Revisions to Level D Methodology of Analyzing Freeway Ramp Weaving Sections

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For ramp weaves on a eight-lane freeway, the total point flow method has been demonstrated to predict point flows in each of the rightmost two lanes more accurately than the Level D methodology. The Level D methodology is one of the current methods used by the California Department of Transportation (Caltrans). Research undertaken at the Institute of Transportation Studies at the University of California, Berkeley, improved the Level D estimates of point flow for weaving sections operating under various flow ranges. The Level D estimate of freeway-to-freeway (FF) percentage in the rightmost through lane was modified to improve the point flow predictions. An equation was developed that predicts the FF percentage as a function of weaving section length, upstream section demand, on-ramp demand, and off-ramp demand. The process involved a calibration effort that compared total point flow and Level D estimates of volumes in the rightmost through freeway lane. From this comparison an FF percentage estimating equation was developed that, when incorporated in Level D, would result in Level D producing volume estimates comparable in accuracy to the total point flow method. It was validated with the empirical data that were used to develop the total point flow method. The FF estimating equation used with Level D produced significant improvements in the point flow prediction. The equation is recommended for inclusion in the Level D methodology incorporated in FRELANE.

The Institute of Transportation Studies at the Berkeley campus of the University of California (ITS-UCB) is developing a computer model, FRELANE, to analyze isolated freeway sections. A ramp weave, a type of simple weaving section, is one of the eight types of sections that FRELANE is capable of analyzing. FRELANE currently applies two methodologies to analyze ramp weaves: the total point flow method and the Level D method. Both methods estimate the total point flow in each of the rightmost two lanes at 152-m (500-ft) intervals. The Level D method was developed for analyzing weaving sections that operate at near-capacity conditions. The total point flow method has been found more accurate in estimating total point flows in a ramp weaving section for a wide range of conditions, including those for which Level D was designed. The Level D methodology is, however, one of the current methods used by the California Department of Transportation (Caltrans) for analysis of ramp weaves. Modifications in the Level D factors are being investigated to revise the Level D method in order to make it an accurate methodology for weaving sections under a wide range of flows. Ultimately, the revisions in the Level D factors will be incorporated into the FRELANE program.

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DEFINITION OF SIMPLE WEAVING SECTIONS

A simple weave has only one on-ramp and one off-ramp connected by one or more auxiliary lanes. This research concentrates on a simple weave with one on-ramp and one off-ramp connected by a single auxiliary lane, a ramp weave. Figure 1 illustrates the ramp weaving section and terminology used in this report.

The ramp-to-ramp (RR) flow enters the weaving section from the on-ramp and exits by the off-ramp. The freeway-to-freeway (FF) flow enters and exits the weaving section on the mainline freeway. The ramp-to-freeway (RF) flow enters the weaving section from the on-ramp and exits by the mainline freeway. The freeway-to-ramp (FR) flow enters the weaving section from the mainline freeway and exits by the off-ramp.

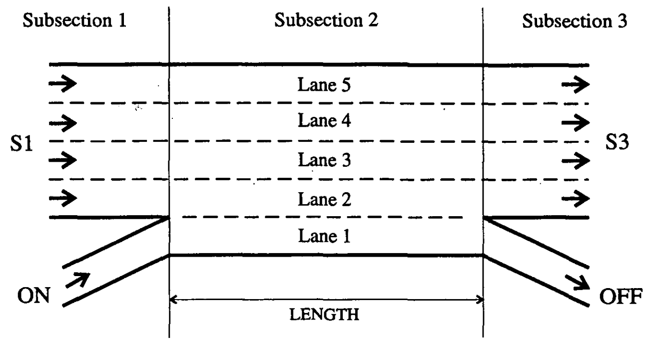
HISTORICAL REVIEW

The 1950 HCM presented the first freeway weaving analysis method, which predicted the capacity and operating speeds of freeway weaving sections (*1*). The 1965 HCM contained a revised version of this 1950 HCM method with added emphasis on quality of flow (*2*). The revised version was based on publications by Norman (*3*), Hess (*4*), and Leisch (unpublished studies, Bureau of Public Roads, U.S. Department of Commerce, 1958–1964). In 1981, TRB published the PINY method and the Leisch method (*5*). The PINY method, developed at the Polytechnic Institute of New York, was a new method for estimating weaving and nonweaving speeds for simple weaving sections (*6*). The Leisch method (*7*) was an enhancement of the nomograph method of the 1965 HCM. The 1985 HCM chapter on weaving analysis predicted the average speeds of weaving and nonweaving vehicles using regression-based equations (*8*).

In 1987 a 6-year research program was initiated at ITS-UCB that was based on the need for additional research on freeway weaving in California, which has produced a number of publications (*9–17*).

CURRENT RESEARCH AND METHODOLOGIES

The first phase of research at ITS-UCB was to evaluate the existing methods of analyzing major weaves. The second phase involved evaluating existing methods for analyzing other types of freeway sections including ramp weaves. The methods evaluated included the speed estimating methods previously listed, the JHK method (*18*), the Fazio method (*19*), and the following flow estimating methods: Caltrans *Traffic Bulletin 4* method (Level D) (*20*) and total point flow method (*21*). The total point flow method was deter-



Ramp Weaving Variables and their Valid Ranges

Weaving Length (LENGTH):	305 m (1000 ft) - 610 m (2000 ft)
Subsection 1 Demand (S1):	4816 - 7200 pcph
On-Ramp Demand (ON):	222 - 1800 pcph
Off-Ramp Demand (OFF):	338 - 1004 pcph
Subsection 3 Demand (S3):	5378 - 7200 pcph
Subsection 2 Demand (S2):	5914 - 9000 pcph
Ramp to Ramp Demand (RR):	4 - 148 pcph
Freeway to Freeway Demand (FF):	4242 - 6500 pcph
Ramp to Freeway Demand (RF):	214 - 1480 pcph
Freeway to Ramp Demand (FR):	330 - 856 pcph
Weave Volume (RF + FR):	950 - 2780 pcph

FIGURE 1 Schematic and variables for ramp weaving section.

mined to produce the best predictions. The next best candidate was the Level D method (*22*).

Ongoing research at ITS-UCB explored the use of the total point flow approach in analyzing freeway weaving sections. The total flow at a point may be estimated directly or found as a sum of the individual movements. A computer model, FRELANE, for predicting traffic performance in weaving sections based on total point flow has been developed from this research. FRELANE uses the predicted point flow at specific locations to calculate the traffic density at these locations. The calculated density is then used to select the appropriate level of service (LOS) for each location. The locations at which the analysis is done in FRELANE include the merge, the diverge, 76 m (250 ft) downstream of the merge, and 152-m (500-ft) increments from the merge to the end of the section. For ramp weaving sections, FRELANE has two methodologies to predict the point flows at the preceding locations in Lanes 1 and 2 along a weaving section: total point flow and Level D.

Total Point Flow Method

The total point flow method, proposed by Holmes, is a regression-based methodology that directly predicts the total flow at an analysis point within a weaving section (*11*). The flow is calculated for each point as a function of length of weaving section, lane being considered, location being considered, mainline freeway flow, RF flow, FR flow, and RR flow. These equations were determined to predict total point flow within 10 percent of the empirical values for 90 percent of the analysis data.

Level D Method

The Level D method was developed by Caltrans in the early 1960s (*20*). The Level D method is appropriate for ramp weaving and non-ramp-weaving sections operating under conditions of high or near-capacity traffic flow. Given the section length and volumes in the weaving section, Level D predicts the point flow as a sum of the individual movements. The point flows are predicted for each of the two rightmost lanes of the freeway weaving section at the same locations as the total point flow method. The point flow 76 m (250 ft) downstream of the merge was not estimated by the Level D method initially but has since been added. The RF and FR percentages in each lane at each location are solely a function of section length. The amount of through traffic in the rightmost through freeway lane (Lane 2) is a function of FF traffic flow and is assumed to be constant throughout the weaving section. The estimates of total flows in Lane 2 are highly sensitive to the estimate of through traffic in the rightmost through freeway lane. The current errors in the estimation of total volumes at points in this lane can be attributed principally to incorrect predictions of FF volumes. The current Level D method predicts the total point flows within 10 percent of the empirical values for 40 percent of the analysis data.

ASSUMPTIONS AND LIMITATIONS OF ANALYSIS

The current Level D method assumes the FF percentage in the rightmost through lane of the weaving section to remain constant along the weaving section. This is also assumed true for this analysis. The

RF and FR percentages in Lane 2 are assumed to be predicted correctly by the Level D methodology.

The entire analysis is limited to a basic four lane one-directional mainline freeway segment. All traffic flows input and calculated are in passenger cars per hour. The estimating equations are considered acceptable for analysis only when all of the input variables are within the range of the empirical data that was used to develop the equations. These ranges are different for the total point flow method and the Level D method. The overlap of these two regions, shown in Figure 1, is the region that was used to develop equations in this analysis.

LEVEL D REVISION METHODOLOGY

Level D required modification in order to improve its accuracy over a wide range of flows. The Level D estimation of the FF percentage in the rightmost through lane was identified as the main factor contributing to the inaccuracies in the Level D estimates in Lane 2. Several approaches were available in attempting to improve the FF percentage estimation in Lane 2. It was decided that a two-step process would be followed, consisting of a calibration effort and a validation effort. In the calibration process, a formulation for estimating FF percentage by the Level D method was based on forcing the Level D method to agree with the total point flow method in terms of total flow at selected points along the rightmost through lane for various flow ranges. The calibration stage assumed that the total point flow estimates were accurate for the various flow ranges in order to derive an equation to estimate an FF percentage that, when incorporated in Level D, would allow the Level D method to accurately predict point flows under various flow ranges. In the validation process, the performance of the derived formulation for estimating FF percentage in Lane 2 was checked. The validation process used the empirical data from four freeway ramp weaving sections used to develop the total point flow method. Therefore, the calibration process derived an equation for estimating FF percentage using the values calculated by the total point flow method over a wide range of flows, and the validation process checked the derived equation using the empirical data, which were the same data that were used to develop the total point flow method.

Calibration Methodology

To improve the FF percentage in Lane 2, three options were considered:

1. Modify the existing FF percentage tables,
2. Use the available data to derive a method for calculating FF percentage, or
3. Simulate new data to derive a method for calculating FF percentage.

The current method uses a table of averages to calculate the FF percentage in Lane 2 on the basis of the through freeway volume (FF) only. A consistent trend between the through freeway volume and the average FF percentages based on the existing empirical data could not be determined, thus a modification of the existing FF percentage table was rejected. Simulation of a data set to estimate FF percentages was deferred because there was no indication that the available data were inadequate to produce accurate results. Therefore, the use of available information was selected to derive new FF percentages for the Level D methodology.

A mathematical formula was derived to calculate the FF percentages needed to improve the current Level D estimates using the existing data. This formula required correct FF percentages for calibration. The FF percentages for calibration could be obtained by using either empirical values or values derived from the total point flow method. The total point flow method was determined from past research to closely replicate reality. The values derived by this method can be considered as valid as the empirical values. The FF percentages derived by the total point flow method also allowed a wider range of combinations of flow conditions than was available using the empirical data. The mathematical equation would then be validated with the empirical data.

Methodology to Regression Equation Derivation

The first phase in deriving an expression for the percentage FF was the development of a set of inputs to estimate volumes by the Level D method and total point flow method. The 23 input data points developed, given in Table 1, covered the widest range of values possible for all input variables and their combinations within the overlapping valid ranges of each estimating method. A wide range of values was desired in order to derive an FF percentage estimating equation that would improve the Level D estimates over a wide range of conditions. Ramp weaving section lengths of 305, 457, and 610 m (1,000, 1,500, and 2,000 ft) were then tested separately using these data sets. The total point flow was calculated at 0, 76, 152, and 305 m (0, 250, 500, and 1,000 ft) along the weaving length for Lane 2. The calculation went to the 305-m (1,000-ft) location to include as much of the information as possible to calculate the FF percentage and to account for as much weaving as possible. Most weaving occurs within the first 152 m (500 ft) of the weaving section, so FF percentage calculations to 305 m (1,000 ft) should cover the majority of the weaving action.

The next phase was to calculate FF percentages for calibrating an FF percentage equation. The assumed FF demand in Lane 2 was calculated by taking the difference between the total point flow calculated by the total point flow method and the Level D method and adding it to the Lane 2 FF demand calculated by the Level D method. A new percentage of FF traffic in Lane 2 was calculated for each location in Lane 2 along the weaving length. The FF percentage required in the Level D method to produce the same total movements as the total point flow method could be one of the following: the average of the FF percentages from 0 to 305 m (1,000 ft), the FF percentage at the critical point (the location with the highest total point flow) along the weaving section, or the FF percentage at 0 m (the merging point) where the FF percentages are calculated in the empirical data.

The total movements calculated by Level D with updated FF percentages were plotted along with total movements calculated by the total point flow method and the current Level D method for each analysis location. These graphs were produced to verify that the updated Level D estimates were a significant improvement in total movement estimation.

Since significant improvements were found in the updated Level D estimates, the next phase was to derive a method to incorporate these revised FF percentages into Level D. A regression equation as a function of the input values entered was chosen over averaging the FF percentages because earlier findings showed that averaging the FF percentages over certain FF volumes would not satisfactorily update the volume-dependent tables already in the Level D method. Regression equations were derived for the following independent

TABLE 1 Input Data Created for Ramp Weaving Section

Data	Input Volumes				Calculated Volumes					
Set	S1	ON	OFF	RR	S2	S3	RF+FR	FF	RF	FR
1	5000	1000	500	125	6000	5500	1250	4625	875	375
2	5000	1600	500	125	6600	6100	1850	4625	1475	375
3	5000	1600	700	125	6600	5900	2050	4425	1475	575
4	5500	1000	500	125	6500	6000	1250	5125	875	375
5	5500	1000	700	125	6500	5800	1450	4925	875	575
6	5500	1000	900	125	6500	5600	1650	4725	875	775
7	5500	1600	500	125	7100	6600	1850	5125	1475	375
8	5500	1600	700	125	7100	6400	2050	4925	1475	575
9	5500	1600	900	125	7100	6200	2250	4725	1475	775
10	6000	400	900	125	6400	5500	1050	5225	275	775
11	6000	1000	500	125	7000	6500	1250	5625	875	375
12	6000	1000	700	125	7000	6300	1450	5425	875	575
13	6000	1000	900	125	7000	6100	1650	5225	875	775
14	6000	1600	500	125	7600	7100	1850	5625	1475	375
15	6000	1600	700	125	7600	6900	2050	5425	1475	575
16	6000	1600	900	125	7600	6700	2250	5225	1475	775
17	6500	400	900	125	6900	6000	1050	5725	275	775
18	6500	1000	500	125	7500	7000	1250	6125	875	375
19	6500	1000	700	125	7500	6800	1450	5925	875	575
20	6500	1000	900	125	7500	6600	1650	5725	875	775
21	6500	1600	900	125	8100	7200	2250	5725	1475	775
22	7000	400	900	125	7400	6500	1050	6225	275	775
23	7000	1000	900	125	8000	7100	1650	6225	875	775

Note: All demands are in passenger cars per hour (pcph).
See Figure 1 for the empirical limits of the above variables.

variables used in various combinations: Section 1 demand (S1), on-ramp demand (ON), off-ramp demand (OFF), FF demand (FF), RF demand (RF), and FR demand (FR). The standard error of the estimate was used to select the best equation containing significant variables.

Ramp Weaving Section Analysis at 457 m

The 457-m (1,500-ft) weaving section was the first section analyzed. The FF percentages were calculated for all the data. The average difference in FF percentage along the section from 0 to 305 m (1,000 ft) was 3.7 percent. The average difference in FF percentage along the weave length was larger than expected. Thus, using the FF percentage at a single point, either at distance 0 or at the critical point, to derive an equation was not considered the way to reflect properly the general trend in FF percentage along the section. Instead, the average FF percentage between 0 and 305 m (1,000 ft) was used to calibrate a regression equation. Figure 2 illustrates that the calculated average FF percentages are higher than the FF percentages used in the current Level D method for the 23 data points. The critical FF percentages are also plotted on this graph. The critical FF percentage and the average FF percentage are effectively interchangeable.

Figure 3 illustrates that the Level D method using the average FF percentages predicted total movements that were very close to the total point flow predictions for the 457-m (1,500-ft) section. The predictions were close for all distances and for a wide range of total point flows—900 to 2,200 passenger cars per hour (pcph). These FF percentages were considered satisfactory to develop a regression equation. An attempt was made to develop a regression equation to estimate FF percentage as a function of FF demand only, which is contained in the 1965 and 1985 HCMs, but there was a very low correlation between FF percentage and FF demand. The following two regression equations were determined to best replicate the average FF percentages for rightmost through lanes calculated for the 23 data points:

$$\mathrm{FF\%} = 25.4 - 0.00209(\mathrm{S1}) - 0.00512(\mathrm{ON}) + 0.0152(\mathrm{OFF}) \quad (1)$$

$$\mathrm{FF\%} = 26.6 - 0.00208(\mathrm{FF}) - 0.00512(\mathrm{RF}) + 0.0132(\mathrm{FR}) \quad (2)$$

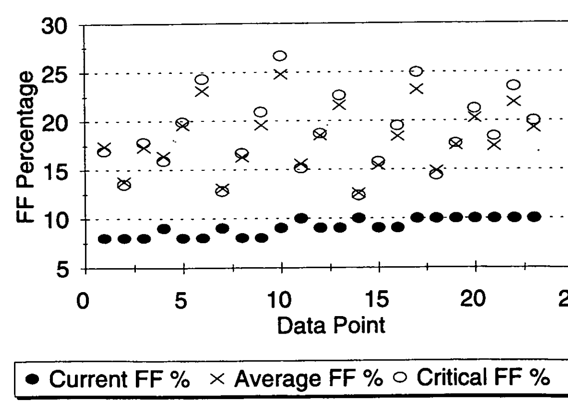


FIGURE 2 FF percentages for 457-m (1,500-ft) ramp weaving section.

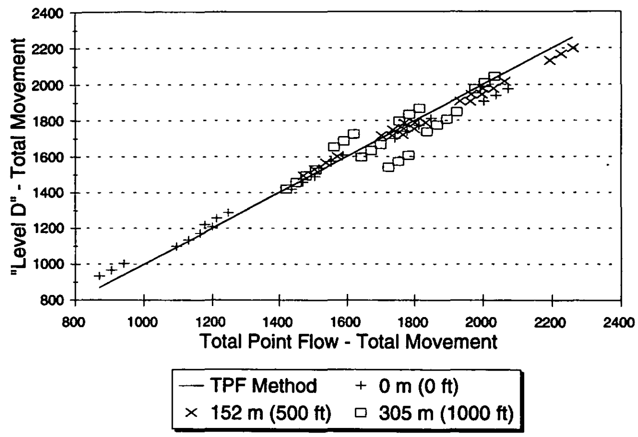


FIGURE 3 Level D method using average FF percentages for 457-m (1,000-ft) section.

The standard error of the estimate was approximately 0.30 for both equations. All the input variables in the Equations 1 and 2 were determined to be statistically significant in the equation by using the *t*-distribution at a 95 percent confidence level. Regression Equation 1 was chosen for further analysis because Section 1 demand, on-ramp demand, and off-ramp demand are variables that are more easily measured directly in the field.

Ramp Weaving Section Analysis at 305 and 610 m

The FF percentages calculated for the 305-m (1,000-ft) weaving section had an average difference in FF percentage along the weaving length of 5.0 percent. Again, the average FF percentage was the most suitable FF percentage to use for further analysis. The graph of the total movements predicted by Level D with these average FF percentages and by the total point flow method was similar to the same graph produced for the 457-m (1,500-ft) section (Figure 3). The following regression equation, with a standard error of 0.35, was determined to best replicate these FF percentages:

$$\text{FF\%} = 15.6 - 0.00103(\text{S1}) - 0.00619(\text{ON}) + 0.0140(\text{OFF}) \tag{3}$$

The FF percentages calculated for the 610-m (2,000-ft) weaving section had an average difference in FF percentage along the weaving section of 6.1 percent. Again, an average FF percentage was the most suitable value to use for calibration. The graph of the total movements predicted by Level D with these average FF percentages and the total point flow predicted total moments was similar to the 457-m (1,500-ft) graph. The following equation, with a standard error of 0.28, was determined to best replicate these average FF percentages:

$$\text{FF\%} = 35.5 - 0.00322(\text{S1}) - 0.00402(\text{ON}) + 0.0172(\text{OFF}) \tag{4}$$

Equation Extension to All Simple Weaving Section Lengths

The FF percentage equations developed for the three weaving section lengths were determined to be statistically different using a *t*-test at a 95 percent confidence level. Figure 4 shows a pattern of FF percentages increasing consistently as the weaving section length increased. Thus, to produce an FF percentage estimation equation that can be applied to all weaving lengths from 305 to 610 m (1,000 to 2,000 ft), an equation that includes length as a variable was required. To develop this equation, the data points for each of the three weaving lengths already analyzed and the corresponding average FF percentages were combined. A regression analysis was performed on these 69 data points, and the following regression equation, with a standard error of 0.77, was derived:

$$\text{FF\%} = 7.92 + 0.0117(\text{LENGTH}) - 0.00211(\text{S1}) - 0.00511(\text{ON}) + 0.0155(\text{OFF}) \tag{5}$$

The Level D method using Equation 5 to estimate FF percentage will be referred to herein as the modified Level D method.

VALIDATION

After the general equation (the regression equation for all lengths) was developed on the basis of values calculated by the total point flow method, the next step was to attempt to validate the equation. The data used for validation were the 22 empirical data points used to develop the total point flow method. These data points were obtained at four freeway ramp weaving sections. The first site (eight data points) was eastbound Interstate 580 from Oakland Avenue to Grand Avenue in Alameda County, California, which had a weaving length of 372 m (1,220 ft). The second site (four data points) was southbound I-5 from Palomar Street to Main Street in San Diego County, California, which had a weaving length of 381 m (1,250 ft). The third site (three data points) was eastbound CA-60 from Paramount Boulevard to San Gabriel Boulevard in Los Angeles County, California, which had a weaving length of 418 m (1,370 ft). The fourth site (seven data points) was westbound CA-91 from 183rd Street to Artesia Boulevard in Los Angeles County, California, which had a weaving length of 578 m (1,895 ft) (*22*).

The average weaving volumes at the four sites were 2,388 pcph at the first site, 1,145 pcph at the second, 615 pcph at the third, and 1,043 pcph at the fourth. The weaving volume is the combined RF and FR traffic flow. Thus the first site, which is operating at near-capacity conditions, has an average weaving volume that is more than twice as high as the average weaving volumes observed at the other sites.

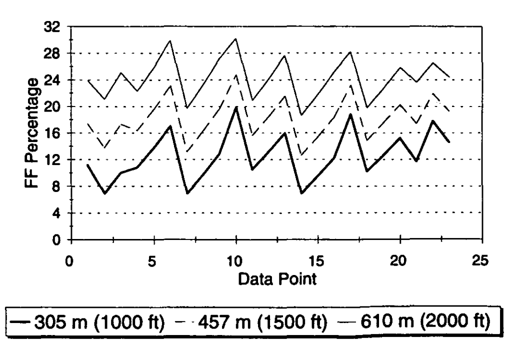


FIGURE 4 Average FF percentages for three ramp weaving sections.

Testing of Developed Equation

The overall performance of the modified Level D method was first determined by comparing the accuracy of the modified Level D total point flow estimations to the current Level D and total point flow method estimates. The FF percentages used in the current Level D method can be found in Table 5-3 of the 1985 HCM. The accuracy of these methods was determined by calculating the average residual of each method's estimates of total point flow for the 22 empirical data points. The merge point in Lane 2 was the location used for this validation effort. The current Level D method had an average residual of 339 pcph, the total point flow method had an average residual of 62 pcph, and the modified Level D method had an average residual of 89 pcph. Therefore, the modified Level D estimates of total point flow were on average 250 pcph closer to the empirical value than the current Level D estimates, for the 22 empirical data points. The modified Level D was comparable in accuracy to the total point flow method, but the total point flow method was slightly more accurate than the modified Level D method.

The validation process also compared each estimate of total point flow by the current Level D method and by the modified Level D method with the empirical value for the 22 empirical data points on a site-by-site basis. The results of this comparison are illustrated in Figure 5. Figure 5 showed that the modified Level D method is predicting total point flows closer to empirical values for Sites 2, 3 and 4, which are not operating at near-capacity conditions. For Site 1, which is operating under near capacity conditions, the current Level D estimates were closer. The current Level D method was designed for sections near capacity, thus reasonable estimates by the current Level D method were expected for this first site. The current Level D method total point flow estimates were generally too low for the other sites, Sites 2, 3 and 4, which were not operating close to capacity. The modified Level D method over estimated the point flows for near-capacity Site 1. However, the modified Level D method reasonably estimated the total point flow for Sites 2, 3 and 4, which were not operating at near-capacity conditions. Therefore, the modified Level D method produced reasonable estimates for all operating conditions with a tendency to overestimate flows for weaving sections operating near capacity.

Validation of Ordinary Least Squares Assumption

The ordinary least squares assumption was also checked using residual plots. The residual plots showed that the ordinary least squares assumption was reasonable. However, the variances exhibited some site dependency, which implied that a factor was probably missing from the general equation.

CONCLUSION

For ramp weaves on an eight-lane freeway, the total point flow method had been demonstrated to predict point flows more accurately than the current Level D methodology, which is one of the methods used by Caltrans. This analysis determined that the overall accuracy of Level D can be improved by modifying the Level D estimation of FF percentage in the rightmost through lane. The FF percentages currently used in the Level D methodology were determined to be consistently low during both the calibration and validation stages of this analysis. The following regression equation

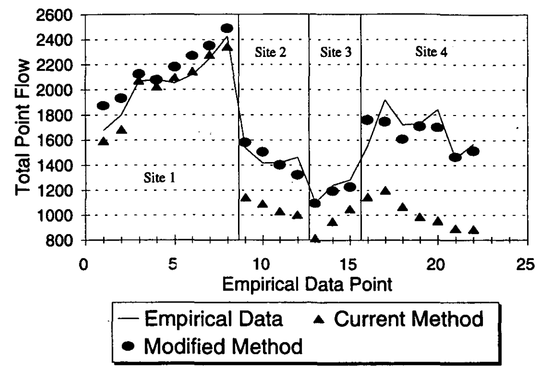


FIGURE 5 Comparison of current and modified Level D methods.

was generated to improve the current Level D estimation of FF percentage, in order to improve the current Level D total point flow estimation:

$$FF\% = 7.92 + 0.0117(LENGTH) - 0.00211(S1) - 0.00511(ON) + 0.0155(OFF)$$

The modified Level D method, using the generated regression equation, increased the current Level D methods accuracy on average by 250 pcph. Thus, the modified Level D method showed a significant improvement in accuracy of estimating total point flow. The modified Level D method did show a tendency to overestimate the total point flow for near-capacity weaving sections. A conservative estimation of total point flow for near-capacity weaving sections was acceptable. Thus, the modified Level D method, which uses the generated Regression Equation 5, is recommended for adoption in the FRELANE model to improve the Level D predictions of point flow.

FUTURE RESEARCH

The RF and FR percentages in the rightmost through lane, which currently depend on only the distance along the weaving section length, appeared to be volume-dependent also. The next phase of research is to determine if RF and FR percentages are dependent on the traffic movements in the weaving section. The calibration of the RF and FR curves was beyond the scope of this project.

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