The Relationships of Vehicle Classification and Geometric Characteristics to Peak Period Freeway Volumes

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The three important parameters describing the operation of a highway facility are speed, volume and density of the traffic stream. This report is concerned with the volume parameter.

An efficient surveillance and control system for an urban freeway should have the ability to obtain information on vehicles at several locations. To locate detection equipment in each lane at several locations is an expensive proposal.

This paper describes the development of linear multiple regression models to predict total freeway volumes as well as individual lane volumes. Classification of vehicles along with the interlane volume characteristics is also considered.

•THE study site was a 3.2-mi section of John C. Lodge Freeway between the Edsel Ford and Davison interchanges in Detroit (Fig. 1). The Lodge Freeway is a depressed facility and the study section was built between 1950 and 1955. It is primarily a six-lane freeway; however, 34 percent of the study section has eight lanes. There are five on-ramps and five off-ramps for northbound (outbound from central business district) traffic and six on-ramps and five off-ramps for southbound (inbound to central business district) traffic. The study section is also the site of the National Proving Ground for Freeway Surveillance, Control and Electronic Traffic Aids, where 14 television monitors at a centrally located control center provide a continuous view of traffic conditions. The picture to each monitor is transmitted from one of 14 transistorized television cameras.

DATA COLLECTION

At two locations, 24-hr classified counts were made manually by 1-min periods on a weekday. These locations were southbound John C. Lodge at the north side of Calvert Ave. bridge and northbound John C. Lodge at the south side of Chicago Blvd. bridge.

At several other locations sample counts were made on a short-time base. The sampling process used was a 60-min classified count by lane by 1-min periods. The samples were taken on weekdays from 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:00 p.m. The following is a list of the locations at which the classified vehicle traffic counts were made (Fig. 2).

1. Southbound 460 ft north of E. Davison Ave. entrance ramp.
2. Southbound 80 ft north of Glendale Ave. overpass.
3. Southbound 220 ft south of Highland Ave. overpass.
4. Southbound 330 ft north of Webb Ave.
5. Southbound at north side of Calvert Ave.
6. Southbound at north side of Chicago Blvd.

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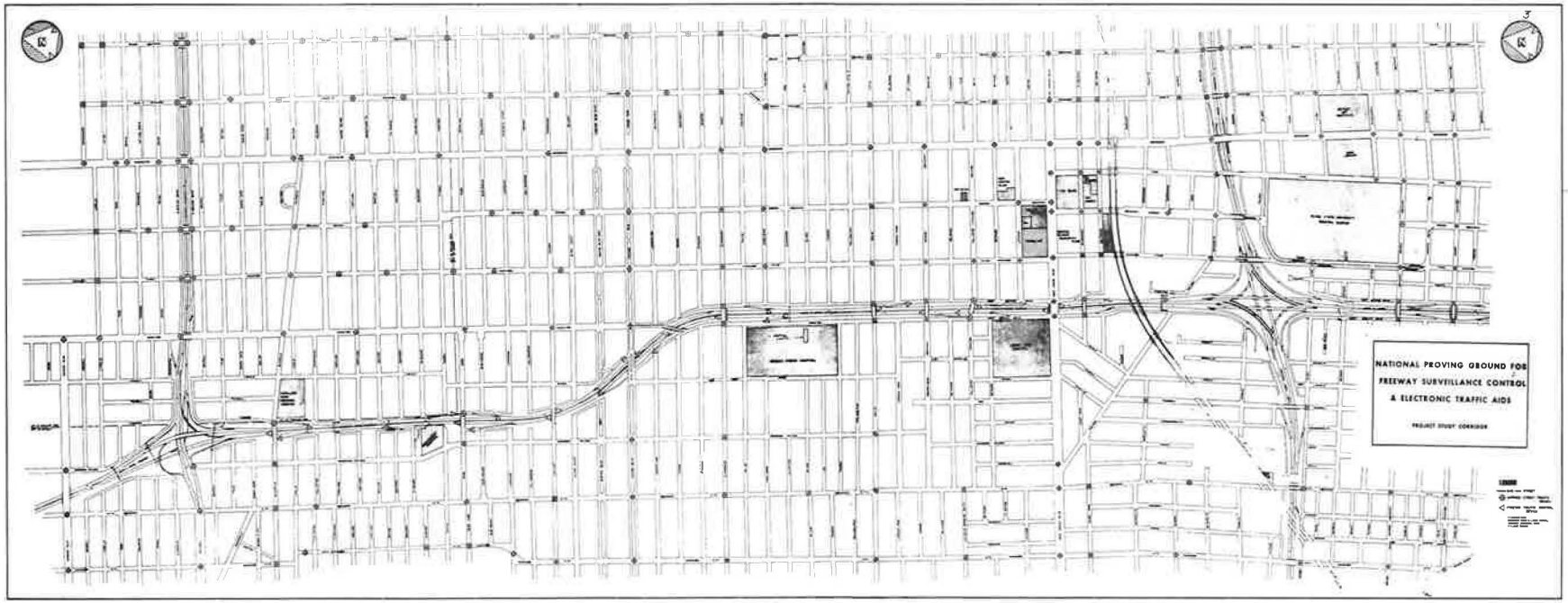
NATIONAL PROVING GROUND FOR
FREEWAY SURVEILLANCE CONTROL
& ELECTRONIC TRAFFIC AIDS

Figure 1.

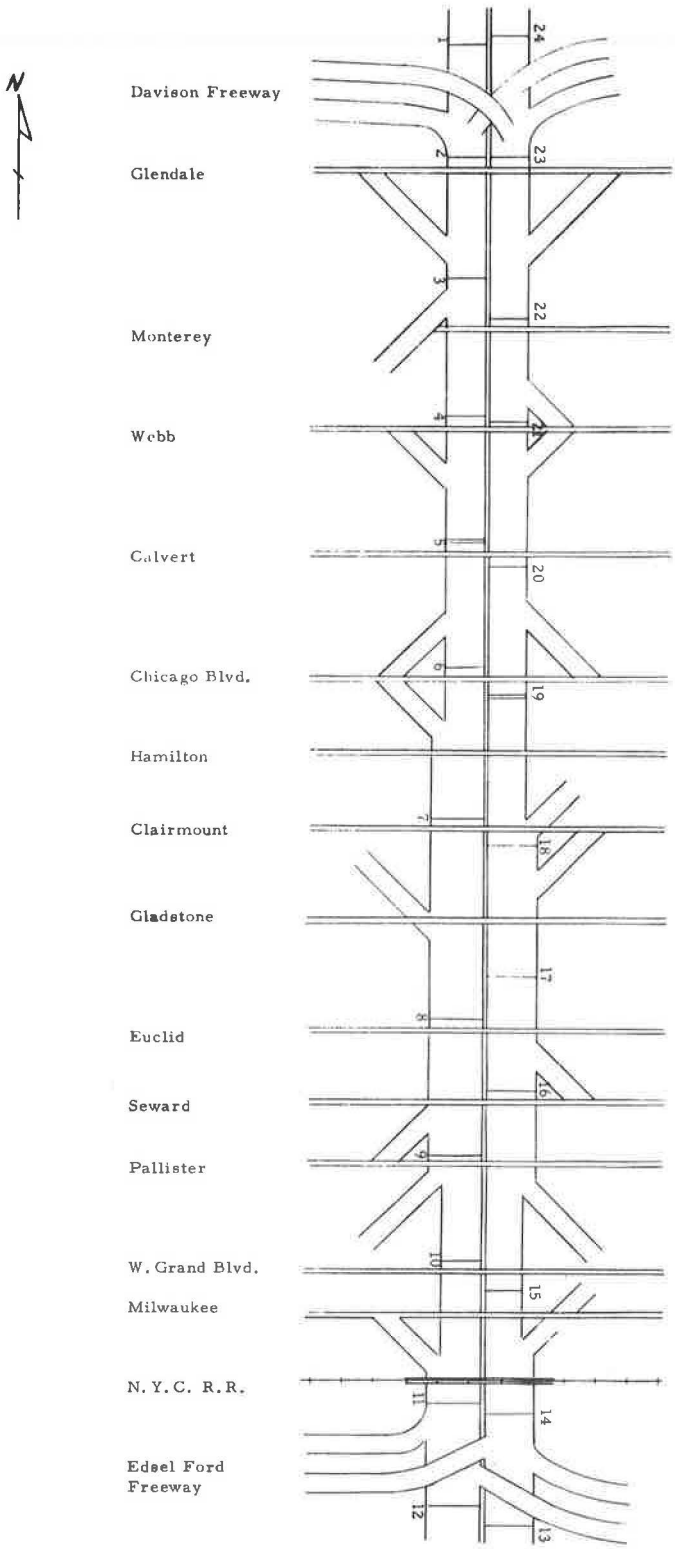

Figure 2. Sample classified traffic count locations.

7. Southbound at north side of Clairmount Ave. overpass.
8. Southbound at north side of Euclid Ave. overpass.
9. Southbound 130 ft north of Pallister Ave. overpass.
10. Southbound 80 ft north of West Grand Blvd. overpass.
11. Southbound at Holden Ave. pedestrian overpass.
12. Southbound 330 ft south of eastbound Edsel Ford exit ramp.
13. Northbound 570 ft south of northbound Edsel Ford entrance ramp.
14. Northbound 150 ft south of Holden Ave. overpass.
15. Northbound 160 ft north of Milwaukee Ave. overpass.
16. Northbound 80 ft north of Seward Ave. overpass.
17. Northbound 610 ft south of Gladstone Ave. overpass.
18. Northbound 110 ft south of Clairmount Ave. overpass.
19. Northbound at south side of Chicago Blvd. overpass.
20. Northbound at south side of Calvert Ave. overpass.
21. Northbound 80 ft north of Webb Ave.
22. Northbound 80 ft north of Monterey Ave.
23. Northbound 80 ft north of Glendale Ave.
24. Northbound 50 ft south of Davison Ave. entrance ramp.

The field data were classified into three general classes and nine specific types: (a) passenger vehicles—standard, compact, and foreign; (b) trucks—panels and pickups, single unit, and tractor-trailer combinations; and (c) miscellaneous—buses, motorcycles, and car and trailer combinations.

To base the analysis on operating characteristics of the vehicles rather than their specific use or designation, the initial classification was further investigated. The Automobile Manufacturers Association was contacted to determine the differences with respect to acceleration, deceleration, and maneuverability between passenger cars and those vehicles generally referred to as "panel and pickup" trucks. It was found that there was no significant difference and hence they were classified along with the passenger vehicles. The car and trailer and motorcycles represented an extremely small number of vehicles and were eliminated from the study. The buses were grouped with single-unit trucks. Thus the final classification was as follows: (a) light—passenger vehicles, panels and pick-ups; (b) single unit—single-unit trucks and buses; and (c) combination—combination trucks.

ANALYSIS PERIODS

Due to manpower limitations, it was not possible to locate observers at all selected stations at the same time for either morning or afternoon data collection. This difficulty was overcome by staggering the hour of counts for each location. For example, at one location, data were collected from 7:00 a.m. to 8:00 a.m., the next 7:15 a.m. to 8:15 a.m., and so forth. Since the traffic behavior and characteristics for the entire high-volume period (7:00 a.m. to 9:00 a.m. or 4:00 p.m. to 6:00 p.m.) were not uniform and since the counts were staggered over a 2-hr period, it was necessary to select some period for each sample 1-hr count that would represent typical composition of traffic for each location. The selections of an arithmetic, geometric or running 15-min average would have a high or low bias effect depending on the time when the data were collected. Some period during the hour had to be obtained which represented peaking characteristics of the traffic. In a previous study (1) it was found that a definite peak period existed within the peak hour for vehicle arrivals at urban intersections. It was decided to determine if such a definite peak period existed during the peak hour for the arrival of vehicles at selected locations on the freeway, and if so, to use this peak period within the peak hour as a basis for analysis. The existence and duration of such a peak period within the peak hour was determined in the following manner.

At each location, 1-hr counts were available by 1-min intervals. These counts showed a wide fluctuation in volumes; hence they were grouped into 5-min intervals. A graph of time against total lane volumes for the 5-min intervals was plotted. On this graph was superimposed the value of a 5-min arithmetic mean volume. The longest period that exceeded this value was identified as the peak period. The duration of the peak period was read from the graph to the nearest 5 min.

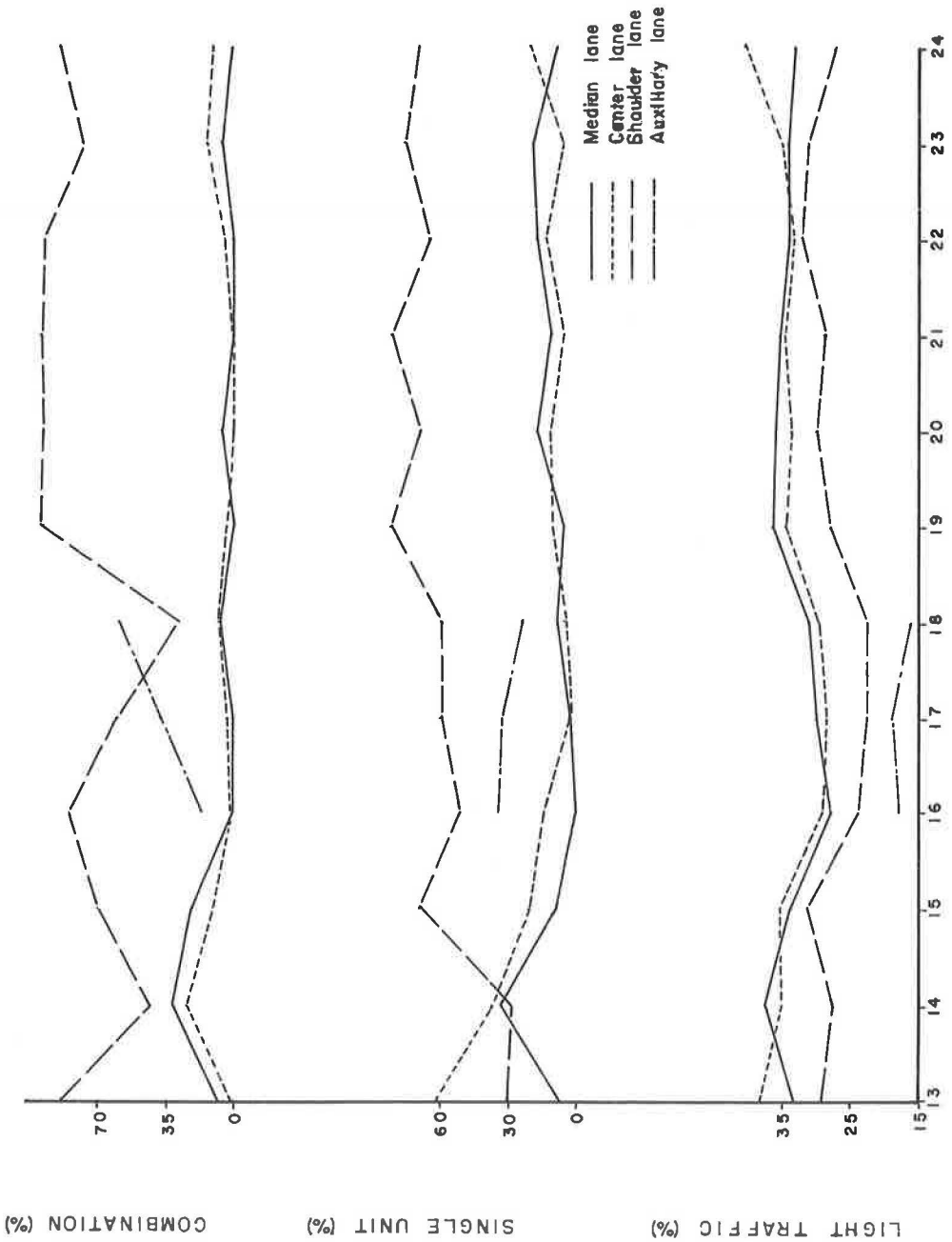

Figure 3. Classified vehicle distribution, afternoon peak—northbound.

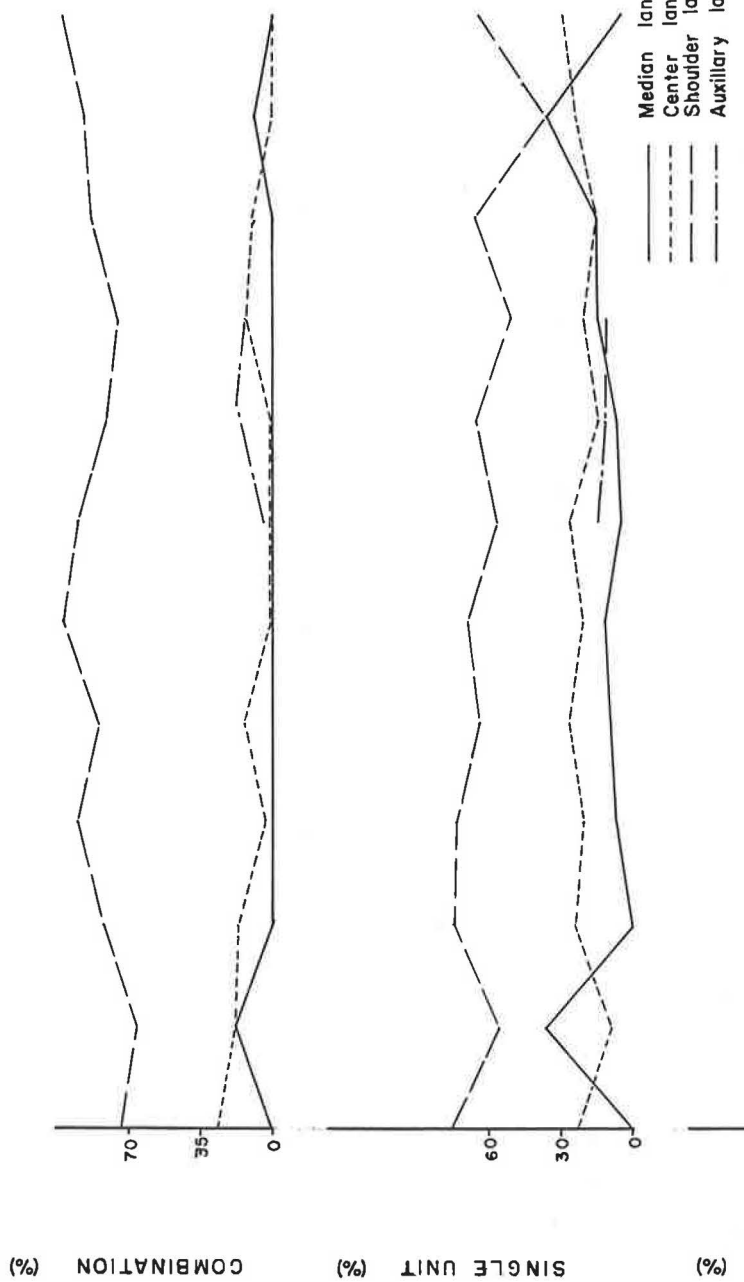

Figure 4. Classified vehicle distribution, morning peak—southbound.

TABLE 1

VEHICLE CLASSIFICATION DISTRIBUTION, A.M. PEAK–SOUTHBOUND

Location	Classification	Median Lane (%)	Center Lane (%)	Shoulder Lane (%)	Auxiliary Lane (%)
1	Light	27.2	34.2	38.6	
	Single unit	0.0	25.0	75.0	
	Combination	0.0	25.0	75.0	
	All vehicles	26.6	34.0	39.4	
2	Light	37.0	32.4	30.6	
	Single unit	35.3	9.8	54.9	
	Combination	16.7	16.7	66.6	
	All vehicles	36.6	31.3	32.1	
3	Light	34.5	35.2	30.3	
	Single unit	0.0	24.0	76.0	
	Combination	0.0	16.7	83.3	
	All vehicles	34.0	35.0	31.0	
4	Light	35.0	36.4	28.6	
	Single unit	7.1	19.1	73.8	
	Combination	0.0	3.3	96.7	
	All vehicles	34.1	35.8	30.1	
5	Light	31.8	36.2	32.0	
	Single unit	8.0	28.0	64.0	
	Combination	0.0	14.3	85.7	
	All vehicles	31.2	35.9	32.9	
6	Light	29.6	42.1	28.3	
	Single unit	12.0	20.0	68.0	
	Combination	0.0	0.0	100.0	
	All vehicles	29.1	41.5	29.4	
7	Light	29.0	31.2	21.8	18.0
	Single unit	5.4	26.8	55.3	12.5
	Combination	0.0	0.0	96.9	3.1
	All vehicles	28.4	30.8	23.0	17.8
8	Light	28.3	26.5	20.5	24.7
	Single unit	7.1	14.3	67.9	10.7
	Combination	0.0	0.0	80.0	20.0
	All vehicles	27.7	26.1	21.9	24.3
9	Light	27.7	27.8	25.7	18.8
	Single unit	16.2	18.9	51.4	13.5
	Combination	0.0	12.5	75.0	12.5
	All vehicles	27.3	27.5	26.5	18.7
10	Light	34.5	35.0	30.5	
	Single unit	16.7	16.7	66.6	
	Combination	0.0	11.0	89.0	
	All vehicles	34.0	34.5	31.5	
11	Light	43.1	34.3	22.6	
	Single unit	38.1	23.8	38.1	
	Combination	9.0	0.0	91.0	
	All vehicles	42.8	33.9	23.3	
12	Light	23.6	41.3	35.1	
	Single unit	6.5	29.0	64.5	
	Combination	0.0	0.0	100.0	
	All vehicles	23.3	40.9	35.8	

TABLE 2

VEHICLE CLASSIFICATION DISTRIBUTION, P.M. PEAK–NORTHBOUND

Location	Classification	Median Lane (%)	Center Lane (%)	Shoulder Lane (%)	Auxiliary Lane (%)
13	Light	32.4	38.4	29.2	
	Single unit	7.7	61.5	30.8	
	Combination	8.6	2.9	88.5	
	All vehicles	31.3	37.8	30.9	
14	Light	37.5	35.0	27.5	
	Single unit	33.3	38.0	28.7	
	Combination	31.3	25.0	43.7	
	All vehicles	37.2	34.6	28.2	
15	Light	33.4	35.4	31.2	
	Single unit	10.0	20.0	70.0	
	Combination	20.0	10.0	70.0	
	All vehicles	32.6	34.9	32.5	
16	Light	28.5	29.2	24.0	18.3
	Single unit	0.0	15.0	50.0	35.0
	Combination	0.0	0.0	83.5	16.5
	All vehicles	27.8	28.8	24.8	18.6
17	Light	29.5	28.7	22.6	19.2
	Single unit	3.1	3.1	61.0	32.8
	Combination	0.0	3.8	57.7	38.5
	All vehicles	28.4	27.6	24.0	20.0
18	Light	31.0	30.8	22.4	15.8
	Single unit	10.3	6.9	58.6	24.6
	Combination	7.2	7.2	28.6	57.0
	All vehicles	30.3	30.0	23.5	16.2
19	Light	36.6	34.8	28.6	
	Single unit	7.9	10.1	82.0	
	Combination	0.0	3.8	96.2	
	All vehicles	35.6	34.0	30.4	
20	Light	36.2	33.5	30.3	
	Single unit	18.0	12.0	70.0	
	Combination	5.3	0.0	94.7	
	All vehicles	35.8	33.1	31.1	
21	Light	35.8	35.3	28.9	
	Single unit	11.1	5.5	83.4	
	Combination	0.0	0.0	100.0	
	All vehicles	35.2	34.6	30.2	
22	Light	33.9	33.6	32.5	
	Single unit	18.9	16.2	64.9	
	Combination	0.0	5.5	94.5	
	All vehicles	33.5	33.2	33.3	
23	Light	33.8	34.9	31.3	
	Single unit	20.0	5.0	75.0	
	Combination	7.1	14.2	78.7	
	All vehicles	33.5	34.5	32.0	
24	Light	32.5	40.5	27.0	
	Single unit	10.0	20.0	70.0	
	Combination	0.0	10.0	90.0	
	All vehicles	32.3	40.3	27.4	

The peak periods for two locations for the northbound afternoon peak and southbound morning peak are presented as examples in Appendix A. The shortest and longest durations of the peak periods were found to be 10 min and 40 min respectively. The average duration of the peak period within the peak hour was higher for the afternoon peak (20.4 min) than the corresponding morning peak period (17.2 min).

VEHICLE DISTRIBUTION

Figures 3 and 4 represent the classified vehicle distribution for the afternoon and morning peak periods respectively. Median and center lanes carried a higher percent of light traffic than either shoulder or auxiliary lane throughout the freeway study section during the afternoon peak, and the same was true for the morning peak with the exception of two boundary locations. On the average, the center lane was a major light-vehicle traffic carrier during the morning peak, whereas approximately equal percentage of light-vehicle traffic was carried by median and shoulder lanes during the afternoon peak.

Single-unit and combination trucks were primary users of the shoulder lane throughout the study section with the exception of location 13 during the afternoon peak, when the center lane carried a higher percentage of single-unit trucks than the shoulder lane. This was probably due to prior knowledge of entrance ramps from left and right just a short distance ahead at the Davison interchange and hence, to avoid delay in merging, there was a tendency to stay in the middle lane.

The existence of an auxiliary lane considerably reduced the usage of the shoulder lane by combination trucks during the afternoon peak. This was also true for single-unit trucks but the reduction was not as significant as in the case of combination trucks. The auxiliary lane helped in redistributing lane traffic for all vehicle classifications.

Tables 1 and 2 give the percentage of vehicle classification distribution by lane, location, time and direction. The average percentage of center-lane usage by all vehicles for the entire study area was slightly higher during the morning peak than the afternoon peak (35.5 percent a.m. peak, 3-lane section; 35.2 percent p.m. peak, 3-lane section; 29.3 percent a.m. peak, 4-lane section; 28.8 percent p.m. peak, 4-lane section). However, in the case of the median lane, usage was reversed (34.1 percent p.m. peak, 3-lane section; 32.4 percent a.m. peak, 3-lane section; 28.9 percent p.m. peak, 4-lane section; 27.8 percent a.m. peak, 4-lane section).

Tables 3 and 4 give the composition of traffic by location, time and direction. Light vehicles comprised the highest traffic volumes, ranging from a low of 94.5 percent to

TABLE 3

COMPOSITION OF TRAFFIC, A.M. PEAK–SOUTHBOUND

Location	Vehicle Classification		
	Light	Single Unit	Combination
1	97.9	1.6	0.5
2	94.5	3.7	1.8
3	98.5	1.2	0.3
4	97.4	1.5	1.1
5	97.6	1.5	0.9
6	97.8	1.6	0.6
7	97.3	1.7	1.0
8	97.3	2.3	0.4
9	97.3	2.0	0.7
10	97.5	1.9	0.6
11	97.8	1.4	0.8
12	97.6	2.1	0.3

TABLE 4

COMPOSITION OF TRAFFIC, P.M. PEAK–NORTHBOUND

Location	Vehicle Classification		
	Light	Single Unit	Combination
13	95.4	2.0	2.6
14	94.5	1.6	3.9
15	96.6	2.3	1.1
16	97.6	1.9	0.5
17	96.0	2.8	1.2
18	96.5	2.4	1.1
19	97.1	2.2	0.7
20	98.3	1.2	0.5
21	97.7	1.8	0.5
22	98.0	1.3	0.7
23	98.4	0.9	0.7
24	98.5	1.3	0.2

TABLE 5

SIMPLE CORRELATIONS OF FACTORS INFLUENCING LANE VOLUMES—AFTERNOON PEAK

Factor	No. of Comb. Veh in Shoulder Lane/5 Min	No. of S.U. Veh in Shoulder Lane/5 Min	Total Veh/5 Min in Median Lane	Total Veh/5 Min in Center Lane	Total Veh/5 Min in Shoulder Lane	Dist to Nearest Upstream Entrance Ramp (ft)	Dist to Nearest Downstream Exit Ramp (ft)	Time of Day	Total Veh/5 Min in All 3 Lanes
No. of comb. veh in shoulder lane/5 min	1.0000	0.2014	0.0937	0.1917	0.0132	-0.0017	-0.0521	0.0854	0.1167
No. of S.U. veh in shoulder lane/5 min		1.0000	0.2651	0.2169	0.2183	0.1807	0.0329	-0.3314	0.2702
Total veh/5 min in median lane			1.0000	0.7227	0.6564	-0.0939	-0.6642	-0.0744	0.9280
Total veh/5 min in center lane				1.0000	0.5060	-0.1514	-0.3741	0.1367	0.8592
Total veh/5 min in shoulder lane					1.0000	-0.2681	-0.4661	0.1087	0.8128
Dist to nearest upstream entrance ramp (ft)						1.0000	0.3526	-0.4531	-0.1180
Dist to nearest downstream exit ramp (ft)							1.0000	-0.0242	-0.5868
Time of day (to nearest 5 min)								1.0000	0.0554
Total veh/5 min in all 3 lanes									1.0000

TABLE 6

SIMPLE CORRELATIONS OF FACTORS INFLUENCING LANE VOLUMES—MORNING PEAK

Factor	No. of Comb. Veh in Shoulder Lane/5 Min	No. of S.U. Veh in Shoulder Lane/5 Min	Total Veh/5 Min in Median Lane	Total Veh/5 Min in Center Lane	Total Veh/5 Min in Shoulder Lane	Dist to Nearest Upstream Entrance Ramp (ft)	Dist to Nearest Downstream Exit Ramp (ft)	Time of Day	Total Veh/5 Min in All 3 Lanes
No. of comb. veh in shoulder lane/5 min	1.0000	-0.0228	-0.0269	-0.0685	-0.0258	0.0192	0.0653	0.3172	-0.0563
No. of S.U. veh in shoulder lane/5 min		1.0000	-0.0205	-0.1340	0.0535	-0.2411	-0.2513	0.3029	-0.0492
Total veh/5 min in median lane			1.0000	0.1882	0.3651	0.0643	-0.2641	-0.2246	0.7969
Total veh/5 min in center lane				1.0000	0.3326	-0.0663	0.3773	-0.4498	0.7084
Total veh/5 min in shoulder lane					1.0000	-0.2766	-0.3057	-0.3470	0.7687
Dist to nearest upstream entrance ramp (ft)						1.0000	0.5417	-0.1614	-0.1252
Dist to nearest downstream exit ramp (ft)							1.0000	-0.1360	-0.0769
Time of day (to nearest 5 min)								1.0000	-0.4701
Total veh/5 min in all 3 lanes									1.0000

a high of 98.5 percent. The range of traffic volumes for single-unit and combination vehicles was quite broad. At most locations the percentage of single-unit traffic was higher than that of combination truck traffic.

CORRELATION ANALYSES

A simple correlation coefficient, r, indicates the extent to which two characteristics are associated. It is a numerical index that varies from 0 to -1.00 in the negative direction, and from 0 to +1.00 in the positive direction. The closer the number is to ±1.00, the stronger is the degree of association between two characteristics. If the sign of r is positive between two factors influencing lane traffic volumes, it means that as one factor increases in magnitude, the other factor is also expected to increase. Where r has a negative value, it means that as one factor increases in magnitude, the other factor should decrease. Perfect correlation between the factors would be indicated by a value of ± 1 and no correlation by a value of zero. Tables 5 and 6 give simple correlation coefficients between factors influencing freeway traffic volumes. This simple correlation coefficient must be interpreted with caution. It does not reveal the extent to which one of the factors causes the change in the other factor. It merely indicates how much, as one of the factors varies in a given direction, the other factor varies also in the same or opposite direction. The highest correlations were found to exist among individual lane and total traffic volumes. The correlations were higher during the afternoon peak than during the morning peak.

STATISTICAL MODELS

During the morning and afternoon rush periods the traffic volumes carried on an urban freeway are dependent on several factors. Use of statistics is made here to analyze selected traffic and geometric freeway characteristics at various locations along a section of an urban freeway.

Multivariate analyses of the data are based on the multiple regression method. The primary aim is to develop an equation by which values of the criterion or dependent variable can be computed by knowledge of the independent or predictor variables. In general, therefore, with a dependent or criterion variable Y, and P independent variables X_1, S_2, . . . , X_p, the relationship will be of the form

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_pX_p$$

where b_1, b_2, . . . , b_p are referred to as partial regression coefficients.

The b values are determined such that the sum of squares of deviation between actual values of the criterion variable, Y, and the value computed by the equation is a minimum. Thus it is required to minimize the errors of estimation and this leads by the method of least squares to p simultaneous equations. For three independent variables, the simultaneous equation will be of the form

$$b_1\Sigma X_1^2 + b_2\Sigma X_1X_2 + b_3\Sigma X_1X_3 = \Sigma X_1Y$$

$$b_1\Sigma X_2X_1 + b_2\Sigma X_2^2 + b_3\Sigma X_2X_3 = \Sigma X_2Y$$

$$b_1\Sigma X_3X_1 + b_2\Sigma X_3X_2 + b_3\Sigma X_3^2 = \Sigma X_3Y$$

The solution of these equations gives the values of b_1, b_2 and b_3 to be inserted into the prediction equation

$$Y = b_1X_1 + b_2X_2 + b_3X_3$$

The method can be extended to any number of variables. However, as the number of equations increases the solution of simultaneous equations becomes extremely laborious and the use of a computer becomes essential.

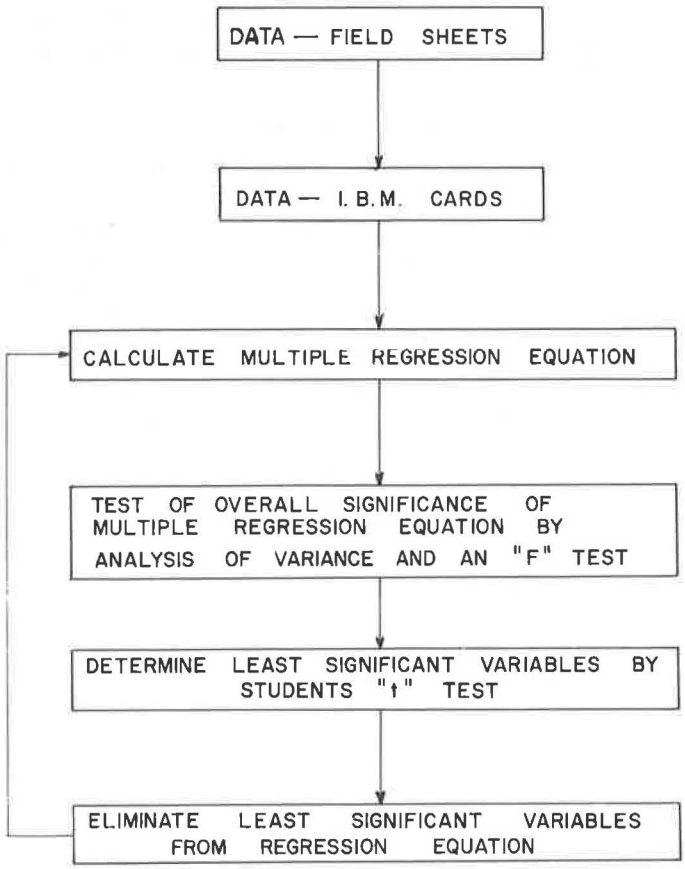

Figure 5. Development of the statistical models.

The data were summarized for each location and transferred to IBM cards. Michigan State University's CDC 3600 computer was used for the analysis. A schematic of the development of the regression models is shown in Figure 5.

The variables used in developing the models were (a) number of combination vehicles in shoulder lane per 5 min, (b) number of single-unit vehicles in shoulder lane per 5 min, (c) median-lane volume per 5 min, (d) center-lane volume per 5 min, (e) shoulder-lane volume per 5 min, (f) distance to nearest upstream entrance ramp, (g) distance to nearest downstream exit ramp, (h) time of day and (i) total volume per 5 min.

First a regression equation was computed to predict an individual lane volume or total three-lane volume as the dependent variable; all the remaining variables were considered as independent variables. Student's t test was used to test the significance of partial regression coefficients for each of the variables. The regression coefficients that were found to be insignificant at a significance level of 10 percent or better were eliminated from the equation and a new equation computed.

Statistics computed along with the regression equation were beta weights, determining coefficient (R^2), R^2 deletes, multiple correlation coefficient (R), standard error of predicted value and partial correlation coefficients.

The beta weights indicate the respective weight given to each of the independent variables in the regression equation. Thus a variable with the highest beta weight is of most importance.

The determining coefficient (R^2) is a measure of how closely the variability in the predicted value is explained by the composite knowledge of independent variables. The

values of R^2 delete correspond to each independent variable as R^2 which would have been obtained had the independent variable not been included in the regression equation. The multiple correlation coefficient (R) is the square root of the determining coefficient and is similar to the simple correlation coefficient discussed previously. It represents the degree of association between the dependent variable and the independent variables.

The standard error of predicted value measures how closely the predicted value agrees with the observed value. A smaller value of the standard error would indicate a better model.

The partial correlation coefficient indicates the relationship between the dependent variable and an independent variable when the effect of remaining independent variables is controlled.

An overall test of significance for each regression equation was made using the analysis of variance technique and an F-test. The results are shown in Appendix B.

RESULTS

Median-Lane Volume Models—Afternoon Peak

Two models for predicting median-lane (lane 1) volume are described.

$$X_3 = -0.4216 + -0.0022\,X_6 - 0.0044\,X_7 + 0.3576\,X_9 \qquad (1)$$

In Model 1 median-lane volume is closely related to total traffic volume in all three lanes, distance to nearest downstream exit ramp and distance to nearest upstream entrance ramp. It is interesting to note the opposite signs of the regression coefficients for these two distances. With the increase in the nearest upstream entrance ramp distance the median-lane volume increases, whereas the increase in the nearest downstream exit ramp distance causes the median-lane volume to decrease. The multiple correlation coefficient for this model is 0.95 and the determining coefficient, 0.90. The test for overall significance shows that this model is highly significant (0.01 level of significance). The beta weights indicate that total three-lane traffic volume, distance to nearest downstream exit ramp, and distance to nearest upstream entrance ramp are of importance in that order. Statistical data for this model are given in Table 7, Appendix B.

Model 2 relates median-lane volume to center-lane volume, shoulder-lane volume, distance to nearest upstream entrance ramp and distance to nearest downstream exit ramp:

$$X_3 = 35.3481 + 0.5273\,X_4 + 0.3634\,X_5 + 0.0031\,X_6 - 0.0081\,X_7 \qquad (2)$$

The multiple correlation coefficient and the determining coefficient values are 0.88 and 0.78 respectively. With an F ratio of 6.01, the model is highly significant at 0.01 level of significance. The beta weights of the four variables considered are nearly the same; that is, each variable is equally important in predicting the median-lane volume. The standard error of predicted median-lane volume is 10.77. Statistical data for this model are given in Table 8, Appendix B.

Median-Lane Volume Models—Morning Peak

Only one model for predicting median-lane volume during the morning peak gave reasonably satisfactory results. In this model median-lane volume is found to be closely related to distance to nearest upstream entrance ramp, distance to nearest downstream exit ramp, and total three-lane volume per 5 min:

$$X_3 = 0.4349 + 0.0055\,X_6 - 0.0048\,X_7 + 0.3289\,X_9 \qquad (3)$$

This model is highly significant at 0.01 level of significance. The multiple correlation and determining coefficients are 0.80 and 0.64 respectively. The reliability of this model is not as good as Model 1 for the afternoon peak. Inspection of beta weights

indicates that total three-lane volume was the most significant factor in predicting the median-lane volume. Statistics for this model are given in Table 9, Appendix B.

Center-Lane Volume Models—Afternoon Peak

The three-dimension model given is based on distance to nearest downstream exit ramp and total three-lane volume:

$$X_4 = -17.3155 + 0.0031\,X_7 + 0.3629\,X_9 \quad (4)$$

The multiple correlation and determining coefficients are 0.87 and 0.76 respectively. With an F ratio of 55.2 this model is highly significant at 0.01 level. The statistics for this model are shown in Table 10, Appendix B.

Center-Lane Volume Models—Morning Peak

The best model for predicting center-lane volume during the morning peak relates distance to nearest upstream entrance ramp, distance to nearest downstream exit ramp and total three-lane volume:

$$X_4 = 2.5122 - 0.0045\,X_6 + 0.0073\,X_7 + 0.3404\,X_9 \quad (5)$$

Unlike the model for the afternoon peak, distance to nearest upstream entrance ramp had a significant effect on the model. The variables in the order of their importance in the prediction value are total three-lane volume, and distance to nearest upstream entrance ramp. The multiple correlation and determining coefficients are 0.87 and 0.75 respectively, and the model is highly significant at 0.01 level. The statistics for this model are given in Table 11, Appendix B.

Shoulder-Lane Volume Models—Afternoon Peak

The best model relates shoulder-lane volume to distance to nearest upstream entrance ramp and total three-lane volume:

$$X_5 = 24.5834 - 0.0014\,X_6 + 0.2669\,X_9 \quad (6)$$

This model is highly significant at the 0.01 level, and the multiple correlation and determining coefficients are 0.82 and 0.67 respectively. The sign of the regression coefficient for the variable distance to the nearest upstream entrance ramp is important; the interpretation is that with the increase in distance to the nearest entrance ramp, the shoulder-lane volume decreases. This is quite logical since the vehicles entering the freeway first use the shoulder lane before orienting themselves in one of the three lanes. The sign for the same variable in the models for predicting the median-lane volumes is opposite; that is, with the increase in distance to the nearest entrance ramp, the median-lane volume also increases. Statistics for this model are given in Table 12, Appendix B.

Shoulder-Lane Volume Models—Morning Peak

Unlike the model for afternoon peak, in the best model, the effect of distance to nearest upstream entrance ramp in predicting the shoulder-lane volume is insignificant. Instead, the shoulder-lane volume is closely related to distance to nearest downstream exit ramp and total three-lane volume:

$$X_5 = -4.9233 - 0.0028\,X_7 + 0.3333\,X_9 \quad (7)$$

The multiple correlation and determining coefficients are 0.81 and 0.65 respectively. This model is significant at the 0.01 level. Statistics for this model are given in Table 13, Appendix B.

Total Three-Lane Volume Models—Afternoon Peak

Four very satisfactory models were developed to predict the total three-lane volumes during the afternoon peak. The multiple correlation coefficient had a range of 0.94 (high) to 0.85 (low). The determining coefficient ranged from 0.88 (high) to 0.72 (low). Each model relates total three-lane volume to either median, center- or shoulder-lane volume and other time or geometric variables. The models are

$$X_9 = 133.9218 + 2.097\,X_3 - 0.0036\,X_6 \quad (8)$$

$$X_9 = -66.5754 + 2.1405\,X_3 + 0.1086\,X_8 \quad (9)$$

$$X_9 = 180.0925 + 2.2271\,X_2 + 0.0138\,X_7 + 1.9087\,X_4 \quad (10)$$

$$X_9 = 190.6431 + 2.0403\,X_5 - 0.0112\,X_7 \quad (11)$$

The best estimates for total three-lane volumes during the afternoon peak are obtained from the median- and center-lane volume (8, 9, 10) models. The shoulder-lane model is not as reliable, probably due to high rates of merging and exiting vehicles. Having the knowledge of median-lane volume and either the time of day or the distance to nearest upstream entrance ramp, one can predict the total three-lane volume with high reliability through the use of the appropriate model. To predict total three-lane volume from the information on center-lane volume, the number of single-unit vehicles in shoulder lane and the distance to nearest downstream exit ramp must also be known. All models are significant at the 0.01 level. Statistics for these models are given in Tables 14 through 17, Appendix B.

Total Three-Lane Volume Models—Morning Peak

Three models for predicting the total three-lane volume during the morning peak are given by Eqs. 12 through 14.

$$X_9 = 411.7560 - 0.0118\,X_6 + 0.0070\,X_7 + 1.6012\,X_3 - 0.2311\,X_8 \quad (12)$$

$$X_9 = 155.2981 + 0.0076\,X_6 - 0.0144\,X_7 + 1.9703\,X_4 \quad (13)$$

$$X_9 = 374.3789 = 1.5486\,X_5 - 0.1622\,X_8 \quad (14)$$

These models produced multiple correlation coefficients ranging from 0.80 to 0.83 and determining coefficients ranging from 0.64 to 0.70. All models are significant at the 0.01 level. Statistics for these models are given in Tables 18 through 20, Appendix B.

SAMPLE PROBLEMS

Described below are two sample problems for utilizing the volume models developed in this study.

1. On a six-lane urban freeway it is desired to know total three-lane volume in the outbound direction from the central business district from 4:20 p.m. to 4:25 p.m. The median-lane volume for that time period is 135 vehicles. On 24-hour clock basis, 4:25 p.m. is 1625. By substitution in Model 9, we have

$$X_9 = 66.5754 + 2.1405\,X_3 + 0.1086\,X_8$$

$$= 66.5754 + 2.1405\,(135) + 0.1086\,(1625)$$

$$\doteqdot 399 \text{ (total three-lane volume from 4:20-4:25 p.m.)}$$

2. Find the total three-lane volume during the morning peak period. The following information is known: center-lane volume, 120 vehicles; distance to nearest upstream entrance ramp, 800 ft; distance to nearest downstream exit ramp, 650 ft. Using model 13:

$$X_9 = 155.2981 + 0.0076\,X_6 - 0.0144\,X_7 + 1.9703\,X_4$$

$$= 155.2981 + 0.0076\,(800) - 0.0144\,(650) + 1.9703\,(120)$$

$$\doteqdot 388 \text{ (total three-lane volume for the morning peak during a 5-min period)}$$

Other models can be used to estimate volumes in a similar manner.

CONCLUSIONS

1. The operating characteristics of panel and pickup trucks are not significantly different from passenger vehicles.
2. A definite peak period existed within the peak hour for both morning and afternoon peaks. The average duration of peak period for afternoon peak was higher (20.4 min) than the corresponding morning peak period (17.2 min).
3. Generally the center lane carried a higher percentage of traffic than either the median or shoulder lane during the morning peak, whereas the median and center lane were approximately equally utilized during the afternoon peak.
4. For the afternoon peak, single-unit and combination trucks were primary users of the shoulder lane. The existence of the auxiliary lane caused considerably less use of the shoulder lane by combination trucks than by single-unit trucks.
5. The average percentage of center-lane usage by all vehicles was slightly higher during the morning peak than the afternoon peak.
6. For most of the study section, the truck traffic stayed in the shoulder lane as required by law. Even in the 4-lane sections, the shoulder lane carried a higher percentage of truck traffic than the auxiliary lane.
7. Through the use of simple correlation procedures it was found that there was a high correlation among the 5-min volumes of median, center, and shoulder lanes and total three lanes. The correlation was higher for the afternoon peak than the morning peak.
8. The prediction of individual lane volume as well as total three-lane volume can be accomplished through the use of linear regression models. In general the models for the afternoon peak had a higher explained variance (R^2) than the corresponding morning peak models. This is probably due to the fact that the afternoon rush period carries a considerably higher volume of traffic, has a longer duration and has a greater number of sustained peaks than the morning peak period.
9. Through the use of the appropriate regression model, total freeway volumes can be estimated at a given location with information from a detector in only one lane. Median- and center-lane models give better estimates of total volumes than shoulder-lane models.

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Appendix A

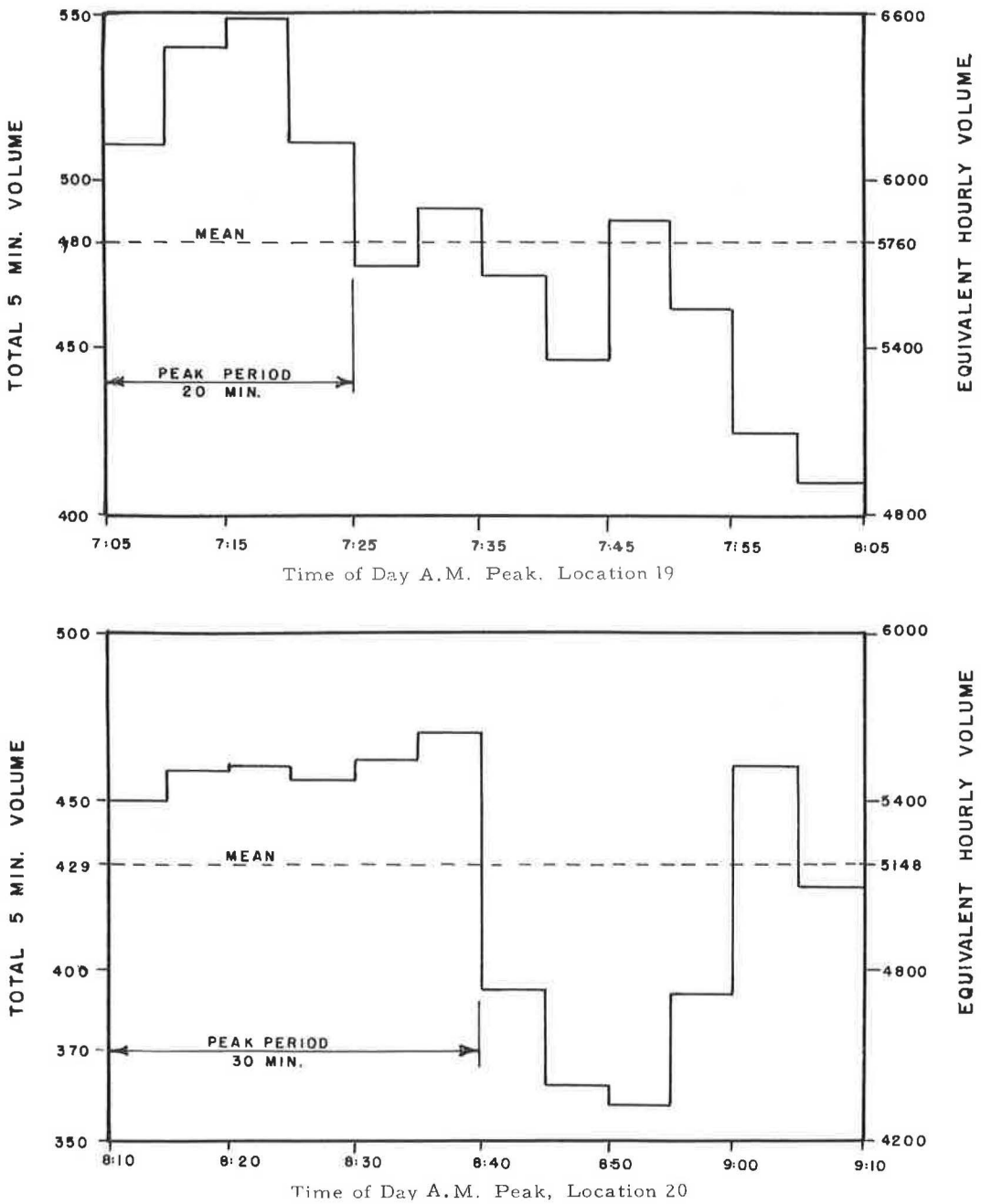

Figure 6. Illustration of afternoon peak period determination within the peak hour.

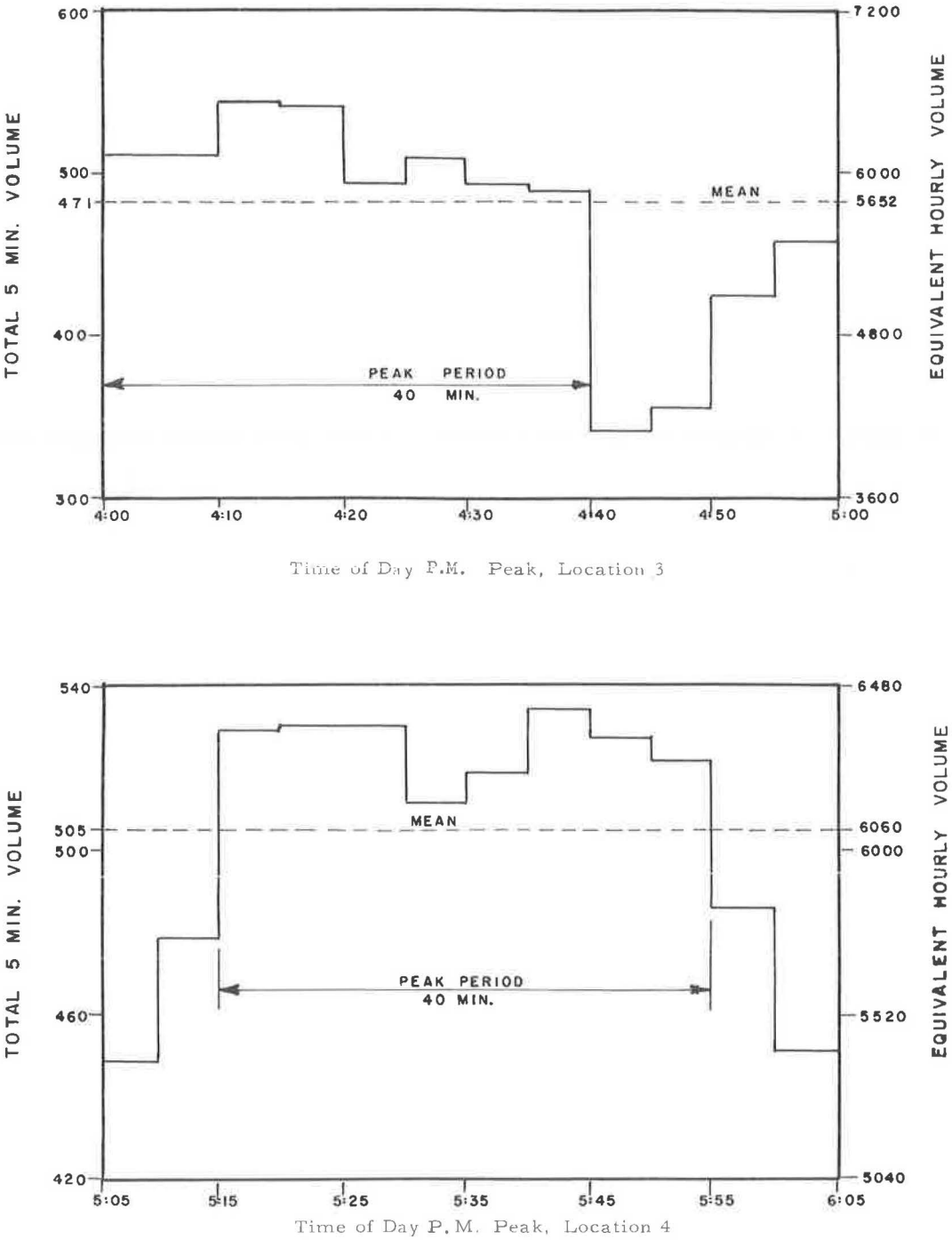

Figure 7. Illustration of morning peak period determination within the peak hour.

Appendix B

TABLE 7

MEDIAN LANE VOLUME RELATED TO TOTAL THREE LANE VOLUME, DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP-AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.3498×10^4	51.5
Regression	4	0.3175×10^5	7940
Total	72	0.3524×10^5	

$F = 7940/51.5 = 154 > F_{0.01}$. ˙. Highly Significant

Predictor Model:

$$X_3 = -0.4216 + 0.0022\,X_6 - 0.0044\,X_7 + 0.3576\,X_9 \quad (1)$$

X_3 = Median lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_7 = Distance to nearest downstream exit ramp (ft.), X_9 = Total three lane volume per five minutes

Multiple Correlation Coefficient R = 0.95

Determining Coefficient, R^2 = 0.90

Standard Error of Predicted Median Lane Volume = 7.17

	X_6	X_7	X_9
Beta Weight	0.143	-0.235	0.817
Partial Correlation Coefficient	0.390	-0.499	0.903
R^2 Delete	0.883	0.868	0.464

TABLE 8

MEDIAN LANE VOLUME RELATED TO CENTER LANE VOLUME, SHOULDER LANE VOLUME, DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP AND DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP—AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.7778×10^5	1142
Regression	4	0.2747×10^5	6870
Total	72	0.3524×10^5	

$F = 6870/1142 = 6.01 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_3 = 35.3481 + 0.5273\,X_4 + 0.3634\,X_5 + 0.0031\,X_6 - 0.0081\,X_7$$

X_3 = Median lane volume per five minutes, X_4 = Center lane volume per five minutes, X_5 = Shoulder lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_7 = Distance to nearest downstream exit ramp (ft.)

Multiple Correlation Coefficient, $R = 0.88$

Determining Coefficient, $R^2 = 0.78$

Standard Error of Predicted Median Lane Volume = 10.77

	X_4	X_5	X_6	X_7
Beta Weight	0.068	0.072	0.062	0.068
Partial Correlation Coefficient	0.629	0.432	0.373	0.612
R^2 Delete	0.635	0.729	0.744	0.645

TABLE 9

MEDIAN LANE VOLUME RELATED TO DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP, DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND TOTAL THREE LANE VOLUME—MORNING PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.8510×10^4	125.2
Regression	4	0.1542×10^5	3860
Total	72	0.2393×10^5	

$F = 3860/125.2 = 30.8 > F_{0.01}$ $\therefore$ Highly Significant

Predictor Model:

$$X_3 = 0.4349 + 0.0055 X_6 - 0.0048 X_7 + 0.3289 X_9$$

X_3 = Median lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_7 = Distance to nearest dounstream exit ramp (ft.), X_9 = Total three lane volume per five minutes

Multiple Correlation Coefficient, $R = 0.80$

Determining Coefficient, $R^2 = 0.64$

Standard Error of Predicted Median Lane Volume = 11.19

	X_6	X_7	X_9
Beta Weight	0.379	-0.414	0.723
Partial Correlation Coefficient	0.469	-0.504	0.769
R^2 delete	0.544	0.523	0.131

TABLE 10

CENTER LANE VOLUME RELATED TO DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND TOTAL THREE LANE VOLUME—AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.6001×10^4	88.2
Regression	4	0.1943×10^5	4870
Total	72	0.2543×10^5	

$F = 4870/88.2 = 55.2 > F_{0.01}$ $\therefore$ Highly Significant

Predictor Model:

$$X_4 = -17.3155 + 0.0031\, X_7 + 0.3629\, X_9$$

X_4 = Center lane volume per five minutes, X_7 = Distance to nearest downstream exit ramp (ft.), X_9 = Total three lane volume per five minutes

Multiple Correlation Coefficient, $R = 0.87$

Determining Coefficient, $R^2 = 0.76$

Standard Error of Predicted Center Lane Volume = 9.33

	X_7	X_9
Beta Weight	0.198	0.976
Partial Correlation Coefficient	0.314	0.852
R^2 delete	0.738	0.140

TABLE 11

CENTER LANE VOLUME RELATED TO DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP, DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND TOTAL THREE LANE VOLUME—MORNING PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.6466×10^4	95.0
Regression	4	0.1958×10^5	4900
Total	72	0.2604×10^5	

$F = 4900/95 = 51.6 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_4 = 2.5122 - 0.0045 X_6 + 0.0073 X_7 + 0.3404 X_9$$

X_4 = Center lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_7 = Distance to nearest downstream exit ramp (ft.), X_9 = Total three lane volume per five minutes

Multiple Correlation Coefficient, R = 0.87

Determining Coefficient, $R^2 = 0.75$

Standard Error of Predicted Center Lane Volume = 9.75

	X_6	X_7	X_9
Beta Weight	-0.298	0.594	0.717
Partial Correlation Coefficient	-0.448	0.708	0.819
R^2 delete	0.689	0.502	0.246

TABLE 12

SHOULDER LANE VOLUME RELATED TO DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP AND TOTAL THREE LANE VOLUME—AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.6824×10^4	100.4
Regression	4	0.1413×10^5	3540
Total	72	0.2096×10^5	

$F = 3540/100.4 = 35.2 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_5 = 24.5834 - 0.0014 X_6 + 0.2669 X_9$$

X_5 = Shoulder lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_9 = Total three lane volume per five minutes

Multiple Correlation Coefficient, R = 0.82

Determining Coefficient, $R^2 = 0.67$

Standard Error of Predicted Shoulder Lane Volume = 9.94

	X_6	X_9
Beta Weight	-0.120	0.790
Partial Correlation Coefficient	-0.201	0.806
R^2 delete	0.661	0.072

TABLE 13

SHOULDER LANE VOLUME RELATED TO DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND TOTAL THREE LANE VOLUME—MORNING PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.7942×10^4	117
Regression	4	0.1488×10^5	3720
Total	72	0.2282×10^5	

$F = 3720/117 = 31.8 > F_{0.01}$ $\therefore$ Highly Significant

Predictor Model:

$$X_5 = -4.9233 - 0.0028\, X_7 + 0.3333\, X_9$$

X_5 = Shoulder lane volume per five minutes, X_7 = Distance to nearest downstream exit ramp (ft.), X_9 = Total three lane volume per five minutes

Multiple Correlation Coefficient, $R = 0.81$

Determining Coefficient, $R^2 = 0.65$

Standard Error of Predicted Shoulder Lane Volume = 10.73

	X_7	X_9
Beta Weight	-0.248	0.752
Partial Correlation Coefficient	-0.389	0.785
R^2 delete	0.591	0.093

TABLE 14

TOTAL THREE LANE VOLUME RELATED TO MEDIAN LANE VOLUME AND DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP—AFTERNOON PEAK

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square
Error	68	0.2364×10^5	348
Regression	4	0.1602×10^6	40,100
Total	72	0.1838×10^6	

$F = 40,100/348 = 115 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_9 = 133.9218 + 2.097\, X_3 - 0.0036\, X_6$$

X_9 = Total three lane volume per five minutes, X_3 = Median lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.)

Multiple Correlation Coefficient, $R = 0.93$

Determining Coefficient, $R^2 = 0.87$

Standard Error of Predicted Total Three Lane Volume = 18.51

	X_3	X_6
Beta Weight	0.918	-0.102
Partial Correlation Coefficient	0.931	-0.272
R^2 delete	0.035	0.861

TABLE 15

TOTAL THREE LANE VOLUME RELATED TO MEDIAN LANE VOLUME, AND TIME OF DAY—AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.2267×10^5	334
Regression	4	0.1611×10^6	40,300
Total	72	0.1831×10^6	

$F = 40,300/334 = 120.5 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_9 = -66.5754 + 2.1405\, X_3 + 0.1086\, X_8$$

X_9 = Total three lane volume per five minutes, X_3 = Median lane volume per five minutes, X_8 = Time of day to nearest five minutes on 24-hour clock basis

Multiple Correlation Coefficient, $R = 0.94$

Determining Coefficient, $R^2 = 0.88$

Standard Error of Predicted Total Three Lane Volume = 18.12

	X_3	X_8
Beta Weight	0.937	0.125
Partial Correlation Coefficient	0.936	0.335
R^2 delete	0.003	0.861

TABLE 16

TOTAL THREE LANE VOLUME RELATED TO NUMBER OF SINGLE UNIT VEHICLES IN SHOULDER LANE, DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND CENTER LANE VOLUME—AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.3029×10^5	446
Regression	4	0.1535×10^6	38,400
Total	72	0.1838×10^6	

$F = 38,400/446 = 86 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_9 = 180.0925 + 2.2271\ X_2 - 0.0138\ X_7 + 1.9087\ X_4$$

X_9 = Total Three lane volume per five minutes, X_2 = Number of single unit vehicles in shoulder lane per five minutes, X_7 = Distance to nearest downstream exit ramp (ft.), X_4 = Center lane volume per five minutes

Multiple Correlation Coefficient, R = 0.91

Determining Coefficient, $R^2 = 0.84$

Standard Error of Predicted Total Three Lane Volume = 21.11

	X_2	X_7	X_4
Beta Weight	0.127	-0.325	0.710
Partial Correlation Coefficient	0.290	-0.594	0.844
R^2 delete	0.820	0.746	0.428

TABLE 17

TOTAL THREE LANE VOLUME RELATED TO SHOULDER LANE VOLUME AND DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP—AFTERNOON PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.5223×10^5	768
Regression	4	0.1316×10^6	32,900
Total	72	0.1838×10^6	

$F = 32,900/768 = 42.8 > F_{0.01}$.·. Highly Significant

Predictor Model:

$$X_9 = 190.6431 + 2.0403\ X_5 - 0.0112\ X_7$$

X_9 = Total three lane volume per five minutes, X_5 = Shoulder lane volume per five minutes, X_7 = Distance to nearest downstream exit ramp (ft.)

Multiple Correlation Coefficient, $R = 0.85$

Determining Coefficient, $R^2 = 0.72$

Standard Error of Predicted Total Three Lane Volume = 27.51

	X_5	X_7
Beta Weight	0.689	-0.266
Partial Correlation Coefficient	0.753	-0.404
R^2 delete	0.344	0.661

TABLE 18

TOTAL THREE LANE VOLUME RELATED TO DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP, DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, MEDIAN LANE VOLUME, AND TIME OF DAY–MORNING PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.3511×10^5	516
Regression	4	0.8036×10^5	20,090
Total	72	0.1155×10^6	

$F = 20,090/516 = 39 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_9 = 411.7560 - 0.0118\, X_6 + 0.0070\, X_7 + 1.6012\, X_3 - 0.2311\, X_8$$

X_9 = Total three lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_7 = Distance to nearest downstream exit ramp (ft.), X_3 = Median lane volume per five minutes, X_8 = Time of day to nearest five minutes on 24-hour clock basis.

Multiple Correlation Coefficient, R = 0.83

Determining Coefficient, $R^2 = .70$

Standard Error of Predicted Total Three Lane Volume = 22.89

	X_6	X_7	X_3	X_8
Beta Weight	-0.373	0.273	0.729	-0.330
Partial Correlation Coefficient	-0.481	0.359	0.766	-0.495
R^2 delete	0.604	0.651	0.264	0.597

TABLE 19

TOTAL THREE LANE VOLUME RELATED TO DISTANCE TO NEAREST UPSTREAM ENTRANCE RAMP, DISTANCE TO NEAREST DOWNSTREAM EXIT RAMP, AND CENTER LANE VOLUME—MORNING PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.3743×10^5	551
Regression	4	0.7805×10^5	19,550
Total	72	0.1155×10^6	

$F = 19,550/551 = 35.5 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_9 = 155.2981 + 0.0076\,X_6 - 0.0144\,X_7 + 1.9703\,X_4$$

X_9 = Total three lane volume per five minutes, X_6 = Distance to nearest upstream entrance ramp (ft.), X_7 = Distance to nearest downstream exit ramp (ft.), X_4 = Center lane volume per five minutes

Multiple Correlation Coefficient, R = 0.82

Determining Coefficient, $R^2 = 0.68$

Standard Error of Predicted Total Three Lane Volume = 23.46

	X_6	X_7	X_4
Beta Weight	0.240	-0.560	0.936
Partial Correlation Coefficient	0.316	-0.584	0.819
R^2 delete	0.640	0.508	0.016

TABLE 20

TOTAL THREE LANE VOLUME RELATED TO SHOULDER LANE VOLUME, AND TIME OF DAY—MORNING PEAK

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Error	68	0.4181×10^5	616
Regression	4	0.7377×10^5	18,450
Total	72	0.1155×10^6	

$F = 18,450/616 = 30.0 > F_{0.01}$ ∴ Highly Significant

Predictor Model:

$$X_9 = 374.3789 + 1.5486\, X_5 - 0.1622\, X_8$$

X_9 = Total three lane volume per five minutes, X_5 = Shoulder lane volume, X_8 = Time of day to nearest five minutes on 24-hour clock basis.

Multiple Correlation Coefficient, $R = 0.80$

Determining Coefficient, $R^2 = 0.64$

	X_5	X_8
Beta Weight	0.688	-0.231
Partial Correlation Coefficient	0.732	-0.339
R^2 delete	0.221	0.591