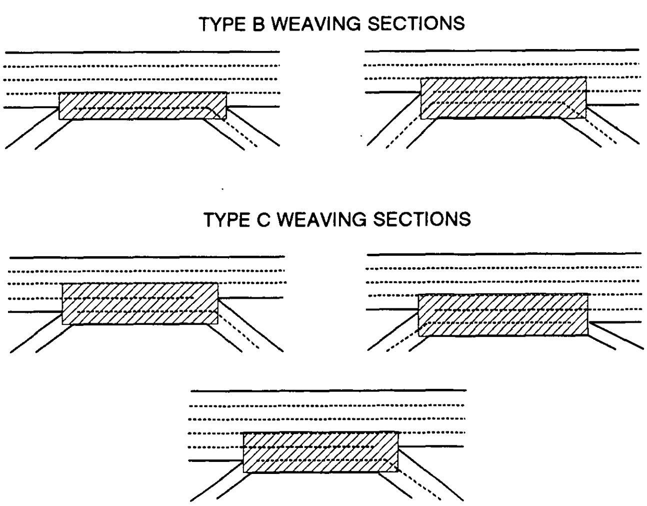

FIGURE 4 Types of weaving sections analyzed by FREWEV.

The input for FREWEV consists of design and demand data for the weaving section and for the sections just upstream and downstream of the weaving section. The design features include the subsection lengths, subsection capacities, position and capacities of on- and off-ramps, number of lanes, and subsection grades. The demands need to be provided for the mainline origin and each on-ramp and off-ramp as well as the ramp-to-ramp demand for the major weaving section. Demand data also include percentage trucks and peak hour factors. The user may supply truck conversion factors and freeway-to-freeway percentages for special circumstances. The data set can be saved for later retrieval and additional analysis.

The FREWEV model calculates the amount of traffic by movement at points along a weaving section for each of the lanes in the conflict area. The four movements involved are those traditionally associated with weaving—through freeway (FF), freeway to off-ramp (FR), on-ramp to freeway (RF), and on-ramp to off-ramp (RR). By summing the flows of the four individual movements at each point, the total flow at each point is determined. The density at each point is then calculated as a function of volume and number of lanes. Density is the criterion to determine the level of service (LOS) at each point based on the LOS range as defined in the initial phase of the research (*3*). The model also calculates the amount of traffic crossing the lane boundaries for each segment between the points that are used for point flows.

FREWEV produces a variety of screen displays and hard copy outputs. Sample output from the FREWEV analysis of a Type C, five-lane major weaving section with a one-lane on-ramp and a two-lane off-ramp is shown in Figures 5 and 6. Figure 5 displays the point flows by movement superimposed on the schematic of the three-lane conflict area. Figure 6 shows the three subsection freeway segment with the density-based LOS printed at the defined points for each lane in the conflict area.

The FREWEV model can be run in two different modes. The empirical mode allows the program to analyze only weaving sections that adhere to the design and demand values for

TYPEC12	ENTER SSEC DESCRIPTION	MAJOR WEAVING SECTION TYPE C (1 ON - 2 OFF)

	0	250	500	750	
FF	806	786	806	806	L
FR	182	112	19	0	A
RF	0	45	370	465	N
RR	0	0	0	0	E
TOT	988	943	1195	1271	3
FF	13	13	0	0	L
FR	1538	1067	1080	1081	A
RF	0	365	115	0	N
RR	1	2	7	11	E
TOT	1552	1447	1202	1092	2
FF	0	0	0	0	L
FR	4	562	642	669	A
RF	500	90	0	0	N
RR	249	248	243	239	E
TOT	753	900	885	908	1

750 ON

2000 OFF

MOVEMENTS ACROSS ALL LANES

FF	3250
FR	1750
RF	500
RR	250
TOTAL	5750

ANALYSIS LIMITED TO EMPIRICAL DATA

All point flows and totals are passenger cars per hour
Analysis subsection assumed independent of neighboring ramps

FIGURE 5 FREWEV output: point flows superimposed on schematic of major weaving section.

which empirical data were observed. The simulation mode allows the program to analyze weaving sections even if they have design and demand values outside the range for which empirical data were collected. The extension of the data ranges has been developed through simulation. The tables of ranges that are valid for each of the two modes and a detailed description of the method used for generating the simulation ranges can be found in the *FREWEV User's Guide* (*19*) and a separate technical document (*18*).

FREWEV is written for the IBM personal computer and requires a math coprocessor. Printouts of the freeway geometry require a printer with the IBM character set.

CONCLUSIONS

Point flow estimation techniques developed in this research produced more reliable estimates of freeway weaving section behavior than other identified tested methods. Sets of movement percentage tables have been derived on the basis of extensive field data sets and extended by simulation for freeway major weaving sections. Regression equations for empirical conditions have been produced for ramp weaving analysis. The analysis for both major weaves and ramp weaves is provided for the right-most lanes at frequent intervals within the weaving sections. Two interactive menu-driven computer programs have been developed to design and analyze freeway weaving sections. The FREWEV computer model analyzes major weaving sections and permits comparison between alternative designs. The FRELANE model, an extension of the FREWEV model, currently permits the analysis and comparisons of major weaving and ramp weaving sections. Further research is under way to extend the FRELANE model to include multiple weaving sections and a variety of ramp merge and diverge situations.

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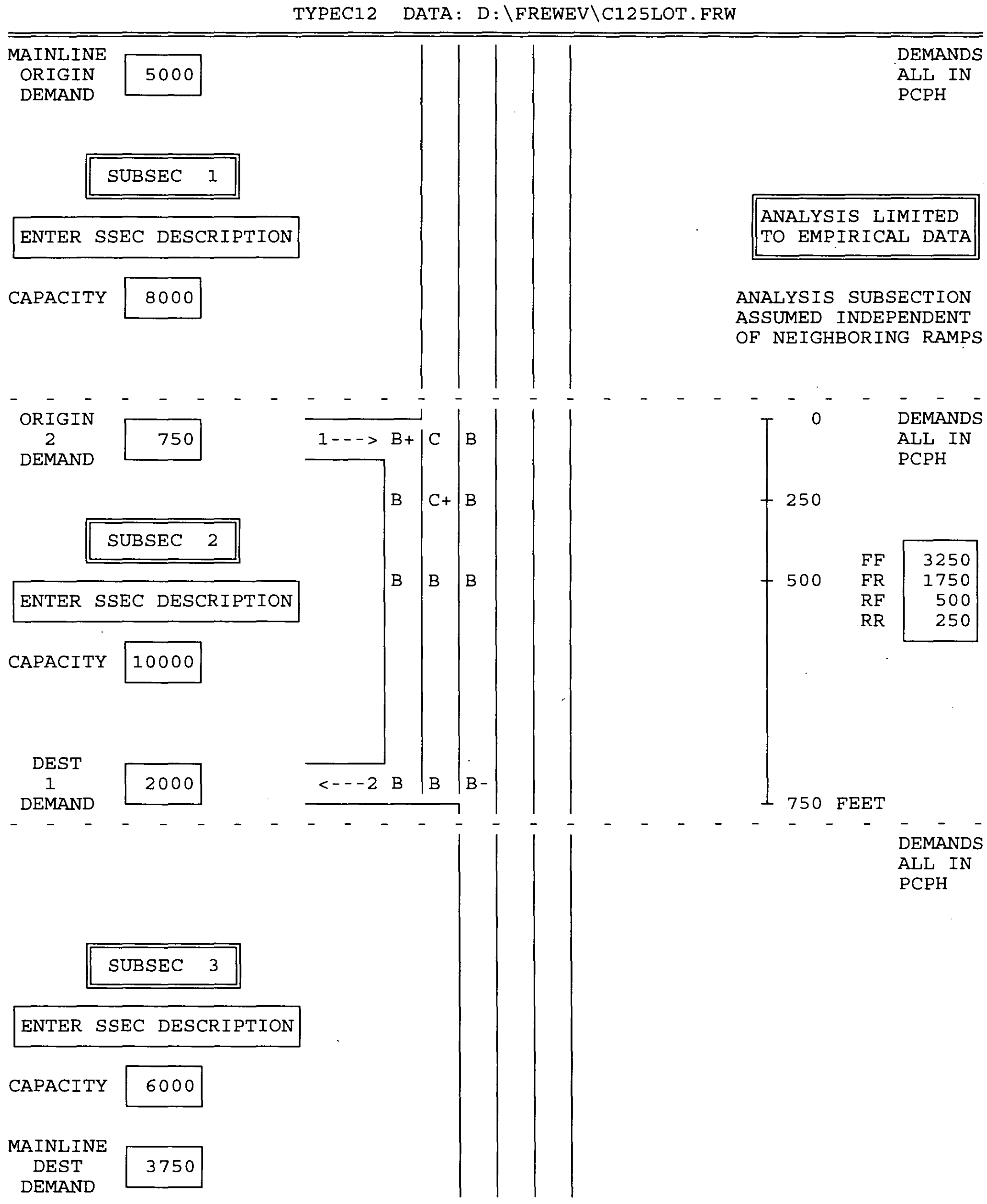

FIGURE 6 FREWEV output: freeway geometry with LOS in critical area.

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