Automobile Occupancy Projections Using A Modal-Split Model

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The use of a diversion-curve, modal-split model is proposed as a method of converting person trips on a highway network to vehicle trips. The model is programmed for the CDC 3600 computer. Investigation was done to determine significant variables for predicting vehicle usage. Median family income at the production end of the trip, orientation of the trip to the central business district or to locations other than the central business district, travel time, and trip purpose were used as variables. Curves relating the percentage of highway person trips made by drivers to these variables were developed and the model was tested with base-year data. The total error in predicted vehicle trips was less than 0.5 percent indicating that this type of model is well suited to prediction of vehicle usage. Projections to a future year indicated that significant decreases in automobile occupancy will occur.

•A MAJOR DESIRED output of the transportation planning process is a highway network that will meet the vehicular travel demand in a given design year. The usual approach to this problem is as follows:

1. Base-year data are collected.
2. A series of generation, distribution, modal-split, and assignment models are calibrated.
3. Projections of independent variables are made to the design year.
4. Total person trips are generated and distributed.
5. A modal split is performed separating transit trips from total person trips.
6. An automobile occupancy factor is applied to the remaining trips to convert them from person trips to vehicle trips.
7. The vehicle trips are assigned to a test network.

At this point, based on established criteria, the network is evaluated. It is either recommended as it is for further consideration by the planning body, or it is modified. If modifications are indicated, the testing process begins again at either the assignment or the distribution phase.

Although not generally recognized, the automobile occupancy factor used in converting highway person trips to highway vehicle trips can be an important factor in determining the adequacy of a proposed system. Given 5 million highway trips, an occupancy factor of 1.5 would yield 3.33 million vehicle trips, and a factor of 1.3 would yield 3.85 million trips—an increase of 16 percent in the number of vehicle trips that must be served. Thus, the projection of automobile occupancy rates can be critical in system design.

At one time, the usual method of arriving at design-year occupancy was to compute average automobile occupancy from base-year data.

Average persons per car = (automobile-driver trips + automobile-passenger trips)/automobile-driver trips

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This factor was applied uniformly to the projected highway person trips.

As the planning process became more sophisticated, it was realized that automobile occupancy would vary with the purpose of the trip. A factor, therefore, was computed for each trip purpose, using base-year data.

$$\text{Average persons per car}_{(N)} = [\text{automobile-driver trips}_{(N)} + \text{automobile-passenger trips}_{(N)}]/\text{automobile-driver trips}_{(N)}$$

where N is purpose of the trip.

This factor was used to convert the projected person trips to vehicle trips on a trip-purpose basis. It, however, introduced additional error because the trip purpose of the passenger is frequently not the same as the purpose of the driver. Where it was felt that the average automobile occupancy would change over time as the characteristics of the region changed, a subjective judgment was made of the magnitude and direction of the shift, and similar factors were applied.

This line of reasoning, that the automobile occupancy would vary with the characteristics of the region, led to the use of different occupancy factors for CBD-oriented trips and for non-CBD-oriented trips, as opposed to a uniform factor for all travel in the region. A logical extension of this thinking led the Twin Cities Transportation Study to develop a model that predicted automobile occupancy rates for work trips based on the income at the production end of the trip. A second equation predicted occupancy for all other trips based on only production zone income.

These equations form what is, in fact, a modal-split model. It divides trips into automobile-driver and nonautomobile-driver trips on the basis of the individual interchanges and the characteristics of the trip ends. It reduces errors resulting from the application of uniform factors to large areas. For the Cleveland-Seven County Transportation-Land Use Study (SCOTS), it was decided to investigate this modal-split model approach to automobile occupancy projection.

MODEL

Model Formulation

The modal-split model that was chosen for use by SCOTS was programmed for the CDC 3600 computer. It is a diversion-curve model in which a series of curves are developed that split a given trip table into two trip tables. The percentage split is read from a curve. The ordinate of the curve is the percentage to be allocated to one table and the remaining trips are allocated to the second table. The abscissa is designed to be the ratio of travel time between the mode associated with the first table and the mode associated with the second table.

Associated with each trip are (a) a production code that relates to the value of a parameter at the production end of the trip, (b) an attraction code that relates to a parameter at the attraction end of the trip, (c) a range code that relates to an interchange parameter, travel time, and (d) purpose. A separate diversion curve may be used for each combination of trip purpose (up to 11 purposes), production code (up to 4 codes), attraction code (up to 4 codes), and range code (up to 4 codes). Thus a total of 11 x 4 x 4 x 4 or 704 curves may be used, if sufficient base data exist to develop and apply the number of curves. In actual practice, the number of curves used is much smaller.

Curve Development and Calibration

Given this formulation of the model, the next steps are the determination of significant production, attraction, and interchange parameters and the values on the diversion curves. A series of regressions were performed to examine the contribution of each set of production zone parameters to the total variance in automobile occupancy. Because the model attributes total variation to four variables, excluding trip purpose, large values of correlation coefficients were not anticipated; a correlation coefficient on the order of 0.25 was considered sufficient to indicate significant production parameters. For simplicity and speed in model operation, it was decided to use the same production parameter for all purposes, although this is not necessary.

Of the production parameters examined, three appeared significant—median family income, automobiles per person, and dwelling units per acre. Of the three, median family income appeared to be the most significant for the majority of purposes, and it was selected to be the production zone parameter. Because the model allows only four levels of the parameter, a stratification was made into high income (above $9,550), medium ($6,550 to $9,550), and low (under $6,550).

An interesting sidelight from the analysis is that the availability of transit service does not have the expected impact on automobile occupancy. Areas with transit service showed higher occupancy rates than those without service. This indicates that the income and automobile ownership characteristics are more significant than transit service in determining automobile occupancy and that trips made by automobile passengers would have been automobile-driver trips had the additional vehicles been available.

For the attraction-area parameter, it was decided to use a simple CBD, non-CBD split. This approximates a measure of the ease of parking. Subsequent investigation has indicated that, for certain trip purposes, accuracy could be increased by an additional stratification to include non-CBD areas in which parking is difficult. This modification may be introduced into later applications of the model.

In determining an interchange parameter, we felt that travel time would be significant. The question arose, however, if it would be a sufficient measure. Base-year trips, obtained in the origin-destination study, were stratified by purpose (home-based including work, shop, social-recreation, school, and miscellaneous, which includes personal business, medical-dental, and eat meal; and nonhome-based), mode (automobile driver, automobile passenger), production code, attraction code, and travel time. For travel time, the skim-tree time from the base-year highway network was used.

PAGE 1

AUTO DRIVER AND PASSENGER TRIPS BY TIME AND INCOME P CODE AND A CODE

NCBD
HIGH
MISC

	DRIV	PASS	
3	43344	6772	50116
4	192237	44309	236546
5	186028	36665	222693
6	446544	98606	545150
7	527422	146788	674210
8	385671	148550	534221
9	478504	120283	598787
10	462923	147336	610259
11	314651	99719	414370
12	271134	72938	344072
13	235484	90568	326052
14	196635	58812	255447
15	179661	70874	250535
16	143379	44643	188022
17	114903	46107	161010
18	117393	53631	171024
19	115956	54328	170284
20	95412	36211	131623
21	76849	33423	110272
22	73773	32719	106492
23	57827	21562	79389
24	66537	32128	98665
25	54473	20119	74592

Figure 1. Example of analysis table.

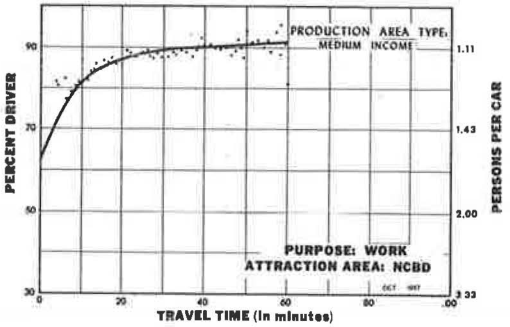

Figure 2. Example of base-year data points with hand-fitted curve.

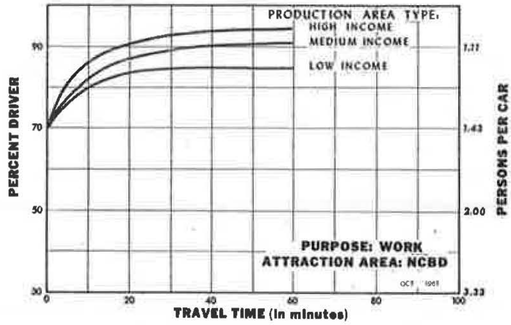

Figure 3. Model diversion curves for automobile driver-passenger split, work purpose to non-CBD area.

Thus, data were obtained on the total number of trips for a given purpose, of a given interchange type and travel time, for each of the two modes. Figure 1 shows an example of these tables.

From these tables, the percentage of total highway trips that were automobile-driver trips was computed for each travel-time increment. The sets of points were plotted with percentage of drivers as the ordinate and travel time as the abscissa. The driver percentage, the reciprocal of automobile occupancy, was used to maintain compatibility with the form of the modal-split model. After the points were plotted, a curve was hand-fitted to them. Figure 2 is an example of one of these charts.

Not all the groupings yielded easily fitted sets of points because, in many cases, an insufficient number of trips fell into the given strata. A guideline was established, therefore, for fitting the curves to the points. This was that, for a given purpose-attraction code combination, the diversion curves for all income groups would have the same shape. The applicability of the rule was apparent for those purposes that had sufficient data in all groupings to show clearly defined curves.

The fit obtained on the majority of these curves indicated that travel time alone would be acceptable as the single interchange parameter. The diversion curves obtained from this analysis are shown in Figures 3 through 11. Curves for school trips are not included. Analysis indicated that acceptable relationships for school trips could not be developed from strictly automobile driver-passenger data because a large number of school trips are made by other modes and because, for most automobile-passenger school trips, the driver's purpose is generally other than that of going to school. This was not felt to be a problem because of the small number of automobile-driver trips with a true school purpose.

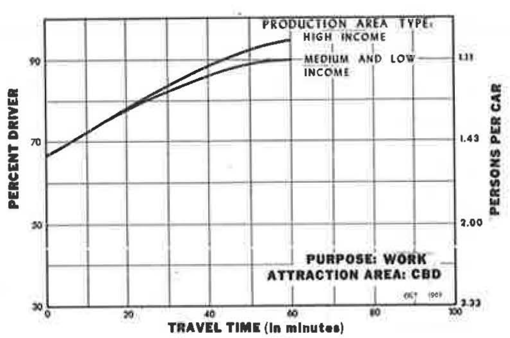

Figure 4. Model diversion curves for automobile driver-passenger split, work purpose to CBD area.

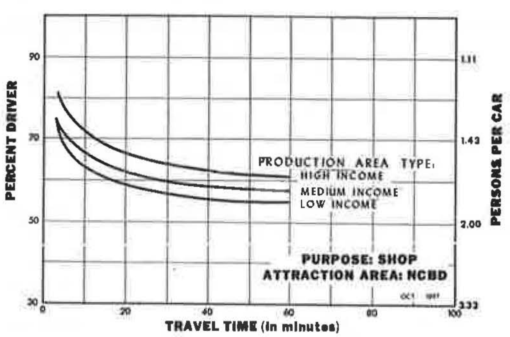

Figure 5. Model diversion curves for automobile driver-passenger split, shop purpose to non-CBD area.

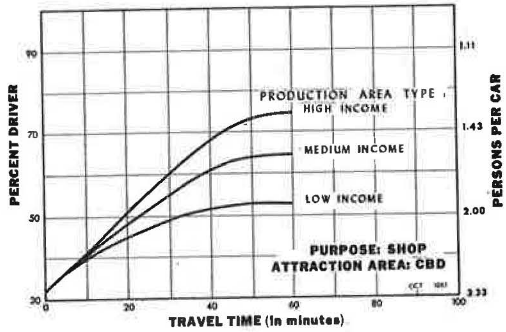

Figure 6. Model diversion curves for automobile driver-passenger split, shop purpose to CBD area.

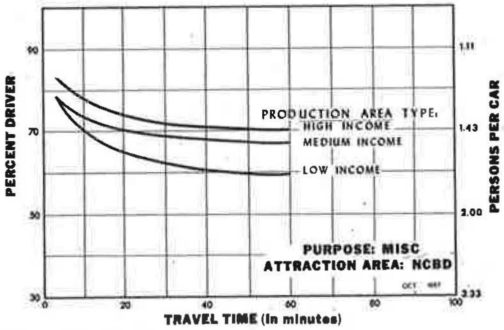

Figure 7. Model diversion curves for automobile driver-passenger split, miscellaneous purpose to non-CBD area.

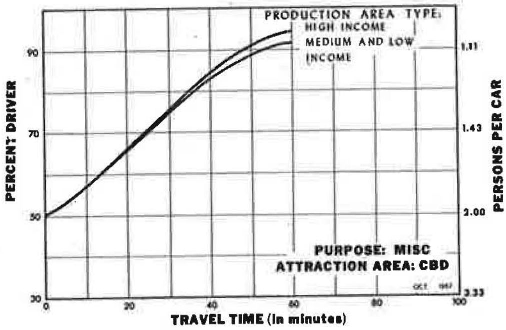

Figure 8. Model diversion curves for automobile driver-passenger split, miscellaneous purpose to CBD area.

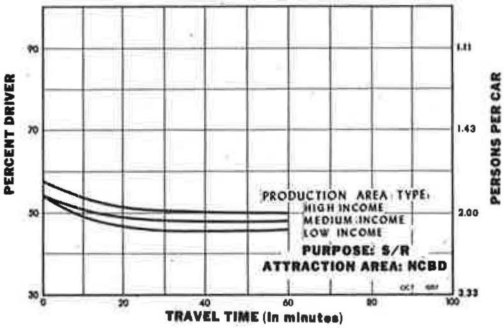

Figure 9. Model diversion curves for automobile driver-passenger split, social-recreation purpose to non-CBD area.

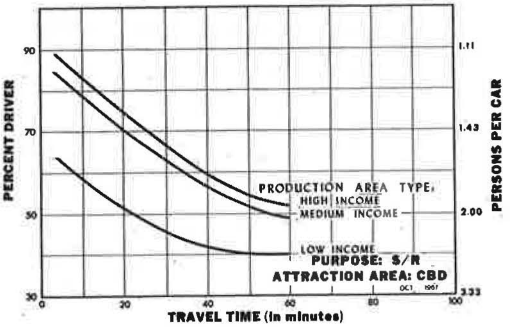

Figure 10. Model diversion curves for automobile driver-passenger split, social-recreation purpose to CBD area.

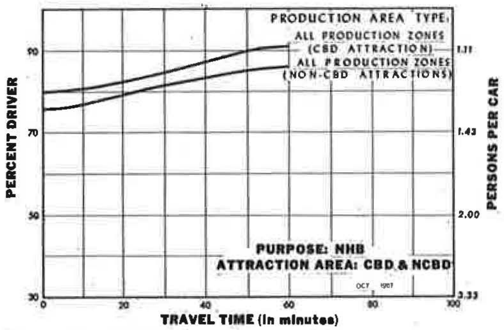

Figure 11. Model diversion curves for automobile driver-passenger split, nonhome-based purpose to non-CBD and CBD area.

Interpretation of Diversion Curves

The curves may be divided into two groups: rising curves for which the driver percentage rises with travel time and falling curves for which the driver percentage falls with travel time. Falling curves seem to be associated with casual trips, i.e., all social-recreational trips as well as shopping and miscellaneous trips with destinations outside the CBD. Rising curves are associated with definite trip purposes, i.e., work and shopping within the CBD. This indicates that longer casual trips are not made unless several persons are involved. Casual passengers, who "go along for the ride," tend to avoid longer trips when the primary trip-maker (the driver) has a definite trip purpose.

TESTS OF TIME MODEL

Total Trips

The prime test of the model was its ability to reproduce base-year trips. For this test, trip tables were prepared of automobile-driver plus automobile-passenger trips for each of the six purposes and for total trips. These tables represented all internal person trips by highway among the 986 internal zones as found in the base-year, origin-destination survey. A modal split was made, and automobile-driver trips predicted by the model were compared to those found in the survey. To facilitate comparison, the tables were compressed to 117 districts, yielding 13,689 possible interchanges, and stratified by volume groups to indicate any improvement in projection of larger volumes. In addition to the usual root-mean-square (rms) statistic, a t-statistic was incorporated into the comparison program to indicate if there were statistically significant differences between the projected interchanges and the actual interchanges. The critical t-value varies with the actual number of interchanges in the volume group being considered. For most volume groups, however, when the absolute value of t is less than 1.97, we have no reason to reject at the 5 percent level the hypothesis that the predicted value is the same as the observed. This comparison is given in Table 1. Figure 12, which shows the percentage of rms error plotted against the volume group, indicates that 68 percent of the projections were within ±10 percent for volumes greater than 600. Estimates of this accuracy are well within the tolerance found in transportation planning models.

TABLE 1

DISTRICT-TO-DISTRICT VOLUMES OBTAINED FROM O-D SURVEY AND ESTIMATED BY MODEL FOR AUTOMOBILE-DRIVER TRIP INTERCHANGES

Volume Groups	O-D Volume		Model Volume		Average Interchange Difference[a]	Standard Deviation	t-Value	Percent rms Error
	Total	Average Interchange	Total	Average Interchange				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0 to 1	0	0.0	2,688	1.0	-0.99	3.17	-16.27	0.00
3 to 3	162	3.0	200	3.7	-0.70	2.17	- 2.39	75.90
4 to 4	772	4.0	963	5.0	-0.99	4.00	- 3.44	102.98
5 to 5	525	5.0	679	6.5	-1.47	4.10	- 3.67	87.02
6 to 6	1,758	6.0	2,037	7.0	-0.95	4.31	- 3.78	73.53
7 to 7	1,372	7.0	1,452	7.4	-0.41	3.75	- 1.53	53.84
8 to 8	864	8.0	1,115	10.3	-2.32	11.32	- 2.13	144.45
9 to 9	2,358	9.0	2,637	10.1	-1.06	5.10	- 3.38	57.94
10 to 10	3,460	10.0	3,595	10.4	-0.39	5.06	- 1.43	50.75
11 to 15	8,959	12.9	9,393	13.5	-0.62	6.32	- 2.61	49.26
16 to 20	12,305	18.2	12,772	18.9	-0.69	7.61	- 2.36	41.96
21 to 25	11,735	22.8	11,853	23.1	-0.23	8.69	- 0.60	38.06
26 to 30	13,196	27.9	13,486	28.5	-0.61	10.49	- 1.27	37.66
31 to 35	13,188	32.9	13,485	33.6	-0.74	11.82	- 1.25	36.02
36 to 40	14,766	37.9	14,835	38.0	-0.18	10.40	- 0.34	27.46
41 to 45	12,736	43.0	12,565	42.4	0.58	11.29	0.88	26.28
46 to 50	13,180	47.9	12,654	46.0	1.91	10.78	2.94	22.85
51 to 60	26,720	55.4	26,205	54.4	1.07	12.51	1.88	22.64
61 to 70	25,870	65.2	25,456	64.1	1.04	13.85	1.50	21.31
71 to 80	25,443	75.3	25,506	75.5	-0.19	15.33	- 0.22	20.37
81 to 90	23,208	85.6	23,221	85.7	-0.05	18.80	- 0.04	21.95
91 to 100	25,470	95.4	25,531	95.6	-0.23	19.45	- 0.19	20.39
101 to 150	107,755	122.6	106,846	121.6	1.03	19.02	1.61	15.54
151 to 200	97,093	174.0	97,302	174.4	-0.37	26.11	- 0.34	15.01
201 to 250	76,978	224.4	76,233	222.3	2.17	28.05	1.43	12.53
251 to 300	85,675	274.6	85,194	273.1	1.54	31.68	0.86	11.55
301 to 350	76,249	323.1	75,876	321.5	1.58	35.36	0.69	10.90
351 to 400	83,781	375.7	82,971	372.1	3.63	34.01	1.59	9.10
401 to 450	68,589	423.4	67,898	419.1	4.27	40.10	1.35	9.52
451 to 500	65,845	473.7	65,405	470.5	3.17	43.03	0.87	9.11
501 to 1,000	385,914	689.1	379,582	677.8	11.31	57.20	4.68	8.46
1,001 to 2,000	367,980	1,378.2	366,463	1,372.5	5.68	95.28	0.97	6.93
2,001 to 3,000	238,222	2,430.8	238,939	2,438.2	-7.32	144.22	- 0.50	5.94
3,001 and over	1,040,442	6,267.7	1,038,548	6,256.3	11.41	346.32	0.42	5.53
Total or average	2,932,570	214.2	2,923,585	213.6	0.66	46.42	1.65	21.67

[a]Column 2 minus column 4.

TABLE 2

AUTOMOBILE-DRIVER TRIPS BY PURPOSE OBTAINED FROM O-D SURVEY AND ESTIMATED BY MODEL

Purpose	O-D Survey	Model Estimations	Model as Percent of O-D
Nonhome-based	609,702	626,076	102.6
Home-based			
Work	805,525	806,875	100.1
Shop	626,118	622,694	99.4
Social-recreation	401,943	402,791	100.2
Miscellaneous	449,710	446,966	99.3
Total, includes school	2,933,034	2,923,985	99.6

Trips by Purpose

In addition to the comparison of the total trip projection, an analysis was made of the estimates for each of the trip purposes to find any bias in the individual curves.

Table 2 gives the total number of automobile-driver trips by purpose as found in the origin-destination survey and as estimated by the model. Figures 13 through 17 show the relationship of the percentage of rms error to volume for each of the purposes. It is felt that the estimates of trips by purpose is adequate, but further analysis is being done on nonhome-based trips to eliminate the overestimate in that category.

As mentioned previously, it was not possible to develop reasonable curves for school trips. For this reason, they were split using a uniform factor in the model test and were included in the total trip comparison. They are not included in the purpose-by-purpose comparison.

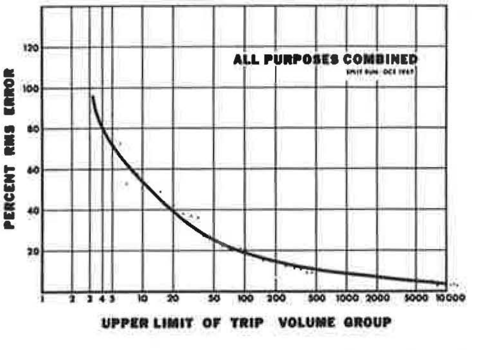

Figure 12. Percentage of rms error for estimated automobile-driver trips, all purposes.

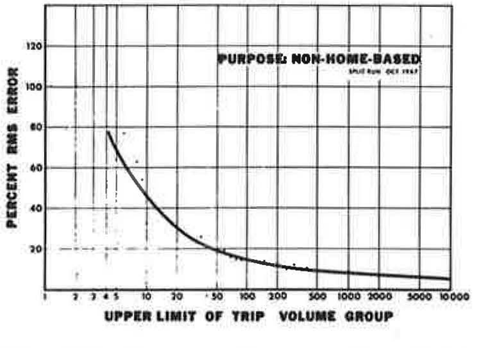

Figure 13. Percentage of rms error for estimated automobile-driver trips, nonhome-based purpose.

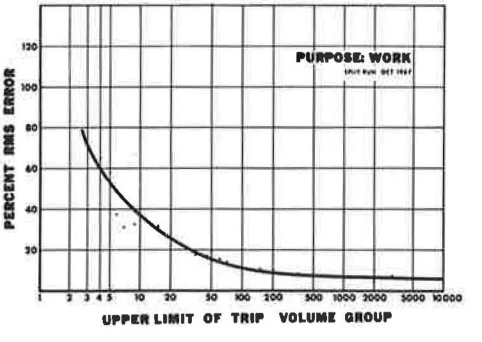

Figure 14. Percentage of rms error for estimated automobile-driver trips, work purpose.

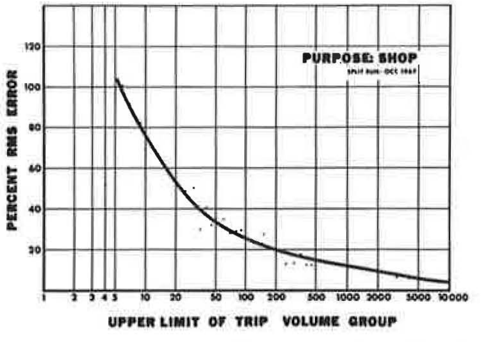

Figure 15. Percentage of rms error for estimated automobile-driver trips, shop purpose.

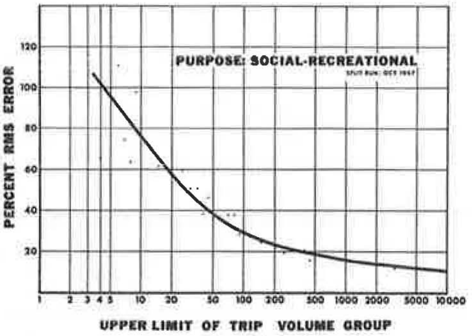

Figure 16. Percentage of rms error for estimated automobile-driver trips, social-recreation purpose.

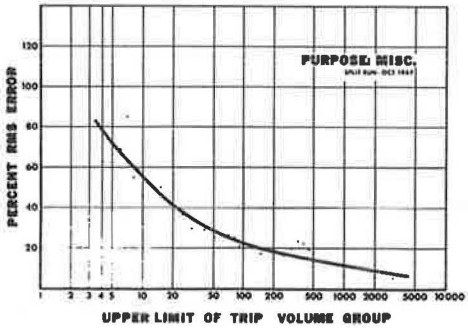

Figure 17. Percentage of rms error for estimated automobile-driver trips, miscellaneous purpose.

Small Areas and CBD

Further investigation was performed to determine if the model was correctly estimating the number of automobile-driver trips to various parts of the region. Table 3 gives the number of productions and attractions of automobile-driver trips by purpose as found in the origin-destination survey and as predicted by the model for a selected

TABLE 3

AUTOMOBILE-DRIVER TRIPS BY PURPOSE OBTAINED FROM O-D SURVEY AND ESTIMATED BY MODEL FOR SMALL AREA

Purpose	Zone[a]	Productions		Attractions	
		O-D Survey	Model Estimations	O-D Survey	Model Estimations
Nonhome-based	All	3,122	3,367	3,113	3,379
	714	277	320	314	365
	715	239	282	250	309
	716	442	459	416	450
	720	696	744	684	670
	721	261	251	260	257
	722	1,207	1,311	1,189	1,328
Home-based					
Work	All	10,233	10,209	5,497	5,271
	714	1,303	1,342	511	457
	715	1,954	1,953	272	273
	716	1,914	1,927	543	562
	720	2,827	2,834	1,062	1,039
	721	1,421	1,371	489	506
	722	814	782	2,620	2,434
Shop	All	1,552	1,163	461	395
	714	190	77	17	28
	715	276	153	16	26
	716	530	385	153	61
	720	337	558	136	158
	721	174	127	64	52
	722	45	63	75	70
Social-recreation	All	1,446	1,323	842	773
	714	229	153	119	111
	715	205	141	55	54
	716	439	426	207	255
	720	344	356	297	215
	721	144	133	106	55
	722	85	114	58	83
Miscellaneous	All	2,145	1,848	1,350	1,361
	714	257	211	98	100
	715	363	310	132	137
	716	431	393	167	156
	720	577	535	339	325
	721	313	250	152	162
	722	184	149	462	481

[a]These zones are in the Hough area.

TABLE 4

AUTOMOBILE-DRIVER TRIPS BY PURPOSE OBTAINED FROM O-D SURVEY AND ESTIMATED BY MODEL FOR CBD

Purpose	Productions			Attractions			Internal		
	O-D Survey	Model Estimations	Model as Percent of O-D	O-D Survey	Model Estimations	Model as Percent of O-D	O-D Survey	Model Estimations	Model as Percent of O-D
Nonhome-based	45,096	44,474	98.5	41,528	41,673	100.1	995	960	96.5
Home-based									
Work	1,408	1,698	120.5	80,942	81,581	100.7	0	30	—
Shop	98	236	241.0	13,954	13,364	95.8	0	4	—
Social-recreation	298	344	115.0	10,738	12,022	112.0	0	0	—
Miscellaneous	482	758	157.0	20,086	20,612	97.5	0	23	—
Total, includes school	47,432	47,529	100.4	169,926	170,165	100.1	1,000	1,018	101.8

area. It is not expected that the model would reproduce the values for individual zones as well as those for the entire region, but the comparison does indicate that it functions well in all areas with little or no systematic bias.

Table 4 gives the estimates for the CBD. For those purposes with significant volumes, the model functions quite well, although there are some larger percentage discrepancies in low-volume cases. The total estimate is again quite satisfactory.

APPLICATION OF THE MODEL

After it was established that the model could indeed reproduce the base-year trip patterns, the next step was the projection of future automobile-driver trip patterns. The trip-generation model produced the total aggregate trip ends that were then allocated to the zones using the direct-trip allocation model (1), converted to productions and attractions by individual purposes using an interface model, and linked to form interchanges using a gravity model. A transit-nontransit modal split was performed using the same model with different parameters, and the nontransit table was used as input into the automobile-driver modal-split model.

Production-area income codes for the design year were established from projections by census tract of median family income. The groupings used for the future year were low (below $9,000), medium ($9,000 to $12,000), and high (over $12,000).

The attraction-area codes were the same as those in the base year, CBD and non-CBD. In order to simplify use of the model, it was necessary to produce dummy curves that assigned 100 percent of the truck-taxi trips to the vehicle-driver trip table.

The results of the projection of automobile-driver trips as represented by the average number of persons per car are given in Table 5. The results indicate that average automobile occupancy is not only dropping but dropping at different rates for the various purposes. The significance of this change can be shown in the following example: If the average occupancy rate had been 1.42 rather than 1.32, the number of automobile-driver trips would have been decreased by an amount nearly equal to the total number of trips projected to use public transit in the design year.

In this application, the transit-split model and the driver-split model were run in series because this offered a logical flow (Fig. 18). The trips are first divided into highway and

TABLE 5

AUTOMOBILE OCCUPANCY BY PURPOSE OBTAINED FROM O-D SURVEY AND ESTIMATED BY MODEL

Purpose	Average No. of Persons per Car	
	O-D Survey	Model Estimations
Nonhome-based	1.18	1.09
Home-based		
Work	1.51	1.38
Shop	2.00	1.68
Social-recreation	1.37	1.27
Miscellaneous	1.30	1.21
Average	1.45	1.32

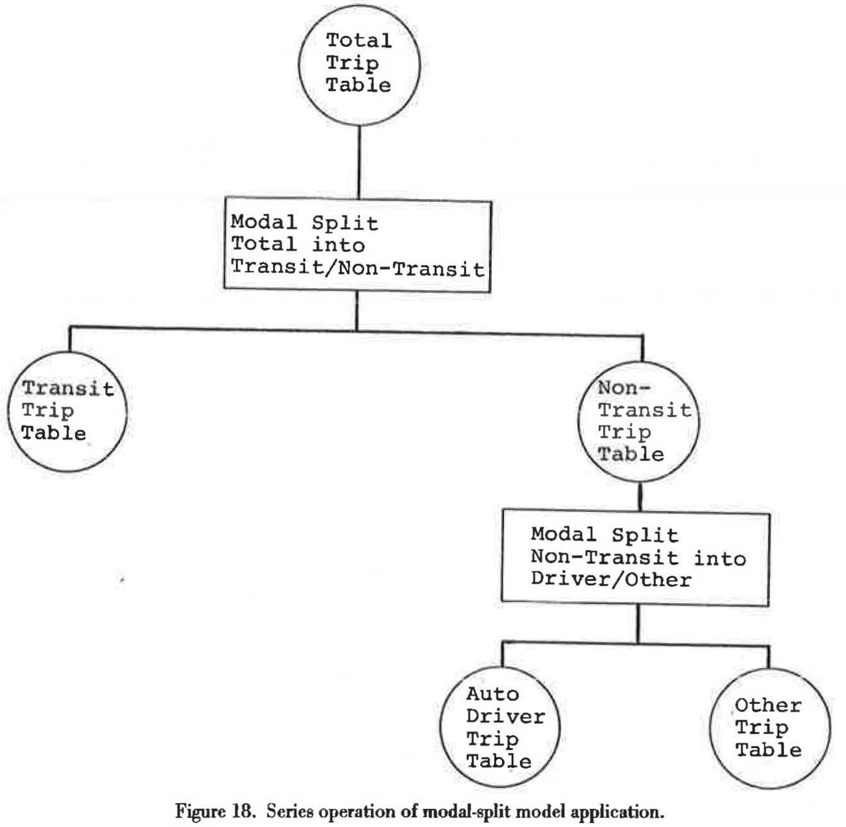

Figure 18. Series operation of modal-split model application.

transit trips. The highway portion is then further divided into automobile-driver trips and all others. This is the same procedure used in the past when an occupancy factor was used. One difficulty in this method is that the final output of the second split (automobile-driver trips) is dependent on the first split. This increases the probability for error in the final output.

There are other equally logical approaches using multimodal-split models that might be explored. One would be to run the models in parallel (Fig. 19). With this procedure, each output would be independent of the other split, and this would probably decrease the error in the final trip tables. It would, however, require the additional normalization because each of the models uses different parameters, and there is no assurance that the total of the three output trip tables will be equal to the original trip table.

Another approach would be a series operation with the trips first being split into automobile-driver trips and others. The other trips would then be split into transit and nontransit trips. This approach might be more desirable because the number of vehicle trips is far more sensitive to the driver split than to the transit split. The logic of this choice pattern would have to be analyzed further.

No tests have been performed to compare these various methods of operation. The obvious test would be to start with a full base-year table and split it in each of the three ways described. The method that produced the least overall error would seem most desirable for use. It also might give insight into the true modal-choice, decision-making process.

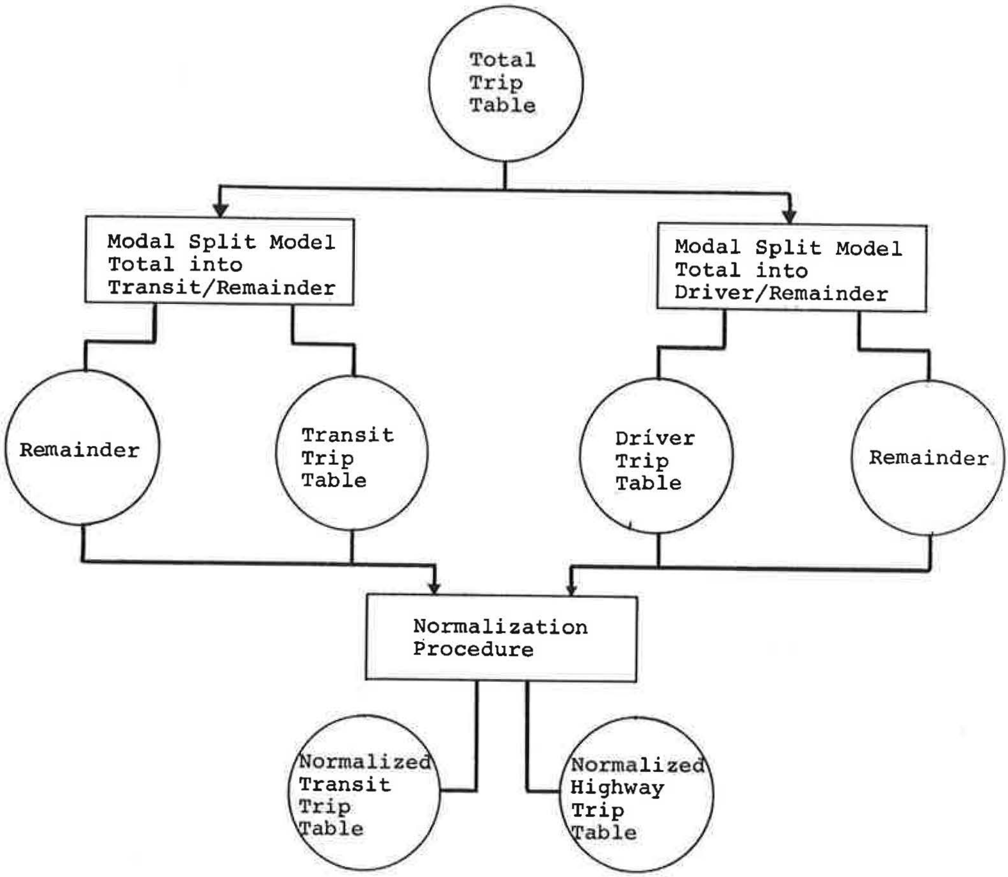

Figure 19. Parallel operation of modal-split model application.

CONCLUSIONS

The following major conclusions may be drawn from this study:

1. A modal-split model is a desirable method for predicting automobile occupancy.
2. It is relatively easy to develop and calibrate diversion curves that will accurately reproduce base-year data.
3. A great deal of effort has been spent on analysis of transit modal split, but there has been relatively little work on automobile-driver modal split. The latter, however, is a far more significant item in estimating future vehicular travel.

The great shift in average automobile occupancy indicates that we can no longer be satisfied with conversion of person trips to vehicle trips by factors held consistent from the base year. A full analysis is needed to determine not only the magnitude of this shift but also the causes. If the causes are known, it may prove possible to design systems that will promote higher occupancy levels, allowing the entire highway networks to serve more efficiently.

REFERENCE

1. Lathrop, G. T., Hamburg, J. R., and Young, G. F. Opportunity-Accessibility Model for Allocating Regional Growth. Highway Research Record 102, 1965, pp. 54-66.