Investigation of the Effect of Change in Vehicular Characteristics on Highway Capacity and Level of Service

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ABSTRACT

Statistical analyses were conducted on a set of traffic flow data to investigate the effect of change in vehicular characteristics on maximum volumes for various levels of service. The results obtained from analysis of traffic flow models and time headways showed that despite the change in vehicular characteristics there has not been a discernible corresponding change in highway capacity parameters.

Capacity and level of service are major objectives in traffic analysis and design of highway elements. Under given traffic conditions, a design engineer is concerned with the production of a design proposal that meets certain demand criteria including capacity and the level of service at which the facility in question will, or is intended to, operate.

The procedures for analysis and design are, in general, facilitated by the use of tables and graphs from manuals that have been developed with reference to certain base conditions. What is often needed is a set of inputs associated with the specifics of a particular analysis or design problem. The specifications normally include, among other things, traffic characteristics and demand conditions.

One of the base conditions used in discussing vehicular traffic is the passenger car unit (pcu). For many years now it has been possible to deal with problems of traffic analysis and design with reasonable efficiency and accuracy. However, in recent years changes in vehicular characteristics have been observed. These changes involve both physical and operating characteristics. The average size of today's passenger car, for instance, is smaller than that of the average car 20 years ago. In addition, technology and scientific development have provided today's car with superiority in operational qualities, such as acceleration capabilities at low speeds, and in safety provisions.

The question that is being asked in connection with the changes in passenger car dimensions and operating characteristics is how these changes affect the traffic stream characteristics with regard to

- Mean speeds at free flow,
- Jam density,
- Highway capacity under ideal conditions, and
- Maximum possible volumes under conditions specified for various levels of service.

Literature Review

Previous research developed speed-density models and flow-density models; some of these models were single-regime and others were multiregime models. Tests have shown that nearly all single-regime traffic stream models may be accurately fitted with field data only within limited ranges of flow levels(1-3; 4,pp.175-216).

Huber (5) and Haynes (6) employed a second-degree polynomial to fit volume-density traffic data. A field study carried out by Drake et al. (7) was aimed at comparing important parameters of the traffic stream models as a basis for determining their relative predicting capabilities. In this study traffic flow data were collected on the Eisenhower Expressway in Chicago and the tests were performed by regressing mean speeds versus their associated mean densities. Seven alternative speed-density hypotheses suggested by this study and their corresponding equations are given in Table 1.

Accordingly, except for the two-regime linear hypothesis, it was concluded that from the standpoint of application all models performed reasonably well and there was no basis for discontinuing the use of any. In respect to logical theoretical consistency, Drake et al. thought that the Edie hypothesis excelled in comparison with the three-regime linear form.

It was found in some studies (2) that, generally, drivers use the criterion of potential time to collision point, with average minimum headway a constant, regardless of speed. Minimum headways vary from 0.5 to 2.0 sec depending on the driver and traffic conditions, with an average of about 1.5 sec. But the value of 1.5 sec corresponds to a rate of flow per lane of 2,400 passenger cars per hour that, according to the Highway Capacity Manual (2), occurs under extremely specialized conditions.

The maximum rate of flow for a given highway is at the point of critical density, and the critical density depends on the minimum headways that drivers find tolerable at particular speeds. Generally, the higher the design standards of a highway, the shorter these headways may be.

OBJECTIVES

Speed, density, and flow and their relationships are the major subjects considered in the analyses of traffic stream characteristics. Because capacity and level of service are defined by these variables, an attempt has been made to find how changes in passenger car characteristics have affected speeds and densities and their relationship in the traffic

TABLE 1 Summary of Results Obtained by Drake (7)

Hypothesis	Equation	r^2	F	U_f	K_j	K_m	U_m	Q_m
Greenshields	$U = 58.6 - 0.468K$	0.896	1,005	58.6	125	62.5	29.3	1,830
2-Regime linear	$U = 60.9 - 0.515K$ $(K \leq 65)$ $U = 40 - 0.265K$ $(K \geq 65)$	0.685	250	60.9	151	59.2	30.4	1,800
3-Regime linear	$U = 50 - 0.098K$ $(K \leq 40)$ $U = 81.4 - 0.913K$ $(40 \leq K \leq 65)$ $U = 40.0 - 0.265K$ $(K \geq 65)$	0.590	167	50.0	151	44.6	40.7	1,815
Modified Greenberg	$U = 48.0$ $(K < 35)$ $U = 32.8 \ln(145.5/K)$ $(K \geq 35)$	0.866	745	48.0	146	53.7	32.8	1,760
Underwood	$U = 76.8e^{-K/56.9}$	0.901	1,050	76.8		56.9	28.3	1,610
Edie	$U = 54.9e^{-K/163.9}$ $(K \leq 50)$ $U = 26.8 \ln(162.5/K)$ $(K \geq 50)$	0.681	245	54.9	162	50.0	40.5	2,025
Bell curve	$U = 48.6e^{-0.00013K^2}$	0.884	872	48.6		62.0	29.5	1,830

stream and how these changes will affect capacity and level of service. To this end, the purpose of this research is

- To investigate the relationship between speed, density, and flow under today's traffic characteristics and composition;
- To compare the results of this investigation with those represented by the existing models of the traffic stream; and
- To reevaluate maximum passenger car volumes possible under operating conditions applicable to specified levels of service.

DATA SOURCE

The traffic data initially obtained for this study were collected from two selected sites: Kingery Expressway in Chicago, Illinois, and LaPorte Freeway in Houston, Texas. Both sites are three-lane basic freeway segments. This set of data is part of the field data collected in 1980, using the Federal Highway Traffic Evaluator System (TES), in order to determine passenger car equivalents (pce's) of trucks and other vehicles on urban freeways (8,9).

SITE DESCRIPTION

The LaPorte Freeway section, the focus of the study, is a 1,500-ft tangent section. The tangent is part of a ramp-bounded section of a roadway, about 2,600 ft long measured from the end of the on-ramp taper to the beginning of the exit-ramp taper.

The details of the experimental setting at the sites are beyond the scope of this paper, but the general site layout includes a system of tape-switches that are affixed to the road surface. The passage of a tire over a tapeswitch activates a high-precision event recorder.

Tapeswitches are configured within travel lanes to form traps. The strategic location of these traps and the subsequent record processing of data via TES software make possible reconstruction of all vehicle trajectories throughout the deployment area (9).

DATA EXTRACTION

To perform analyses for traffic stream models, it was deemed necessary to first obtain records of vehicular flow, speed, and density. But the data base, in the tape files from the pce study, contains records stored in a form that required sorting out to obtain the desired data. For this reason seven record items were extracted by a computer program that was tailor written for this purpose. The items are

- Lane of entry,
- Vehicle type,
- Mean speed across the deployment traps,
- Mean time headway (calculated by the program from individual headway from each trap) across the deployment area,
- Data quality flag,
- Data reasonableness flag, and
- Time of entry.

DATA PROCESSING

The term processing is employed here to mean the mathematical treatment applied to prepare the extracted data for statistical analysis. In this case processing involved

- Calculation of mean speeds for specified speed ranges. The speed ranges from which the mean speeds were calculated are 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100, 100-110, 110-120, and 120-130 feet per second.
- Conversion of the mean speeds from feet per second to miles per hour.
- Determination of mean rates of flow corresponding to the mean speeds. At each trap, flow was computed from time headways for each vehicle pair. The mean rate of flow for any mean speed was then obtained by the arithmetic average of all values of rate of flow within the speed range from which the pertinent mean speed was calculated. The speed distribution within each speed class was observed to be normal, and use of the mean speed is considered acceptable.
- Calculation of vehicular densities corresponding to the flow rates and speeds. Because it is known that rate of flow (Q) is equal to the product of density (K) and speed (U), ($Q = KU$), the values of density were calculated as $K = Q/U$ for all values of U greater than zero.

In connection with the data processing, a condition of data reasonableness was imposed so that only reasonably doubt-free data were processed. This was achieved by selecting only those records for which the data reasonableness flag was zero, which is, according to the data base, the indicator for records free of all discernible indicators of doubt about data reasonableness.

PILOT ANALYSIS

In all there were seven tape files of which five contained data collected on LaPorte Freeway in Houston and two contained data obtained on Kingery Expressway in Chicago.

To establish the characteristics of these data a pilot analysis was carried out wherein the scatter of density in each file was observed. Density was picked as a suitable variable for preliminary analysis because its distribution can be used to predict performance of the traffic stream models and to estimate operational parameters of traffic flow. Previous researchers (10-12) have shown that speed-density and volume-density relations are quite characteristic of density zones--low, medium, and high density.

STATISTICS OF PILOT ANALYSIS

Both files of data from Kingery Expressway and two files of data from LaPorte Freeway are characterized by densities of less than 10 vehicles per mile. The remaining three files of data from LaPorte Freeway have density figures ranging between 4 and 144 vehicles per mile.

Because of the observed density characteristics of the sets of data, it was decided that all data from Kingery Expressway and two files of LaPorte Freeway data could not be of much practical use to this research, and those files were thereupon dropped from further analysis.

TRAFFIC CLASSIFICATION AND COMPOSITION

The typological classification of data includes 10 categories of vehicles given in Table 2. For the purpose of this research, Category 4, motorcycles, was excluded and its effect was neglected in order to simplify the work of analysis and, above all, because its overall proportion in the traffic stream was less than 1 percent (8,9). The three categories of automobiles (small, medium, and large) were collapsed into one class of automobiles and all categories (except Category 4) were combined to form a second class of mixed traffic.

TABLE 2 Vehicle Topology *(9)*

Vehicle Category	Vehicle Description	Wheelbase Length (ft)
1	Small automobile	6.0–8.8
2	Medium automobile	8.8–9.5
3	Large automobile	9.5–10.3
4	Motorcycle	3.5–6.0
5	Pickup/van/utility vehicle	10.3–13.0
7	2-axle truck	13.0–20.0
8	3-axle truck	Less than 25.0
9	Bus	Greater than 25.0
10	Combination tractor semitrailer truck	
	3 axles	Greater than 25.0
	4 or 5 axles	Any
12	Combination truck (6 or more axles)	–[a]

[a]No data available.

SIZE OF DATA BASE

By discarding all data from Kingery Expressway and in the two files from LaPorte Freeway the size of the data base was reduced from the original total of approximately 98,000 to about 49,000 vehicle counts. Nonetheless, the 49,000 vehicle counts finally used represent more than 75 percent of all vehicle counts taken at the LaPorte Freeway site. In addition, each vehicle was involved in multiple records across the deployment traps (9) so that actual data calculations were based on nearly 240,000 records. A statistical test showed no significant difference among the three files and, therefore, they were pooled into one data set (Tables 3 and 4). Table 5 gives the pooled mixed traffic classified by the three lanes.

TIME HEADWAYS

Because of the dependence of maximum rates of flow and density on minimum tolerable headways, it was considered that results of an independent statistical analysis of headways should complement the parametric results from the analysis of traffic stream models. In view of this anticipation, a sample of headway data was obtained for headway analysis as described in the paragraphs that follow.

The time headway between any two consecutive vehicles was calculated as the difference between the time of entry of the follower and the time of entry of the leader.

The source of headway data is a set of data from one file of traffic flows observed before 8:00 a.m. The choice of time was so made in order to capture the morning peak of inbound traffic flow for the analysis of headways at near-to-capacity flow. The set of data was reduced to a manageable form by classification. Nine headway classes were defined: 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, and 8-9 sec.

TABLE 3 Speed, Density, and Volume of Automobile Data from LaPorte Freeway

Speed (mph)	Density (vpm)	Volume (vph)
12.00	125.13	1,505.60
18.13	92.74	1,669.08
24.20	73.90	1,781.60
30.84	60.29	1,857.39
36.99	48.33	1,774.49
45.36	21.14	953.07
52.09	14.41	751.37
57.88	15.19	879.66
63.61	12.73	808.52
70.09	9.85	691.02
76.96	4.29	330.23
84.13	7.62	639.39
18.90	93.00	1,760.30
24.90	60.90	1,496.40
30.40	41.70	1,267.40
37.20	42.40	1,570.00
45.10	30.80	1,383.50
51.60	26.40	1,360.50
56.90	28.50	1,614.60
63.40	24.10	1,528.10
75.70	11.90	903.10
10.80	144.00	1,480.70
18.00	88.90	1,597.00
24.10	71.50	1,720.40
29.80	58.90	1,749.80
37.30	49.10	1,811.70
45.40	22.30	1,008.30
52.10	16.30	851.40
58.00	17.00	984.00
63.90	13.70	873.50
70.30	10.30	726.50
77.10	6.90	527.80

TABLE 4 Speed, Density, and Volume of Mixed Traffic Data from LaPorte Freeway

Speed (mph)	Density (vpm)	Volume (vph)
18.20	84.70	1,531.70
24.60	63.10	1,543.70
31.10	52.60	1,631.80
37.10	43.70	1,610.60
45.20	16.70	750.70
51.90	13.50	700.10
57.80	15.00	869.20
63.60	12.60	799.60
70.10	9.30	654.30
77.00	8.50	666.50
84.10	7.60	639.40
89.40	5.50	491.10
18.90	83.80	1,566.90
24.90	59.20	1,453.70
30.60	42.20	1,288.90
36.90	41.60	1,532.40
45.90	29.90	1,343.80
51.50	28.30	1,461.00
56.80	30.50	1,723.90
11.80	91.10	1,027.60
18.10	83.10	1,496.10
24.40	66.30	1,609.70
30.20	56.60	1,709.50
37.30	44.80	1,652.80
45.20	19.70	887.40
52.00	15.40	802.10
58.00	16.80	974.90
63.90	15.10	964.40
70.30	13.70	920.80
77.10	8.50	650.90
83.30	6.80	570.40

TABLE 5 Lane Speed-Volume Data for Mixed Traffic by Lane

Median Lane		Middle Lane		Shoulder Lane	
Speed (mph)	Flow (vph)	Speed (mph)	Flow (vph)	Speed (mph)	Flow (vph)
12	1,500	12	1,503	NA	NA
18.8	1,886	18.8	1,715	19	1,763
24.1	1,829	24.1	1,623	24.8	1,638
30.2	1,540	30.8	1,637	31.0	1,735
37.9	1,386	37.0	1,802	36.4	1,692
45.2	1,052	45.1	1,332	45.4	1,515
50.8	1,030	52.1	1,080	52.4	1,076
56.4	1,046	57.3	1,018	57.6	1,175
62.9	741	63.1	908	63.7	1,187

Note: mph = miles per hour; vph = vehicles per hour; NA = not available.

Table 6 Frequency of Headways by Type

Headway (sec)		Headway Types[a]			
Class Interval	Middle Point	1	2	3	4
0–0.99	0.5	34	14	21	10
1–1.99	1.5	122	22	28	19
2–2.99	2.5	65	25	12	9
3–3.99	3.5	12	8	6	5
4–4.99	4.5	4	2	2	3
5–5.99	5.5	2	1	2	0
6–6.99	6.5	2	1	1	0
7–7.99	7.5	0	0	0	0
8–8.99	8.5	0	0	0	0

[a]1 = automobile following automobile,
2 = automobile following truck,
3 = truck following automobile, and
4 = truck following truck.

TABLE 7 Mean Time Headways for Headway Types 1-4

Headway Type	Mean Headway (sec)	Variance (sec^2)	No. of Observations
1	1.85	0.98	241
2	2.08	1.45	73
3	1.81	1.76	71
4	1.89	1.31	46

Frequency tallies of these classes for four different headway types are given in Table 6. The four headway types are

- Automobile following automobile (AA),
- Automobile following truck (AT),
- Truck following automobile (TA), and
- Truck following truck (TT).

A summary of calculated values of mean headways and their variance under traffic conditions of near-to-capacity flow is given in Table 7. The rate of traffic flow during the period from which the data sample was taken was about 1,800 vehicles per hour (vph).

It can be seen that the mean time headways for vehicle pairs in which the leaders are trucks are longer than the mean headways in which automobiles lead, other factors being the same. But an analysis of variance shows that at the 95 percent level of significance the four types of headways are not significantly different from each other at the pertinent rates of flow. This observation is in agreement with recent findings by Cunagin and Chang (13) who observed that the difference among headway types diminishes with increasing rate of flow per lane-hour.

The overall mean value of time headway is 1.89 sec. A t-test at the 95 percent level of confidence shows that this value is significantly greater than 1.8 sec and smaller than 2.0 sec.

ANALYSIS OF TRAFFIC STREAM MODELS

Curve fitting by the method of least squares (14) was conducted on five known speed-density traffic stream models, namely, Greenshields linear, Greenberg logarithmic, Underwood exponential, Drake bell curve, and Drew parabolic model. The models were fitted on two sets of data, automobiles and mixed vehicles. Goodness of fit of each regression model was checked by the coefficient of determination (r^2) and the F-ratio test, and the comparison of parameters was done in two stages:

1. Parametric comparison of models: This involved the comparison of values of U_f, K_j, K_m, U_m, and Q_m obtained by different models analyzed with the same data [from LaPorte Freeway, collected in 1980 (see Tables 8 and 9)].
2. Parametric comparison of data: For the linear model the values of U_f, K_j, K_m, U_m, and Q_m obtained from LaPorte Freeway data were compared with values previously obtained by Drake et al. (7). A summary of the comparison is given in Table 10.

VOLUME-DENSITY MODEL

Haynes (6) investigated the volume-density relationship from data in which both flow and density were measured quantities. Despite the difference in the methods used to collect data it was thought that there was adequate basis for comparison of Haynes'

TABLE 8 Stream Equations and Parameters for Automobiles

	Greenshields	Greenberg	Underwood	Drew	Drake
Equation[a]	1	2	3	4	5
F-value	130	407	579	291	119
r^2	.812	.931	.951	.907	.798
U_f	67.9	–[b]	75.6	90.8	55.1
K_j	128.6	225	–[b]	142.8	–[b]
K_m	64.3	82.8	66.2	63.5	69.0
U_m	34.0	22.2	27.8	30.3	33.4
Q_m	2,190	1,840	1,840	1,920	2,300

[a]Equations: 1, $U = 67.92 - .53K$; 2, $U = 22.2\ln(225/K)$; 3, $U = 75.6e^{-(K/66.2)}$; 4, $U = 90.8[1 - (K/142.8)^{1/2}]$; and 5, $U = 55.1e^{-1/2(K/69)}$, where U is space mean speed in miles per hour and K is density in vehicles per mile.

[b]Model does not predict this information.

TABLE 9 Stream Equations and Parameters for Mixed Traffic

	Greenshields	Greenberg	Underwood	Drew	Drake
Equation[a]	1	2	3	4	5
F-value	154	441	472	278	204
r^2	.84	.94	.94	.91	.88
U_f	74.3	–[b]	83.0	98.7	62.6
K_j	99.1	173.5	–[b]	113.7	–[b]
K_m	49.4	63.8	52.4	50.5	60.0
U_m	37.2	24.9	30.5	32.9	23.0
Q_m	1,840	1,590	1,600	1,660	1,150

[a]Equations: 1, $U = 74.30 - .75K$; 2, $U = 24.9\ln(173.5/K)$; 3, $U = 83.0e^{-(K/52.4)}$; 4, $U = 98.7[(K/113.7)^{1/2}]$; and 5, $U = 62.6e^{-1/2(K/50)2}$

[b]Model does not predict this information.

TABLE 10 Comparison of Regression Parameters for Linear Model: LaPorte Freeway Versus Eisenhower Expressway

Parameter	LaPorte (mixed)	Eisenhower	LaPorte (automobile)
Equation	$U = 74.3 - .75K$	$U = 58.6 - .457K$	$U = 67.9 - .53K$
F-value	154	1,005	130
r^2	.841	.896	.812
U_f	74.3	58.6	67.9
K_j	99.1	125	128.6
K_m	49.4	62.5	64.3
U_m	37.2	29.3	34.0
Q_m	1,840	1,830	2,190

results and those obtained from the set of data from LaPorte Freeway. The grounds for the comparison are discussed in the next two paragraphs.

The truck proportion in Haynes' data is estimated at an average of 3 percent. In LaPorte Freeway data, trucks constitute about 9 percent. Although the percentage of trucks in the two sets of data is different, the availability of the information about their difference is sufficiently helpful as a basis for reasonable inference. The only problem is that it is difficult to make an exact inference similar to that which could be made if the truck proportions were the same in the two sets of data.

Although the lengths of the two experimental roadway sections are different, a 5-mile section in Haynes' data and 0.50 mile for the LaPorte Freeway, the equality in their number of lanes provides adequate resemblance for comparison.

In this comparison the parameters of interest were the maximum volume and the density associated with the maximum volume. Haynes obtained two volume-density equations:

$$V = 75D^2 - 0.205D - 812 \quad (1)$$

$$V = 65.5D^2 - 0.179D - 80 \quad (2)$$

where V is three-lane volume and D is three-lane density. Both equations estimated maximum three-lane volumes of about 6,000 vehicles per hour and predicted the same value of three-lane density associated with maximum volumes at 183 vehicles per mile.

The parameters obtained from a similar curvilinear regression, involving a second-degree parabola, for the LaPorte data resulted in the equation:

$$V = 43.73D^2 - 0.135D + 772 \quad (3)$$

From this relationship the value of the maximum three-lane volume is 4,860 vehicles per hour, and the value of three-lane density associated with the maximum volume is 177 vehicles per mile. These values are lower than those obtained by Haynes. But they are consistent in that

- They have been estimated from data on traffic roughly 10 percent of which is trucks, and
- The values of maximum volume and critical density estimated from this model do not differ significantly from those estimated by the speed-density hypotheses.

ANALYSIS OF AUTOMOBILE FLOW BY LANE

For each of the three freeway lanes a speed-density linear relationship was estimated for automobiles. The following parameters were observed from the equations:

1. The mean speeds at free flow decreased from the median lane to the shoulder lane. These speeds are 75, 63, and 59 mph for median, middle, and shoulder lane, respectively.
2. Jam density increased from the median lane to the shoulder lane. The values of jam density were 114, 131, and 143 vehicles per mile in the median, middle, and shoulder lane, respectively.

3. The maximum volumes for the median, middle, and shoulder lane were 2,130, 2,150 and 2,100 vehicles per hour, respectively.

Table 11 gives a summary, by lane, of the linear equations and their respective parameters. A statistical t-test, performed at the 95 percent significance level to test whether these rates are different from each other, showed that the volumes 2,130, 2,150, and 2,100 vehicles per hour were not significantly different from each other.

TABLE 11 Summary of Lane Flows of Automobiles

	Lanes		
Description	Median Lane	Middle Lane	Outer Lane
Equation	$U = 74.74 - .66K$	$U = 62.82 - .46K$	$U = 58.72 - .41K$
r^2	.93	.92	.90
U_f	74.74	62.82	58.72
K_j	114	137	143
K_m	57	68.5	71.5
U_m	37.4	31.4	29.4
Q_m	2,130	2,150	2,100

DISCUSSION OF RESULTS

Traffic Composition and Characteristics

The maximum traffic volumes that have been estimated by the models from the 1980 LaPorte Freeway data are, to a certain extent, comparable to those estimated by Drake's equations (Table 1) developed from the 1965 data. For the case of mixed traffic, of which 10 percent is trucks, the maximum volumes predicted from LaPorte data are practically equal to the corresponding values estimated by Drake with the Greenshields, Greenberg, and Underwood hypotheses. For automobiles, all maximum volumes estimated for the LaPorte data are higher than Drake's.

Incidentally, Drake did not explicitly report the composition of the vehicular traffic data that were used in the comparative statistical analysis of the traffic stream models. Because of the lack of information about traffic composition it, unfortunately, becomes difficult to make direct comparison between the parameters obtained by Drake and those estimated from the data collected on LaPorte Freeway in 1980. Consequently, no inference can be made with certainty regarding between-data comparison.

The results of comparison of the various models for LaPorte data exhibited a trend that is in agreement with previous observations made by Drake wherein

1. The value of U_f predicted by the Underwood curve has been observed to be considerably high,
2. The values of critical speed estimated by most of the models are much lower than the critical speeds obtainable by inspection of speed-volume data, and
3. The linear model tends to underestimate jam density but predicts high values of maximum volumes.

Capacity and Maximum Service Volumes

In both the 1965 Highway Capacity Manual (2) and the Interim Materials on Highway Capacity (3), six levels of service, A through F, are defined. For each level of service performance criteria based on threshold speeds and ceiling densities are given.

With the speed-density linear equation estimated for automobiles on LaPorte Freeway, estimates of maximum service volumes for levels of service A through E were calculated according to the criteria specified in the 1980 Interim Materials on Highway Capacity. The volumes so obtained agree with those estimated in the Interim Materials for levels of service B, C, and D. The Interim Materials give rather conservative values of maximum volumes for levels of service A and E (see Table 12).

TABLE 12 Service Volumes for Basic Freeway Segment

	Performance Criteria		Maximum Service Volume (vph)[a]		
Level of Service	Speed (mph)	Density (vpm)	1 Lane	2 Lanes	3 Lanes
A	> 50	< 15	2,700	2,400	2,400
B	> 50	< 25	4,100	3,900	3,500
C	> 48	< 35	5,180	5,100	4,800
D	> 40	< 47	6,060	5,775	5,400
E	> 30	< 67	6,510	6,000	6,000
F	< 30	> 67	–[b]	–[b]	–[b]

[a] Maximum service volumes: 1 lane, estimated from linear equation $U = 67.9 - .53K$ (LaPorte data); 2 lanes, given in Interim Materials on Highway Capacity, 1980. *(3)*; and 3 lanes, old figures from the 1965 Highway Capacity Manual, 1965 *(2)*.

[b] Not applicable.

Time Headways at Near-to-Capacity Flow

On the basis of the overall average value of time headway, which was 1.89 sec for peak flow, it appears that the maximum uniform rate of flow that can be expected under the traffic conditions appertaining to the experimental data is around 1,900 vehicles per hour. This value is an estimate for mixed traffic.

From the mean headway estimated for headway Type 1 (automobile following automobile), the 95 percent confidence interval for maximum volumes is estimated to be 1,830 to 2,080 passenger cars per hour (pcph), with a mean of 1,955 pcph. This estimate is not unreasonable considering that it is not based on homogeneous automobile traffic. It should be noted that although the volume estimate of 1,955 pcph is based on the mean of Type 1 headways (automobile following automobile) these passenger cars experience a wave of turbulence caused by the trucks that are in the traffic stream.

PROBLEMS ENCOUNTERED IN COMPARATIVE ANALYSIS

The most stubborn problem in this research was that of lack of exact comparable conditions under which data were collected for the various previous traffic stream analyses. Some of the problems associated with the incomparability between data from LaPorte Freeway and data from earlier studies are discussed next.

It was difficult to compare model parameters estimated on the basis of data from LaPorte Freeway with those obtained by Greenberg (15), Edie (16), and Gazis (17) and data from Lincoln Tunnel because traffic flow in tunnels resembles single-lane conditions in which, unlike in three-lane flow, overtaking is not possible.

Huber (5) studied the performance of the Merritt Parkway in Norwalk, Connecticut, operating over a temporary bridge. The study conditions on the parkway were dissimilar to those of LaPorte Freeway in that

- LaPorte Freeway carried mixed traffic with 10 percent trucks;

• LaPorte Freeway study site was a three-lane section; and

• Overtaking was prohibited at the Merritt Parkway study site so traffic flow was, to a large extent, similar to that under single-lane conditions.

Studies carried out by Haynes (6), in Houston, and Drake (7), in Chicago, are the two that involved, to the author's knowledge, data with the greatest similarities to the 1980 LaPorte Freeway data. But here too there was a problem of dissimilarities in truck proportions.

SUMMARY

Due to the problems encountered because of lack of exact correspondence between the conditions associated with data from LaPorte Freeway and those associated with data previously collected elsewhere it was not possible to make numerical comparisons of the parameters obtained in this analysis and those previously obtained. However, two of the three objectives that were defined at the outset of the research were achieved. These objectives were

1. Investigation of speed-density-flow relations under current traffic conditions. The set of traffic flow data collected in 1980 was taken to represent current traffic conditions. This analysis involved estimation of traffic flow parameters obtainable by speed-density models, the predicting capabilities of which were compared in terms of results from statistical tests and inspection of flow data.
2. Evaluation of maximum possible passenger car volumes under operating conditions applicable to specified levels of service. The volumes estimated were calculated in accordance with the threshold speeds and ceiling densities specified in Interim Materials on Highway Capacity.

In addition, the analysis of time headways at near-to-capacity flow was conducted to supplement the efforts to estimate maximum possible values of capacity flow on freeway sections under traffic conditions similar to those of the analysis data.

CONCLUSIONS

On the basis of the results obtained from the analysis, the following conclusions can be drawn:

1. Among the speed-density models, the Underwood exponential curve has the highest predicting capability. The Greenberg logarithmic curve follows with the second highest predicting capability.
2. The value of jam density estimated by the Greenshields linear model is lower than those predicted by other models and than would reasonably be expected on inspection of traffic flow data.
3. The Greenshields relation is the most accurate in predicting critical speeds, and despite its tendency to underestimate jam density it out performs the other models in predicting reasonable high values of maximum volume. Its merit in estimating critical speeds and maximum volumes apparently outweighs its shortcoming in relation to jam density.
4. The values of maximum passenger car volumes obtained in the analysis of data from the LaPorte Freeway suggest that conditions affecting the characteristics of traffic flow are probably compensating so that the macro-characteristics of traffic flow ultimately remain essentially unchanged.

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