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Intermediate and Final Quality Checks Developing a Traffic Model

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• A TRAFFIC model was recently developed as part of the work being done for the Hamilton Area Transportation Study (HATS). The model was used as a substitute for the home-interview survey commonly associated with a transportation study, and fairly extensive checking procedures were devised to test the model's results and to improve its accuracy. The primary purpose of this paper is to describe the checks made and to discuss the results obtained. The testing procedure applied to individual components of the model, as well as to the final results. This was done to isolate and correct errors or bias at the stage in which they occurred, rather than compensate for any errors by making a blanket adjustment to the end product of the model. The tests were concerned with the following: basic traffic data, land-use planning data, trip production estimates, attraction factor calculations, trip distribution procedures (total person trips estimates), modal split results, and total vehicle trips estimates.

Although it is believed that the testing procedures outlined are of general applicability, it is felt that some of the details are peculiar to the particular type of model tested. Consequently, the initial section of the paper contains a brief description of the components of the Hamilton traffic model. The description of the Hamilton model components has been expanded in Appendix A, which discusses some of the forms of traffic model possible, their advantages and disadvantages, and gives the reasons for the selection of the form used in the Hamilton study. This is not intended to be a definitive evaluation of the different models available.

HAMILTON AREA TRANSPORTATION STUDY

The city of Hamilton is located at the head of Lake Ontario about midway between Toronto, Ont., and Buffalo, N.Y. The present population is 271,000 with approximately an additional 100,000 people living in the immediate vicinity. Hamilton is the steel producing center of Canada, and the attendant manufacturing is extensive, varied, and expanding rapidly. With a large, completely protected harbor on Lake Ontario and the St. Lawrence Seaway, it is also a fast-growing lake and ocean port.

A comprehensive transportation study for the Hamilton area was begun in mid-1961, to be completed in 1963. The study area consists of the 46 sq mi of the city and 466 sq mi of the surrounding area for which Hamilton is the hub. The major objective is to develop a transportation plan incorporating new expressways, major street improvements, mass transit, parking, and terminal facilities of area significance. The study is also to establish the priority of needed improvements and their staging through the design year, 1985.

Inasmuch as it was intended to develop a traffic model for projecting travel patterns, an evaluation was made of the possibility of also using the model to synthesize present patterns and thus reduce the study's cost. After a careful review of available traffic data, it was concluded that a traffic model could be used if a limited home-interview survey were made to supplement the existing information.

MODEL COMPONENTS

The basic components of the Hamilton model and their interrelationships are shown in Figure 1. The gravity principle (1) is utilized in the model to distribute person trips according to five trip purposes: work, shopping, social-recreation, other homebased,

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and non-homebased. A similar procedure is followed to develop a commercial vehicle trips table. The trip production, attraction, and distribution procedures are applied only to internal trips—the external-internal and through trips coming directly as a result of the roadside interviews on the external cordon. The total person trips table is eventually divided by the application of diversion curves into a transit rider O-D table and an auto vehicle O-D table. In the final stage of the model the commercial vehicle trips are converted into equivalent automobile trips and added to the auto-vehicle trips to obtain an equivalent auto-vehicle O-D table suitable for assignment to various street and highway networks.

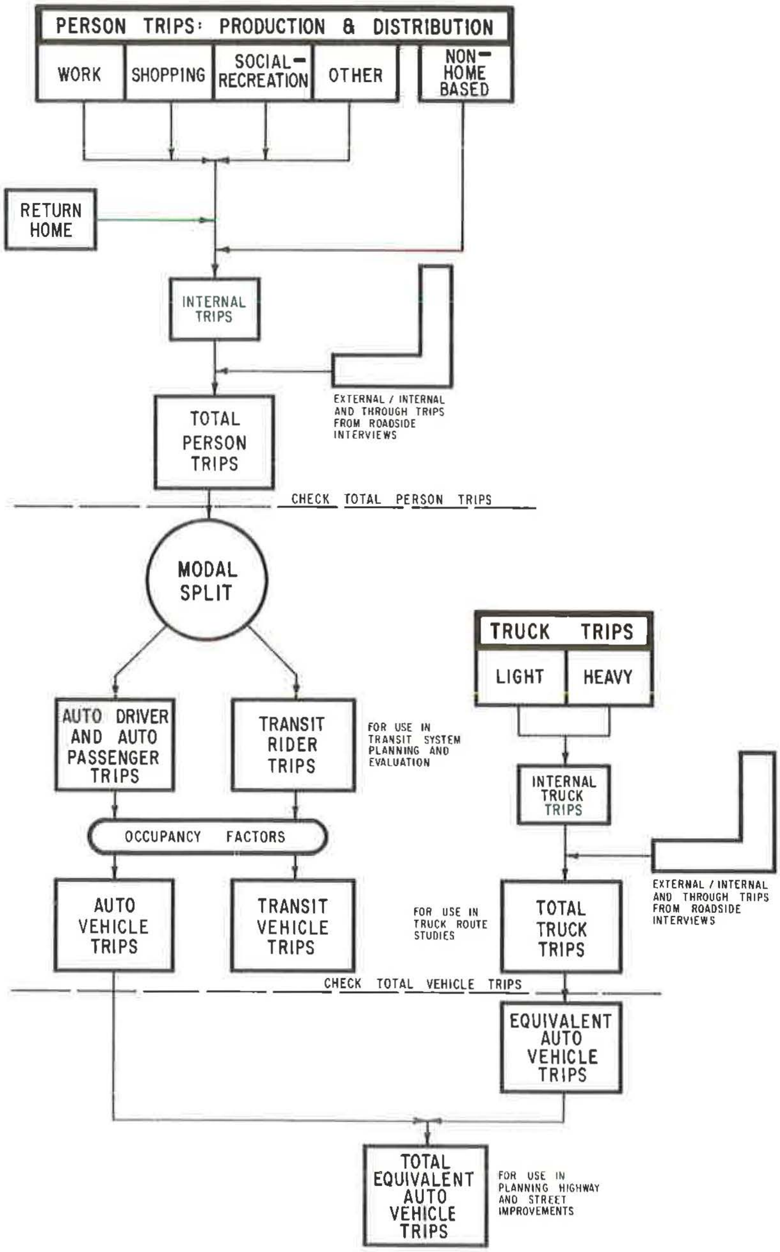


Figure 1. Interrelationships of the Hamilton model components.

BASE DATA

The following information was provided by the participating agencies for each traffic zone and was basic in preparing the input to the model: (a) number of families, (b) population, (c) industrial and manufacturing employment, (d) retail and service employment, (e) other employment, (f) economic level of the resident population, (g) automobile ownership, and (h) predominant land use or uses.

Traffic data were collected to serve a variety of purposes, including model development. These consisted of travel time measurements, volume and turning movement counts, vehicle occupancy, etc. The major field work carried out specifically for the model development consisted of a 10 percent home-interview survey (2) in selected areas of the city only (Fig. 2), the roadside motorist interviews carried out on the external cordon line and internal screenline (Fig. 3), and classification counts made on a cordon around the central business district (CBD) and the base of the "mountain."

The results of the home-interview study were checked in the usual manner and were also compared with findings reported in HRB Bulletin 203 for cities of similar size. This comparison indicated that the sample size used in the Hamilton study was large enough to provide stable, reasonable results and that Hamilton did not have any abnormal travel characteristic. Some of the more important comparisons are given in Tables 1, 2, and 3.

The results of the limited home-interview survey were analyzed to determine the form that the traffic model should take. Considerable guidance in making this determination was obtained from material and techniques developed by Voorhees. Briefly, the details of the model were selected after a review of the trip production relationships, attraction factors, and trip length distributions for each trip purpose, as found from the home-interview data.

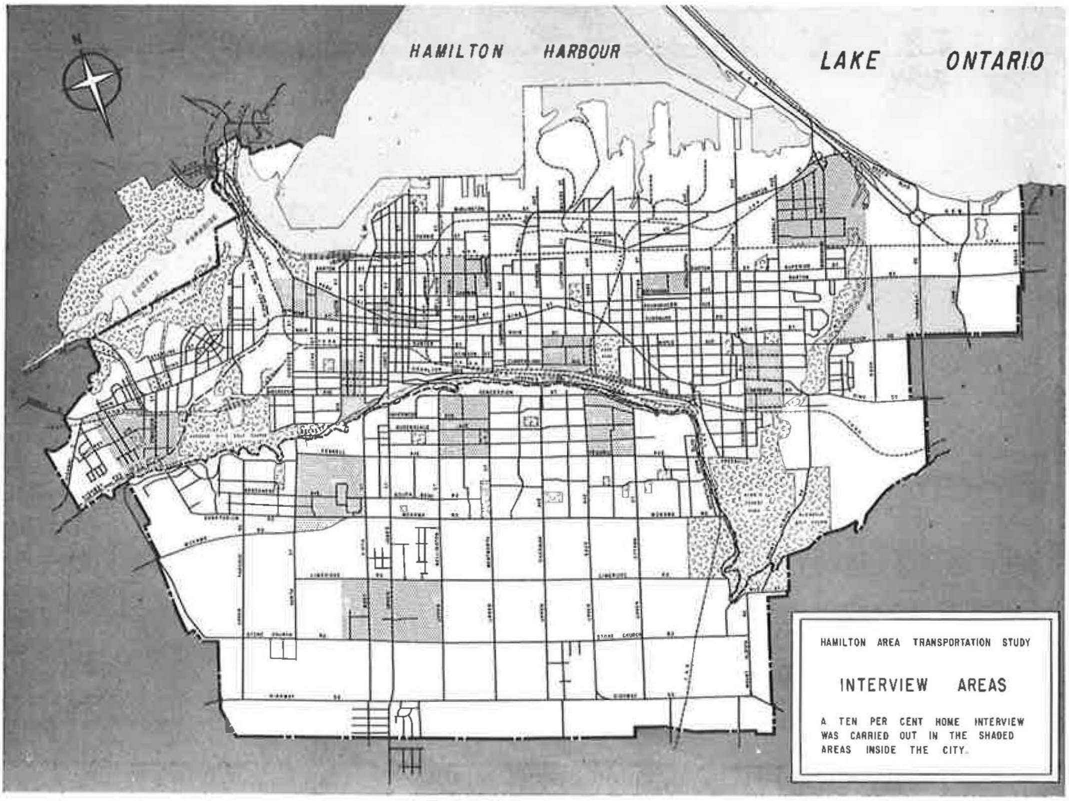


Figure 2.

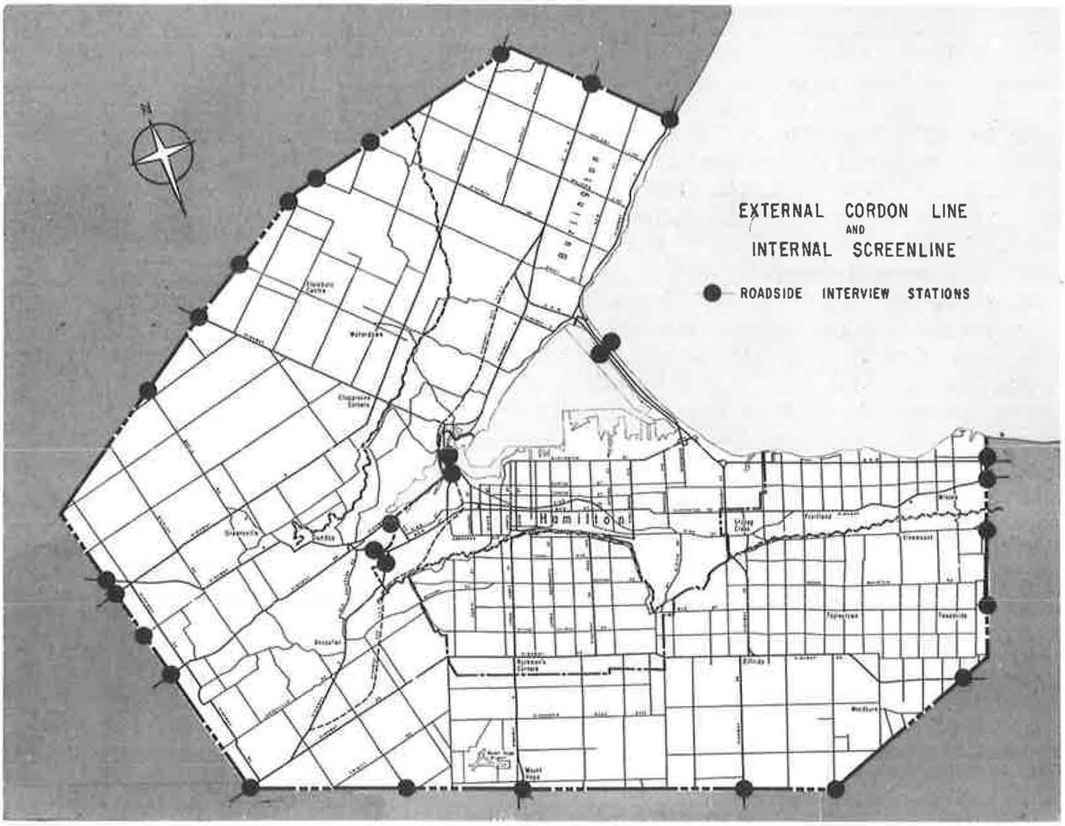


Figure 3.

TABLE 1

TRIP PRODUCTION

Basis	Hamilton	Avg. Other Cities
Trips per dwelling unit	6.40	6.29
Trips per person	2.03	1.94

TABLE 2

PURPOSE OF TRAVEL

Purpose	Hamilton (%)	Avg. Other Cities (%)
Work and business	29.1	28.4
Social and recreation	10.8	13.8
Shopping	9.1	8.0
Miscellaneous	8.4	10.4
Return home	42.6	39.4
Total	100.0	100.0

COMPILING AND CHECKING DATA

Planning data were obtained from existing files insofar as possible. The planning agencies in the city and surrounding area had compiled an impressive amount of planning information, including an existing land-use map and a population study. Also, a commercial firm was able to supply the study with a list of current motor vehicle registrations sorted by street address, which it had compiled as a mailing list.

Unfortunately, although data on the size of the labor force and occupation breakdowns were available from census records, no information was available on the distribution

TABLE 3

MODE OF TRAVEL

Mode	Avg. Other Cities (%)	Hamilton Interview (%)	Hamilton Mtn. Cordon (%)	Hamilton CBD Cordon (%)
Auto driver	50.1	53.3	58.1	54.0
Auto passenger	28.4	29.4	25.6	23.6
Transit rider	21.5	17.3	16.3	22.4
Total	100.0	100.0	100.0	100.0

of employment opportunities. Various other potential sources were unable to furnish data on employment distributions. Because the traffic model requires an estimate of employment opportunities in several categories for each zone, the only course open was to interview employers to obtain an estimate of the size of their staff. This work was performed by the city planning department with a crew of 12 interviewers in 4 weeks. The coding of these interviews required an additional 12 man-weeks. A coding manual was prepared which defined 5 major employment classifications and subclassifications. The manual contained 88 broad examples and more than 1,300 specific examples of classification. This was required to insure common agreement as to the demarcation between the various employment and land-use categories. This manual was essential since different staffs coded the land use obtained from the home-interview study and the type of employment obtained from the employer survey.

The magnitude of the field work and clerical effort required to collect and code the employment data made it most important to check the final results for general reasonableness before using them in the preparation of input to the model. The first check made involved compiling a list of the major industries, department stores, hospitals, etc., from the city directory and industrial commission's records. The field sheets turned in by the employment survey crew were then checked against the list of major employers to make sure that all employers listed had been interviewed.

The next check made was a zone-by-zone comparison of the tabulated employment and population figures with the existing land-use maps. This check served to uncover any inconsistencies such as a large amount of industrial employment listed in a predominantly residential area. This work was done by persons familiar with the city who could interpret the detailed land-use maps through personal experience with the areas involved. Aerial photographs were also used to determine size and density of development. They helped to evaluate the magnitude of the number of employees and population tabulated by comparing values listed for similar zones.

The rate of automobile ownership in each zone was based on registration lists. These lists, however, were incomplete for the suburban areas; they also included company fleets and did not list station wagons. Extensive reworking was required, therefore, to put the data by zones in usable form. It was found necessary to adjust many of the ownership rates. This adjustment was based on data from the home interviews, economic level, availability of public transportation, distance from the CBD, and the opinions of the planners. The total number of automobiles in the study area yielded by the adjusted ownership rates agreed with the total figure supplied by the Ontario Department of Transport.

The last check made consisted of plotting the employment opportunities population, and automobile ownership on large-scale zone maps. These maps were then reviewed with the planning agencies to see if transitions between high, low, and medium employment; population; and automobile ownership areas were reasonable and internally consistent. Wherever possible, subtotals and totals were cross-checked against other sources. Thus, for example, estimated zone populations were compiled into wards and each ward total compared with ward totals obtained from records in the city assessment bureau.

It was concluded after the checks and necessary adjustments had been made that the planning data available for model development were of satisfactory accuracy and free from statistical bias.

TRIP PRODUCTION EQUATIONS

The trip production equations were derived from the home-interview data using the Department of Highway's linear regression analysis computer program. Each of five different forms of equations (straight line, quadratic, logarithmic, exponential, and power series to 9 terms) was each fitted to 37 different combinations of dependent and independent variables. Eqs. 1 to 6 were selected to compute the internal trip production per family in each traffic zone. It was necessary to reduce the trip production in several of the zones at the boundary of the study area by 10 percent because of an overlap with external to internal trips recorded from the roadside interviews. For all other zones, the results were used as computed.

$$\text{Work trips} = +0.429 + 0.219\,(\text{persons/family}) \tag{1}$$

Coefficient of correlation = 0.829
Standard deviation = ± 0.084

$$\text{Shopping trips} = -0.598 + 1.323\,(\text{autos/family}) \tag{2}$$

Coefficient of correlation = 0.890
Standard deviation = ± 0.119

$$\text{Social-recreation trips} = -0.117 + 0.896\,(\text{autos/family}) \tag{3}$$

Coefficient of correlation = 0.693
Standard deviation = ± 0.163

$$\text{None-work home-origin trips} = -0.882 + 2.718\,(\text{autos/family}) \tag{4}$$

Coefficient of correlation = 0.931
Standard deviation = ± 0.187

$$\text{Non-home-based trips} = -1.042 + 2.218\,(\text{autos/family}) \tag{5}$$

Coefficient of correlation = 0.815
Standard deviation = ± 0.276

$$\text{Total trips} = -1.51 + 8.91\,(\text{autos/family}) \tag{6}$$

Coefficient of correlation = 0.958
Standard deviation = ± 0.467

Eqs. 1 to 6 were tested by comparing the results they gave with the results found in the home-interview survey (Table 4).

The work trip production found by using Eq. 1 was checked by computing the labor force in residence in any zone and applying a reduction factor of 0.95 (determined from the home-interview data) to account for that portion of the labor force which does not go to work on a given day. The two estimates of work trips production were found to be in close agreement.

A further check was made on the actual trip production values computed for each zone by calculating the trip production separately for each trip purpose and then independently for total trips. A check was made to see that the sum of all individual trip purposes was within 5 percent of the independently computed total trip production.

ATTRACTION FACTORS

The attraction factors were developed from an analysis of the type of land use reported at the destination of trips recorded in the home interviews. A separate analysis

TABLE 4

COMPARISON OF PREDICTED AND OBSERVED TRIP PRODUCTION IN HOME-INTERVIEW ZONES

Interview Area	Work Trips		Non-Work Trips	
	Predicted	Observed	Predicted	Observed
1	28	28	14	19
2	74	80	66	60
3	145	146	145	126
4	117	117	132	110
5	56	54	78	71
6	114	116	149	135
7	96	89	126	154
8	103	95	126	145
9	157	156	216	221
10	110	106	170	180
11	130	151	201	186
12	122	127	202	194
Total	1,252	1,265	1,625	1,601

was made for each of the various trip purposes being considered in the model. The attraction factor selected for work trips was taken as total employment. Figure 4 shows the close agreement between the distribution of type of land use reported at the destination of work trips with the distribution of the type of employment as obtained from the employment survey. The number of retail employees was selected as the attraction factor for shopping trips. The attraction factors for the remaining trip purposes are shown in Figure 5.

FREQUENCY FACTORS

Frequency factors were determined separately for each trip purpose used in the model. This required finding the actual distribution of trip lengths in 1-min intervals using the zone-to-zone transfers recorded in the home-interview survey and travel time obtained from the minimum path program. Next a distribution of these same trips was found by setting the frequency factors all equal to unity and allowing the traffic model to determine the zone-to-zone distribution and consequently a new distribution of trip lengths. Setting the frequency factors equal to unity in effect gives no weight to the time element in determining the distribution of trips from each zone. The frequency factor for each 5-min interval was then computed as the ratio of the actual distribution to the time independent distribution. A smooth curve was then fitted to these points and the 1-min factors selected from the curve. The goodness of fit of the frequency factor curve was then tested by comparing each actual trip length distribution with the predicted distribution. The results of this test are given in Table 5. The frequency factors themselves are given in Appendix B.

TOTAL PERSON TRIPS

The total person trips O-D table was obtained by combining the internal trips from the model made for the various purposes considered and then adding in the external-internal and through trips from the roadside interviews. This procedure was shown in Figure 1, and the results are given in Table 6.

Since one of the objectives of the transportation study is to evaluate different modes of travel, it was essential that the estimates of total person trips movements produced by the model be reliable. The total person trips table was tested, therefore, in three

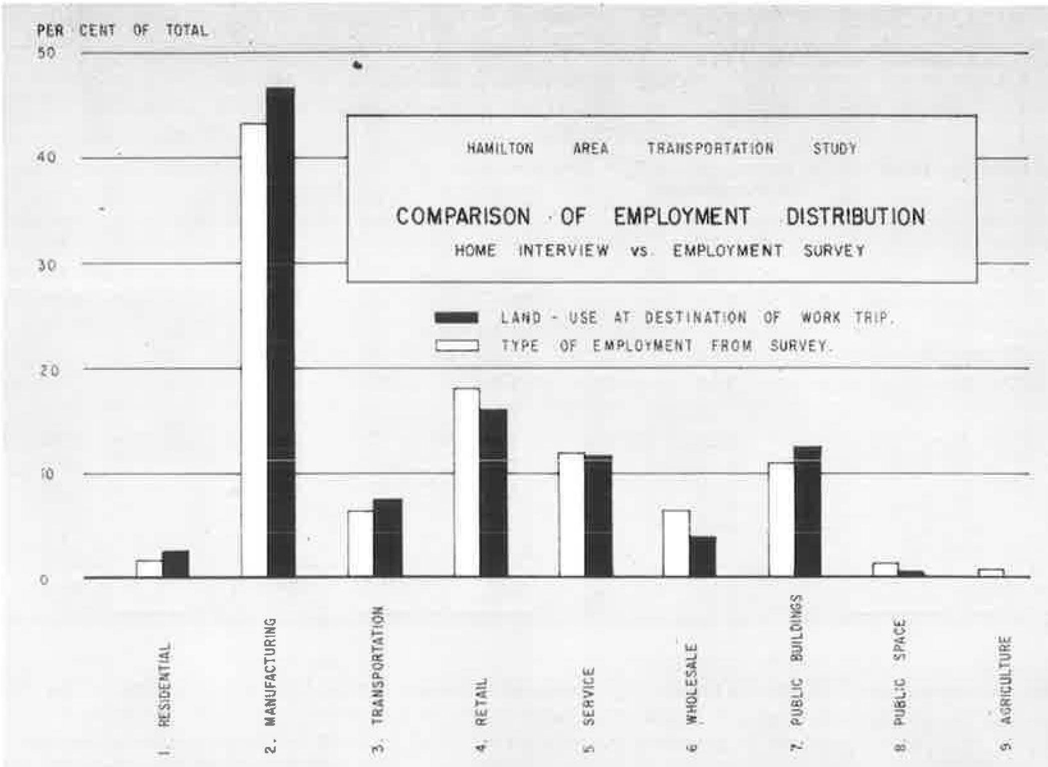
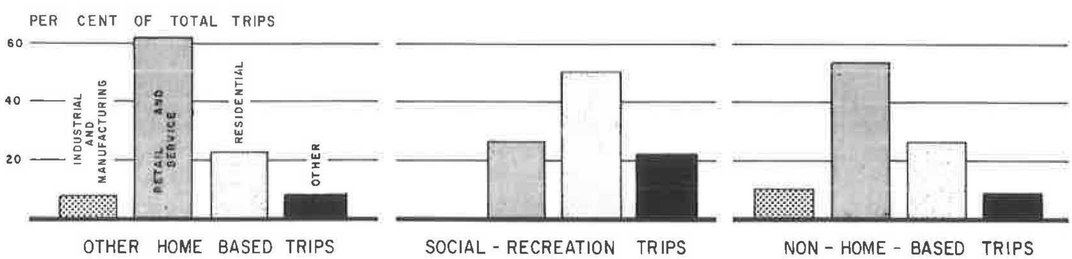


Figure 4.

TOTAL EMPLOYMENT WAS USED AS THE ATTRACTOR FOR WORK TRIPS AND RETAIL EMPLOYMENT WAS USED AS THE ATTRACTOR FOR SHOPPING TRIPS.

THE LAND USE AT DESTINATION OF OTHER KINDS OF TRIPS, AS REPORTED IN THE HOME INTERVIEW SURVEY, WAS:



THE BEST MEASURE OF RESIDENTIAL LAND USE WAS TAKEN AS POPULATION AND THE CORRESPONDING EMPLOYMENT WAS SELECTED AS THE TYPES OF LAND USE. SINCE POPULATION AND EMPLOYMENT ARE NOT DIRECTLY COMPARABLE, A MEANS HAD TO BE FOUND FOR GIVING THEM EQUAL WEIGHT. STANDARD PRACTICE HAS BEEN TO USE THE RELATIONSHIP BETWEEN AREA-WIDE TOTALS, THUS:

INDUSTRIAL AND MANUFACTURING EMPLOYMENT:	372,000 ÷ 65,900 = 5·6	} EQUIVILANCY FACTOR
RETAIL AND SERVICE EMPLOYMENT:	372,000 ÷ 52,600 = 7·1	
"OTHER" EMPLOYMENT:	372,000 ÷ 7,000 = 52·6	

THE ATTRACTION FACTOR FOR OTHER-HOME-BASED TRIPS, THEN = 0·083 (5·6)(INDUSTRIAL AND MANUFACTURING EMPLOYMENT) + 0·607 (7·1)(RETAIL AND SERVICE EMPLOYMENT) + 0·228 (1·0) (POPULATION) + 0·082 (52·6) (OTHER EMPLOYMENT).

THE ATTRACTION FACTOR FOR SOCIAL-RECREATION TRIPS = 0·269 (7·1)(RETAIL AND SERVICE EMPLOYMENT) + 0·511 (1·0) (POPULATION) + 0·216 (52·6) (OTHER EMPLOYMENT)

THE ATTRACTION FACTOR FOR NON-HOME-BASED TRIPS = 0·108 (5·6) (INDUSTRIAL AND MANUFACTURING EMPLOYMENT) + 0·54 (7·1) (RETAIL AND SERVICE EMPLOYMENT) + 0·266 (1·0) (POPULATION) + 0·86 (52·6) (OTHER EMPLOYMENT).

Figure 5. Derivation of person trip attraction factors.

TABLE 5

RESULTS OF GOODNESS-OF-FIT TEST

Time Interval (min.)	Work		Shopping		Soc.-Rec.		OHB		NHB	
	% Model	% Actual	% Model	% Actual	% Model	% Actual	% Model	% Actual	% Model	% Actual
0-5	12.3	13.7	29.7	34.3	15.2	16.6	22.3	25.9	20.5	23.9
5-10	27.5	27.6	29.5	27.9	32.4	32.4	33.2	32.9	35.6	34.5
10-15	36.9	36.2	27.2	26.1	32.2	32.2	32.2	28.8	27.8	24.7
15-20	16.9	16.9	11.3	10.3	12.3	12.5	9.3	10.0	11.2	10.9
20-25	4.9	4.7	2.3	1.4	5.7	3.6	2.2	1.8	4.2	5.3
25-30	1.4	0.8	0.0	0.0	1.7	1.6	0.8	0.6	0.7	0.7
30-35	0.1	0.1	0.0	0.0	0.5	1.1	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ways: the trips were assigned to the highway and streets network and a comparison of predicted and observed screenline crossings was made; the distribution of trip lengths as predicted by the model was compared to the distribution as obtained by the home interviews; and the zone-to-zone travel patterns predicted using the model were compared with actually observed zone-to-zone patterns wherever available.

Screenline Checks

The location of the seven screenlines used to check the total person trips movements are shown in Figure 6. Five (Nos. 1, 3, 4, 5, and 7) followed the natural and man-made barriers that divide the city and thus were ideal for comparison purposes. The other screenlines were established in less desirable locations but were needed to appraise the model more completely. The results of the initial and final assignments of 1961 volumes are given in Table 7.

The volumes on four screenlines were found to be substantially in error on the first assignment. The pattern checks indicated that those errors were due to overestimates of the movements between Hamilton and satellite communities. Consequently, the travel times between the city and the adjacent areas were increased to bring the estimated values into closer agreement with the observed movements. No changes were made in either the trip attraction factors or frequency factors. All of the predicted screenline crossings on the final assignment were within 10 percent of the observed volumes.

TABLE 6

TOTAL PERSON TRIPS

Type	Daily Trips
Internal:	
Work	122,100
Shopping	63,500
Social-recreation	68,900
Other homebased	31,000
Non-homebased	100,300
Return home	285,500
Subtotal	671,300
External-internal	86,400
Through	22,000
Total	779,700

Trip Length Distribution Check

The comparison of the predicted and observed trip length distribution is given in Table 8. This comparison indicates that the model is reproducing the existing trip length distributions reasonably well.

Pattern Checks

It was felt that comparison of the O-D patterns predicted by the model with the patterns obtained from other sources was

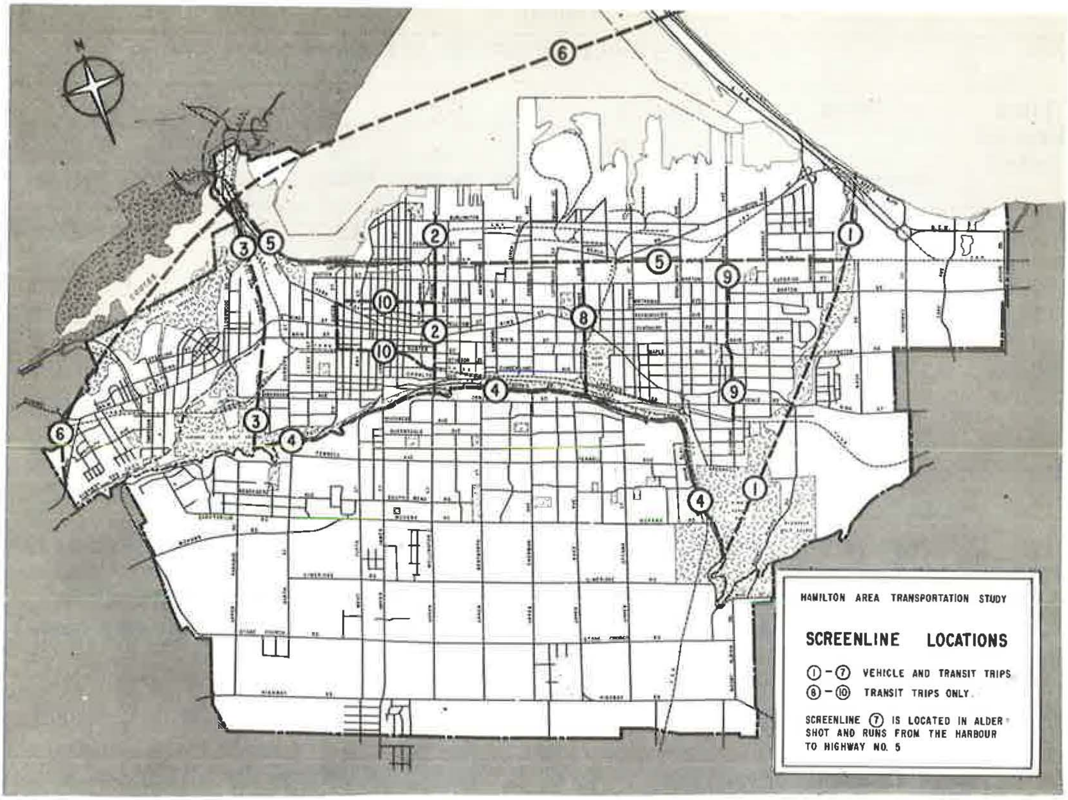


Figure 6.

TABLE 7

SCREENLINE CROSSINGS, TOTAL DAILY PERSON TRIPS

Screenline No.	Initial Est.	Final Est.	Observed
1	92,160	88,556	88,700
2	193,278	171,411	183,900
3	76,671	73,200	70,700
4	150,402	127,918	123,500
5	141,007	127,505	136,000
6	165,531	128,058	136,500
7	132,161	101,779	101,600

a rigorous test of the model. This comparison furnished one of the best guides in determining what changes should be made in calibrating the model. Three basic pattern checks were possible.

1. Comparison of work trip destinations with employment opportunities. It was thought that the model should produce reasonable agreement between the total work trips destined to a zone and the total employment opportunities in that zone.

2. Comparison of the movements crossing screenline 6 (Fig. 6). The observed movements were based on 16-24 hour roadside interviews made in 1961.

TABLE 8

TRIP LENGTH DISTRIBUTIONS, TOTAL PERSON TRIPS

Trip Length (min)	Actual (%)	Model (%)
1-4	16.7	14.0
4-7	15.8	13.2
7-10	18.0	19.6
10-13	22.4	21.7
13-16	13.5	15.6
16-19	7.1	8.0
19-22	3.6	4.6
22-25	1.8	2.2
Over 25	1.3	1.1
Total	100.0	100.0

3. Comparison of the movements crossing screenline 4 (Fig. 6). The observed movements on this screenline were taken from 16-24 hour roadside interviews made in 1956. It was felt that while there were changes in magnitude from 1956 to 1961, the pattern of movement should not have changed substantially.

Comparisons were also made between the movements observed in the home interviews and those predicted by the model. These were useful for appraising the results of the model, but the small sample size in the home interviews precluded any extensive use of comparisons.

In making the pattern checks, χ^2 values were used to determine whether better agreement was being obtained with each run of the model.

$$\chi^2 = \frac{(fa - fe)^2}{fe} \qquad (7)$$

in which fa = the actual results, and fe = the expected result. The main advantage in using χ^2 as an index is that both the size of the difference and the percentage difference are considered. For example, a large difference between large numbers would yield a smaller χ^2 than the same difference between smaller numbers. Similarly, a large percentage occurring with small numbers would not be considered as serious as the same percentage difference between large numbers. The χ^2 values obtained from the first, second, and third runs of the model for each of the four basic pattern comparisons are given in Table 9. A reduction in the χ^2 value indicates an improvement in the model.

There is little change in the χ^2 value for screenline 4 because it did not require adjustment. The results of the pattern checks themselves are given in Tables 10, 11 and 12.

The comparison of patterns indicated that most major movements were in good agreement and that the results were sufficiently accurate for planning purposes. It was found in adjusting the model that a point was reached where changes in travel time introduced to correct one condition had an adverse effect on other areas. At that point, it would have been possible to introduce weights to modify all zone-to-zone movements which still differed from observed movements (3). This general approach was not followed for the Hamilton model because the remaining differences were not pronounced enough to indicate an adjustment was required for socio-economic factors not included in the model.

In addition to the more formal testing, the study staff attempted to use whatever "scraps" of information that were available. For example, a survey carried out in conjunction with the development of an official plan for a satellite community indicated

TABLE 9

χ^2 VALUES, PATTERN COMPARISONS

Comparison	1st Run	2nd Run	3rd Run
Work trips vs employment	39	35	17
Screenline 6 (1961)	50	47	41
Screenline 4 (1956)	20	19	20

that 63 percent of the labor force worked in Hamilton; the model predicted 69 percent. These small pieces of information did not themselves shape the model, but were used to interpret the findings of the more comprehensive tests.

TRANSIT RIDER TRIPS

The transit rider O-D table was obtained by splitting the total person trips through the use of diversion curves. This required the preparation of a transit link-node system and the use of the minimum path program to compute every interzonal travel time via the transit system. The diversion curve program then computed the ratio between the time via the transit system and the time via automobile for each zone-to-zone movement and divided the interzonal volume accordingly. The diversion curves (Figs. 7 and 8) used in the Hamilton study were based on research conducted in the San Francisco Bay Area (4) and were adopted after analysis of the home interviews and other data obtained from the transit company.

The major checks on the number of transit riders estimated by use of the model

TABLE 10

COMPARISON OF WORK TRIP DESTINATIONS WITH EMPLOYMENT OPPORTUNITIES

O-D District	Total Employ. in District	No. of Work Trips Attracted
1	13,704	12,856
2	6,801	6,383
3	3,589	3,668
4	8,608	9,523
5	5,706	6,014
6	13,338	12,990
7	7,374	8,506
8	602	789
9	26,979	24,871
10	6,760	6,630
11	1,884	2,008
12	6,741	6,840
13	1,137	1,246
14	1,516	1,580
15	2,489	2,808
16	1,241	1,511
17	800	827
18	400	403
19	2,454	2,020
20	246	179
21	246	189
22	3,093	2,419
23	702	521
24	189	131
25	585	334
26	1,699	1,642
27	1,063	748
28	3,000	2,421
29	1,773	1,491
30	504	378
31	242	154
Total	125,465	122,080

TABLE 11

COMPARISON OF ACTUAL AND PREDICTED MOVEMENTS ACROSS SCREENLINE 6

Origin	Destination				
	Dundas	Aldershot	Central Burlington	North Burlington	Total
CBD and vicinity	3,141 2,978	2,813 3,071	2,729 2,393	2,084 2,839	10,767 11,281
West Hamilton	2,090 1,847	831 788	602 887	538 875	4,061 4,397
Industrial area	844 1,038	1,361 1,123	2,611 2,936	1,441 2,069	6,357 7,166
Central Hamilton	1,120 1,113	1,171 1,094	1,524 1,028	985 997	4,800 4,232
East Hamilton	523 680	1,022 859	1,561 2,108	1,033 1,261	4,139 4,908
Mountain	898 1,005	652 688	789 371	507 447	2,846 2,511
Total	8,616 8,661	7,850 7,623	9,916 9,723	6,588 8,488	32,970 34,495

Note: The upper figure in each cell was obtained from the roadside interviews on Screenline 6; the lower figure is the number of trips predicted by the model.

TABLE 12

COMPARISON OF PERCENTAGE DISTRIBUTION OF DESTINATIONS OF TRIPS CROSSING SCREENLINE 4

Destination District	1961 Model (%)	1956 Interviews (%)
1	15.5	15.4
2, 3, 4	24.5	24.2
5	9.1	10.5
6	11.6	14.0
7	12.7	10.9
8	4.6	3.1
9	10.4	10.8
10, 11	4.9	5.2
12	6.7	5.9
Total	100.0	100.0

consisted of screenline volume comparisons, a more refined comparison of travel corridors on each screenline, a comparison of volume profiles along the entire length of major corridors, and miscellaneous comparisons, such as comparisons of total passenger miles of travel, average trip length on the entire system, overall percentages of transit trips throughout the city and to the CBD, and the grand total number of all transit trips as obtained from transit company records.

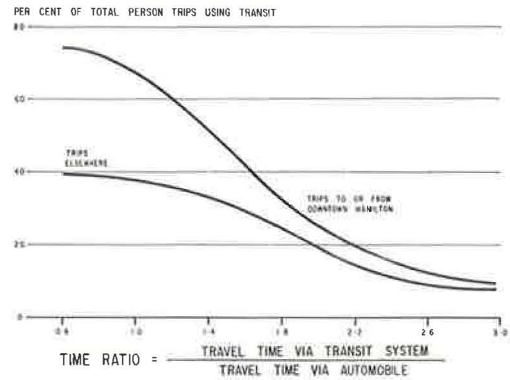


Figure 7. Transit usage inside the city.

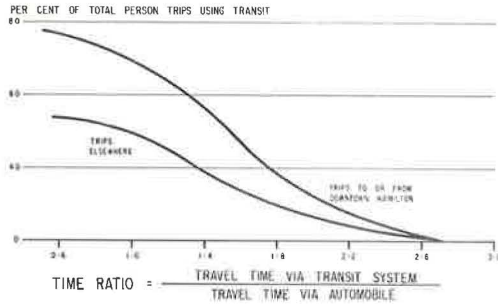


Figure 8. Transit usage suburban area.

Screenline Comparisons

In addition to the 7 screenlines in Figure 6, 3 more were added to provide a check on the internal flow on the transit system. The actual volumes of transit riders (Table 13) were determined by use of a flow map showing 1961 annual average weekday (AAWD) passengers on each transit line within the city and from screenline occupancy counts at approaches to the city and outside the city. The accuracy of these screenline volumes is on the order of 10 to 15 percent.

From the home interviews, it has been determined that transit person trips make up about 17 percent of all person trips within the city. With a maximum discrepancy of 14.1 percent on screenline 8, the modal split of total person trips across this screenline is then within $14.1 \times 0.17 = 2.4$ percent.

The screenline comparisons were carried one step farther to see if the volumes through each of the major corridors crossing the screenline were also in substantial agreement (Table 14).

A review of the assigned and actual corridor volumes indicates that in general, corridors having large actual volumes also have large assigned volumes which agree reasonably well and that the results are adequate for planning purposes.

Corridor Volume Profiles

The comparison of predicted and observed transit passenger trips to the CBD (Fig. 9) indicates that the model is reliably reproducing the flow of transit passenger trips along the entire length of the corridors. The comparison is complicated somewhat by buses along different routes, and at times even buses serving different corridors, using the same street sections for portions of their route.

TABLE 13

SCREENLINE COMPARISONS, TRANSIT RIDER TRIPS

Screenline	Actual Vol.	Assigned Vol.
1	3,792	3,287
2	36,838	34,501
3	9,609	10,432
4	17,442	17,136
5	11,416	12,805
6	6,668	6,158
7	1,530	1,587
8	22,401	19,230
9	8,310	7,424
10	73,399	73,309

Miscellaneous Comparisons

1. A check on the modal split of all person trips produced within the city limits by diversion curves shows transit person trips to be 17 percent of all person trips vs 17.5 percent observed in the home interviews.

2. From the modal split procedure, 36.2 percent of all 1961 person trips originating in or destined to the CBD core travel by transit vs 40 percent estimated from a review of a 1956 CBD core cordon

TABLE 14

ASSIGNED VS ACTUAL CORRIDOR VOLUMES

Screenline	Corridor	Actual Vol.	Assigned Vol.
1	1	1,420	928
	2	2,372	2,369
2	1	16,470	14,042
	2	16,693	14,910
	3	3,675	5,549
3	1	9,009	9,859
	2	600	573
4	1	1,505	1,406
	2	14,360	12,908
	3	1,577	2,822
5	1	5,045	6,707
	2	622	675
	3	4,819	4,739
	4	930	684
6	1	1,930	2,287
	2	2,100	1,740
	3	2,132	1,509
	4	506	622
7	1	1,530	1,587
8	1	11,645	10,413
	2	10,756	8,817
9	1	3,490	3,800
	2	4,820	3,624
10	1	16,570	14,070
	2	21,273	21,216
	3	14,400	17,556
	4	20,656	20,507

survey. This is consistent with the continuing decline in transit patronage since 1956.

3. From the modal split procedure, transit person trips destined to the CBD core as a percentage of all transit trips produced within city limits is 18.5 percent vs 17.8 percent obtained from home interviews.

4. From the modal split procedure, the total number of transit person trips produced within city limits is 84,800 vs 81,000 from transit company records.

5. From diversion curve modal split and minimum path assignment, the average length of a transit passenger trip is 2.66 mi vs 2.65 mi from transit company files.

TOTAL VEHICLE TRIPS

The auto vehicle trips table was developed after the transit trips had been removed from the total person trips tables. This was accomplished by applying auto occupancy factors which varied from 1.58 to 2.07 persons per vehicle at the external cordon stations for external-internal and through trips, and an average factor of 1.44 persons per vehicle for trips within the study area.

Truck trips were developed in a manner similar to person trips. The production "equations" and attraction factors were derived from the results of a limited interview

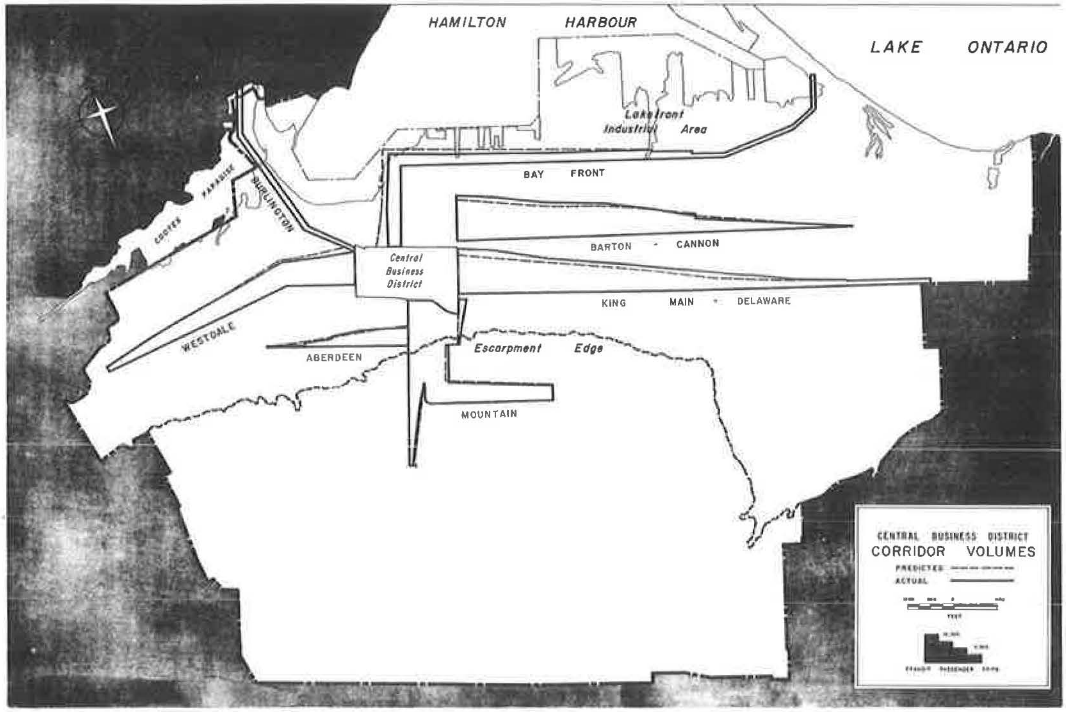


Figure 9.

with truck owners in the study area. Analysis of these interviews indicated that trucks should be segregated on the basis of weight, since trip production and attraction characteristics were different for vehicles with gross weight less then 10,000 lb and for vehicles weighing more than 10,000 lb. After some trial and error, good results were found using a production value of 11.0 trips per truck per day for light trucks and 7.1 trips per truck per day for heavy trucks. The production factor for light truck trips was found to equal 1.851×10^{-4} (industrial and manufacturing employment) + 10.627×10^{-4} (retail and service employment) + 10.428×10^{-4} ("other" employment) + 0.661×10^{-4} (population). The production factor for heavy trucks was equal to 8.437×10^{-4} (industrial and manufacturing employment) + 5.399×10^{-4} (retail and service employment) + 21×10^{-4} ("other" employment) + 0.035×10^{-4} (population). The frequency factors for light trucks ranged from 12.00 at 1 min to 1.15 at 7 min and 0.1 at 26 min. The factors for heavy trucks ranged from 3.2 at 1 min to 1.05 at 12 min and 0.1 at 23 min.

After the first truck assignment and screenline check, the truck tables were added to the automobile table to form a total vehicle table. Subsequent tests were made using the combined vehicle tables.

Some difficulty was encountered in trying to estimate occupancies and truck volume on the screenlines. This difficulty was caused primarily by differences in classification. The classification counts followed standard practice and pickup and light panel trucks were classified as passenger cars, since they have similar acceleration and driving characteristics. The model, however, was set up to consider all commercial vehicles, including panels and pickups, as trucks. Similarly, school buses were combined with the transit buses in the classification study, initially distorting the bus occupancy values used. Additional field work in the form of classification counts and occupancy studies were needed to develop correction factors to be applied to the original volume counts.

The major checks made on the total vehicle trips developed by the model consisted of volume comparisons on the 7 basic screenlines, corridor volume comparisons for

TABLE 15

COMPARISON OF TOTAL VEHICLE SCREENLINE VOLUMES

Screenline	Predicted Crossings	Actual Crossings
1	60,140	56,800
2	111,755	121,600
3	50,463	48,500
4	85,177	83,800
5	95,001	102,100
6	90,820	90,200
7	71,854	70,000

each screenline, volume profiles along the length of major corridors, and total vehicle-miles of travel and average trip length comparisons.

Screenline Comparisons

The screenline comparisons for total vehicles are given in Table 15. Table 16 gives a more detailed comparison of corridor volumes on the screenlines.

The total vehicular volumes across all screenlines were within 10 percent of the observed volumes. The corridor volume comparisons for each screenline were not as satisfactory. A further analysis of the corridor volumes was made through the use of a "selective link" assignment program. All of the movements using designated links were traced and data were furnished on the origins and destinations of trips using the link. It was found that virtually all the corridor differences were attributable to the traffic assignment procedure rather than to the trip distribution techniques. After consideration of the computer limitations and program running times, it was decided to adjust manually the final corridor assignments. It should be noted that volume differences after even a casual application of engineering judgment regarding their interpretation are not sufficient to alter design requirements for any new or improved facilities.

Corridor Volume Profiles

In general, the comparison of predicted and observed vehicle volumes along the entire length of the corridors (Figs. 10 and 11) give good agreement between the two

TABLE 16

COMPARISON OF TOTAL VEHICLES CORRIDOR VOLUMES

Screenline	Corridor	Predicted Vol.	Actual Vol.
1	1	36,539	31,400
	2	23,601	25,300
2	1	49,480	53,500
	2	62,275	68,100
3	1	50,463	48,500
4	1	39,230	47,200
	2	32,466	19,100
	3	13,481	17,500
5	1	31,272	30,800
	2	22,425	30,300
	3	41,304	41,900
6	1	34,386	33,900
	2	37,006	34,600
	3	19,428	21,700
7	1	27,754	26,500
	2	9,714	9,500

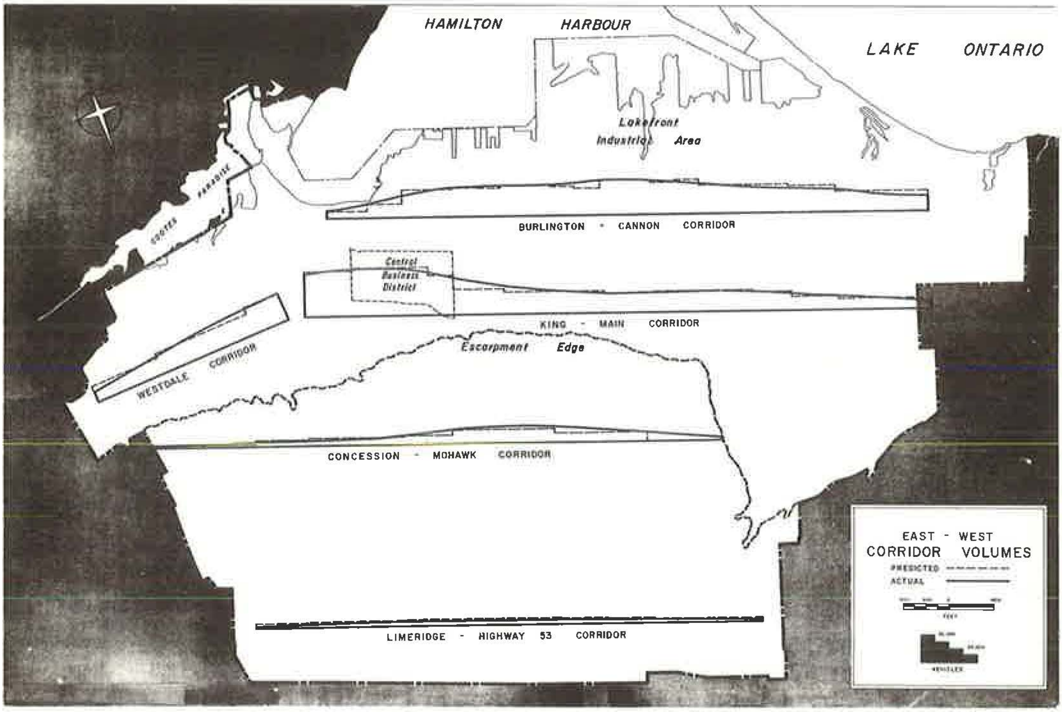


Figure 10.

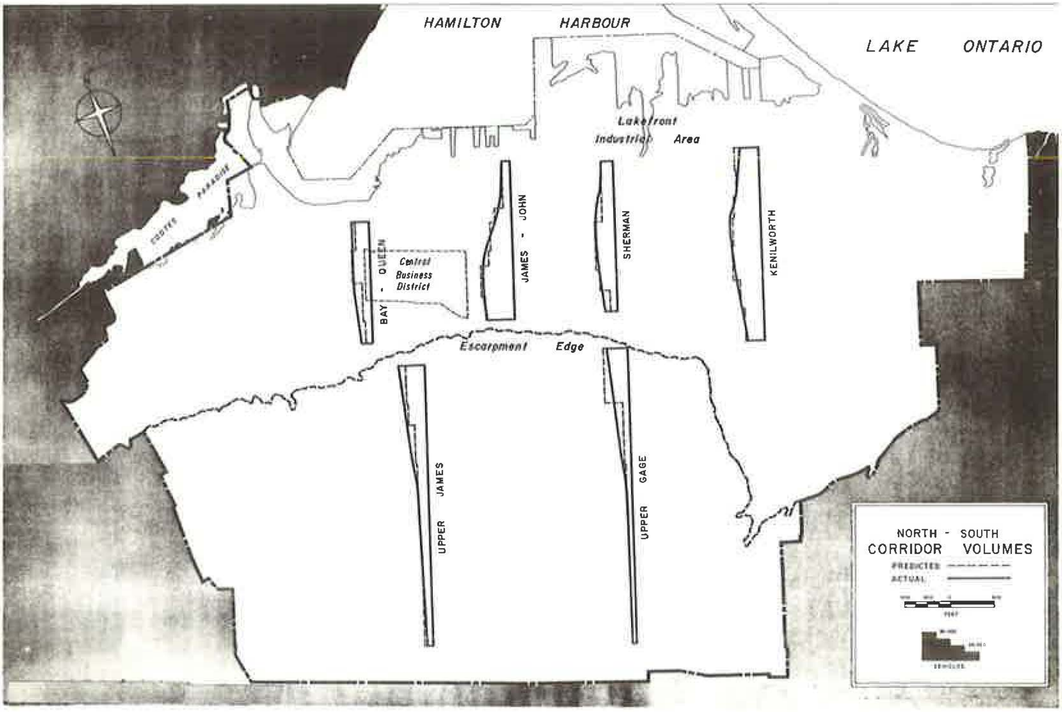


Figure 11.

volumes. The buildup of traffic in the vicinity of the CBD and the lakefront industrial area is clearly being duplicated by the model. The model is also giving the proper relative weight to the various different corridors. An analysis of volumes grouped according to corridors tends to compensate for the deficiencies of the "all-or-none" concept of traffic assignment. Large zones, however, still cause some distortion by concentrating volumes at relatively fewer points.

Vehicle-Miles Comparison

The last comparison made was between the total amount of travel in the area predicted by the model and that obtained from the vehicle flow map. Good agreement was obtained; the model predicting 2,780,000 vehicle-miles of travel per day versus the 2,645,000 vehicle-miles measured from the flow map.

CONCLUSION

It was concluded on the basis of the tests that the Hamilton model produces traffic patterns with sufficient accuracy for planning new and improved facilities. The model results, however, must be interpreted using engineering judgment and cannot be followed blindly. It is felt that the tests and checks made in the early stages of the model development were very important in improving its accuracy. It is thought that the limited home interview constitutes an indispensable source of data for the model, and that a full home-interview survey using a normal or even reduced sample size would be a still better source of data. This is especially true since many factors and influences on travel patterns are still imperfectly understood at present. It was concluded that the recommended procedure would be first to develop a model from a full home-interview study and then update it at 5-yr intervals using a limited home-interview survey, the full-scale study being repeated approximately every 20 years.

Significant savings in both time and money are possible through the use of a model to synthesize present O-D patterns. These savings were not as great as were originally expected because of the extensive field and clerical work required to obtain data on automobile ownership and distribution of employment opportunities. Improvements in automobile registration listing procedures or insertion of questions in the census form could simplify the collection of needed data.

The limitations of computer facilities can cause undesirable restrictions in the size of the networks to be analyzed and increase considerably the time required for data processing. These limitations ultimately reduce the accuracy and usefulness of the model and should be avoided wherever possible.

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Appendix A

EVOLUTION OF THE HAMILTON TRAFFIC MODEL

There are at present several different types of traffic models being used by analysts engaged in transportation planning. It does not appear that enough research work has been done to decide which, if any, of the several methods is to be clearly preferred. One of the most widely used methods is the one which utilizes the gravity principle in trip distribution. This particular type of model was selected for the Hamilton study because of the advantages of its relative simplicity and because its history of use in a number of cities indicated that it was a reliable method of general applicability. It was soon found that there still remained a great many choices in the form of the model even after the basic type had been selected.

Person Trips or Vehicle Trips

The first choice which had to be made was whether the model should produce and distribute person trips or vehicle trips. The answer to this question was a direct result of the objectives and needs of the study. Since it was required to analyze different levels of mass transit service and since a dynamic rather than a static approach to the question of modal split was desirable, the model was designed to accommodate total person trips. The dynamic approach permits transit and the automobile to compete for travel between any two zones, based on the travel time ratio of the two modes and other factors. Hence a table of total person trips must first be prepared and then divided between the two modes in accordance with the results of the competition. The dynamic approach allows improvements in either mode to be evaluated directly, inasmuch as a change in the competitive position of the mode can be inserted directly in the mechanics of the model and thus result in a change in the number of persons using that mode.

The static approach generally makes the modal split at the trip production stage; that is, first the number of transit riders is estimated for each zone and distributed; then the number of vehicles (passenger cars and trucks) is estimated and distributed independently of the transit riders. Any change in the competitive position of the two modes must be treated indirectly by estimating the effect of the change on the trip production equations. The static approach does not require a person trips model but rather two models: one for transit riders and one for vehicles. In smaller cities or in studies where transit is not a significant factor, it is possible to have only a single model for total vehicle travel.

Peak-Hour or 24-Hour Travel

The Hamilton model was designed to reproduce 24-hr travel patterns, but with some provision for adaptation to peak-hour travel at a later date. It was felt that the new facilities and improvements should be located where they provide the most service, hence data for the 24-hour period were needed. It was also felt that the determination of the design-hour volumes (DHV) required an estimate of ADT values and not just typical peak-hour values. It should be noted that the DHV on some sections of highway in the area occurs on Saturday, on some sections on Sunday, and on most streets on weekdays—sometimes during the morning rush and sometimes during the evening rush. This would be a very difficult combination of conditions to reproduce with a single peak-hour traffic model.

In certain circumstances, particularly where time and funds are limited, a simplified peak-hour analysis may be justified (5). It is also recognized that a peak-hour traffic assignment of volumes which comes the closest to representing the design conditions can be of some help in refining design and operational details. It is intended, therefore, if time and resources permit, to make a peak-hour model analysis of the final, recommended transportation plan.

Selecting Travel Time

The selection of peak, off-peak or weighted travel time between zones used in a model depends both on the type of model being developed and the existing conditions in the study area. In the Hamilton study, off-peak automobile driving times plus automobile terminal times were used in the trip distribution phase of the model. (In the modal-split phase of the model, transit running time, transfer time, and access time were computed and compared with the automobile time in dividing up the total person trips table.) This was done after a study of the extent of transit riding, transit speeds, off-peak automobile speeds, peak-hour automobile speeds, and terminal times. It was concluded that off-peak automobile speeds and terminal times were sufficiently typical for use in determining 24-hr total person trip distribution in the area. If there had been a greater differential between peak-hour speeds and off-peak speeds, or if there were many more transit riders, a weighted speed would have had to be used. Similarly, if a peak-hour model were being developed, it would have been logical to use peak-hour speeds; if a transit rider model were being developed to use transit speeds, etc.

Regardless of which kind of travel time or weighted travel time is selected, the values used in the model should be computed from a minimum path computer program and not taken from the times reported in the home interview since people tend to report travel time to the nearest quarter-hour, half-hour, and hour even when asked to specify time to the nearest minute. This is evident by the cluster of reported trip lengths around these times. It is also difficult to get people consistently to include or exclude terminal time and consequently difficult to make sure data are readily comparable. For these reasons, the actual distribution of trip lengths from the home-interview survey was obtained by applying the calculated minimum path computer times to the zone-to-zone movements reported.

Intrazonal travel times were computed manually based on the size of each zone, the location of major generators within the zone, observed driving speeds and the travel times to adjacent zones. Auto terminal times were computed on the basis of average walking distance (a variable dependent upon the parking available in the zone and the size of the zone) and an assumed average walking speed. The terminal times ranged up to a maximum of 6 minutes. It was observed that intrazonal travel times and terminal times had a pronounced effect on the calibration of the model.

A time penalty of 5 minutes was introduced to compensate for a 5-cent toll. This was equal to the difference in travel time using an alternate facility between two major generators. Although this seemed high initially, considering that 93 percent of the trips are less than 20 minutes in length, it was found to give good results.

In calibrating the model to agree with measured present patterns, the only significant changes that had to be made were in the values used for travel times. It was necessary to substitute peak-hour speeds for off-peak-hour speeds on several major facilities in order to reduce the attractiveness of suburban areas. It was also necessary to increase or decrease the terminal times in various areas by about 1 minute.

The transit times were computed in three categories: access time, travel time, and transfer time. Access time consisted of the time required to walk from the zone centroid to the nearest transit stop plus a waiting time which was a function of the bus headway on the line. The travel time was determined directly from the average schedule speeds over a 24-hr period. The transfer time was computed as a function of the bus headways. It was possible to draw a curve with bus headway as the abscissa and waiting or transfer time as the ordinate, thus greatly simplifying the transit time computations.

Number of Trip Purposes

Traffic models have been developed using as few as one trip purpose (6) and as many as six or more (7). Again, there seems to be no clear agreement on this point, and it is at least partially a function of the scope and objectives of the study, as well as the inclinations of the analyst. At the start of the Hamilton study, it was assumed on the basis of experiences with cities of similar size that three trip purposes would be required. Upon examination of the home-interview data, however, this assumption was questioned. Analysis of the data brought out several conflicting tendencies. It was noted that trip production equations showed the greatest stability and best correlations for the larger trip groupings. That is, the equation for total trips was much stronger than the equation for shopping or social-recreation trips, for example. On the other hand, the land-use pattern at the destination, which decides the attraction factor to be used in the trip distribution process, differed for the various trip purposes. The amount of data preparation time, computer time, and analysis time is, of course, reduced if fewer trip purposes are used. Yet the distribution of trip lengths indicated that different frequency factors would be desirable for the different trip purposes. It was ultimately decided that separate distributions should be made for work, shopping, social-recreation, other-homebased, and non-homebased trips. The characteristics of all other trip purposes were either close enough to be joined, or the volume of trips was too small to justify separate treatment. It was also decided that the strong trip production equations such as the one for total trips could be utilized as a check on the sum of the results from the weaker trip production equations.

Interrelationship of Model Components

The ultimate objective of the traffic model procedure is the preparation of one or more O-D tables that can be used as the basis for constructing travel desire lines and as the basis for traffic assignments to various systems. There is still much to be done after the trip production and distribution have been carried out before this ultimate objective is achieved. The first step is to combine the various trip purpose tables into a single table. This was done by direct addition of work, shopping, social-recreation, and other homebased trips. Each of these trips was then assumed to have a return home trip and then the non-homebased trips were added as one-way trips.

The treatment accorded to external-internal and through trips also presents the analyst with a choice. In some studies, the external cordon stations are considered as fictitious zones and are assumed to produce and attract trips in a similar manner to the internal zones. This was not done principally because it was felt this was a problem where more conventional techniques would yield better results than were possible with the model. The model functions best where land-use and planning statistics are known or can be estimated with reliability. To assume a hypothetical set of zone characteristics which will attract trips in approximately the manner measured by the roadside interviews seemed unnecessary when the roadside interviews themselves had already established the actual patterns.

With respect to future traffic, the projection of the hypothetical set of characteristics required by the model seemed to be rather arbitrary without data to correspond to the land-use study that is available inside the study area. Consequently, for present conditions the external-internal and through movements were taken directly as measured by the roadside interviews. The first step in computing the future through trips was to obtain future total through volumes at each external station. This was done by analyzing the population and vehicle registration projections for virtually all counties reported as trip terminals for trips passing across the cordon and applying appropriate growth factors at each station. This estimate of total through volume was checked by projecting the volume history at the station. The 1985 through trip pattern was then established by simple iteration using the 1961 pattern as a base matrix and the projected 1985 through volumes as row and column control totals.

The 1985 station totals for external-internal trips were obtained by using the same station growth factor. Although it would then have been possible simply to distribute the 1985 volume in accordance with the distribution pattern found in 1961, it was felt that this would be inaccurate since changes in land use should have altered the attractiveness of the internal zones by 1985. That is, a particular internal zone may not have attracted any trips from an external station in 1961 but if it has grown in population and employment faster than its neighbors, it might very well attract external to internal trips by 1985. Consequently, the 1961 pattern was first modified on the basis of the change in internal attraction factors for each zone. These changes in attraction factors were weighted in accordance with the proportion of trips for each purpose which were attracted to the zones. The 1985 external-internal pattern was then obtained by expanding the modified 1961 pattern to the estimated 1985 station totals.

Once the complete O-D table of internal, external-internal and through person trips had been compiled, the next step was to split the table into two tables; a transit rider table and an auto driver-auto passenger table. This sequence (Fig. 1) was accomplished by means of diversion curves based primarily on the time ratio between the two modes of travel. The auto driver-auto passenger table was next converted to an auto vehicle trips table by applying a series of occupancy factors. Commercial vehicle trips were treated in a similar manner to person trips. That is, estimates of internal commercial trip production and distribution were made separately according to vehicle weight class and then combined to give total internal commercial trips. The internal trips were then compiled with the external and external-internal commercial trips to form a total commercial vehicle trips table. This total trips table was then converted to an equivalent passenger car table using a weighted factor derived from one light truck equaling one passenger car, and one heavy truck equaling 2.7 passenger cars. Finally, the two tables were added together to provide a total table of equivalent passenger cars for assignment to the streets and highway network.

Conclusions

The concept of model has been broadened at times in this paper to include all the mathematical relationships used in trip production, trip distribution, route selections, modal split, and traffic assignment. The testing of the model included checks made on its components but concentrated on the final results, because these, after all, are of the most importance.

There soon comes a time in the model development when it becomes difficult to determine if discrepancies are being caused by weaknesses in the trip production-distribution procedure, the zone sizes involved, the traffic assignment technique, or the observed values which are used as a yardstick. In the Hamilton study variables were isolated and tested separately for as long as possible.

Available computer facilities (an IBM 650 computer with 4,000 word internal memory and 4 accessory tape units) limited the number of zones and the size of the link-node networks. Even so, the systems still required 15 hours of computer time for each minimum path run and 15 hours for each traffic assignment. This long computer time had a tendency to reduce the extent of the testing of possible revisions to the model and to cause some difficulties at the traffic assignment stage. It was concluded that the all-or-none traffic assignment technique has some undesirable limitations. Although these limitations might have been reduced somewhat by using smaller zone sizes, it is still believed that some means of generating several different routes and proportioning interzonal movements between these routes must be developed to improve the ability to predict use of new or improved facilities.

The difficulty of developing an adequate yardstick to test a model has been cited by others (8). It is difficult when comparing O-D patterns and even volumes. There is perhaps no simpler concept in traffic engineering than the use of master stations to expand, say, 16-hour counts to AADT volumes or to iron out seasonal variations. Unfortunately, very few cities, if any, have a completely adequate system of primary and secondary master stations. On some streets, it was necessary to recount volumes 4 and 5 times before stable data in reasonable agreement with the adjacent areas were obtained. It is felt that even after the best attempts had been made, any specific corridor or screenline volume should be considered accurate only within about 10 percent.

The end product of the computer routines, though adequate for design decisions, is still an imperfect representation of what actually happens on the streets and highways. Consequently, the model results should not be considered as absolute answers, but as very strong evidence that this is the way things will happen.

Increased consideration has been given lately to the use of models as a substitute for the conventional home-interview survey. It is apparent that the model is a very powerful tool for developing and evaluating transportation plans. The mere act of developing the model does much to increase understanding of traffic movement and to improve judgment. The Hamilton model development was based, however, on detailed analysis of home interviews and roadside interviews on an internal screenline. If a full home-interview study had been available, the model would have been still better and the improvement in understanding still more pronounced. If the model had simply been derived from findings reported in other studies without any home interviewing, it would have forced the use of trip production equations, attraction factors, and frequency factors significantly different from those actually used. Differences in observed and predicted screenline volumes would then have been resolved by the use of correction factors. Such a model may eventually produce good agreement. It is possible that the application of arbitrary (though rationalized) correction factors will calibrate the model sufficiently well to produce answers of sufficient accuracy for planning purposes. It is doubted, however, that much will have been done by this exercise to improve the analyst's understanding of the traffic patterns with which he is concerned.

Appendix B

TABLE 17

TRAVEL TIME FACTORS

Time	Work	Shopping	Social-Recreation	Other Homebased	Non-Homebased
0	0	0	0	0	0
1	4.55	11.29	4.00	5.50	6.00
2	3.32	9.36	2.60	4.50	4.72
3	2.60	7.43	2.18	3.50	3.75
4	2.06	5.50	1.93	2.50	2.98
5	1.69	3.57	1.74	1.92	2.40
6	1.43	2.03	1.59	1.65	1.92
7	1.26	1.42	1.46	1.46	1.55
8	1.16	1.11	1.35	1.31	1.29
9	1.10	0.93	1.24	1.17	1.10
10	1.06	0.84	1.15	1.05	0.97
11	1.01	0.78	1.07	0.95	0.90
12	0.07	0.73	0.99	0.86	0.85
13	0.92	0.68	0.92	0.77	0.80
14	0.88	0.63	0.87	0.70	0.75
15	0.84	0.58	0.81	0.63	0.70
16	0.80	0.53	0.76	0.57	0.65
17	0.76	0.47	0.71	0.52	0.60
18	0.72	0.42	0.66	0.46	0.55
19	0.67	0.37	0.62	0.41	0.50
20	0.63	0.32	0.58	0.36	0.45
21	0.58	0.27	0.55	0.32	0.40
22	0.54	0.22	0.51	0.28	0.35
23	0.50	0.17	0.48	0.24	0.30
24	0.46	0.12	0.44	0.20	0.25
25	0.42	0.07	0.41	0.18	0.20
26	0.37	0.02	0.37	0.15	0.15
27	0.33	0	0.34	0.13	0.10
28	0.29	0	0.31	0.10	0.05
29	0.25	0	0.27	0.08	0
30	0.21	0	0.23	0.05	0
31	0.16	0	0.20	0.03	0
32	0.12	0	0.17	0	0
33	0.07	0	0.13	0	0
34	0.03	0	0.10	0	0
35	0	0	0.07	0	0
36	0	0	0.03	0	0
37	0	0	0	0	0

Suburbanization of Employment and Population 1948-1975

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Analysis of data from the Censuses of Population, Manufactures, and Business indicates that during the period after World War II very little population and employment growth took place in the largest cities.

This paper presents an analysis of and empirical findings about changes in land-use patterns occurring within the 39 largest metropolitan areas during the post-war period, pertinent to the debate about alternative solutions to the urban transportation problem. Descriptive statistics on land-use trends in these areas during the periods 1948-1954 and 1954-1958 are discussed. An 11 equation econometric model is presented to explain population and employment changes within central cities and metropolitan rings for the 1954-1958 period. The model is then used to predict the land-use pattern in a typical metropolitan area during the years 1965 and 1975. The implications of the analysis and the empirical findings for the various proposed solutions to the urban transportation problem are also discussed.

• DURING the post-war period, urban transportation has become recognized as an increasingly important and difficult problem. Secular growth and migration trends are causing population to concentrate mainly in urban areas. For several decades the United States has been rapidly changing from a land of small towns and farms to one of gigantic metropolitan areas. Within these, suburban growth has been much faster than central city growth. In the post-war period this rapid growth has been accompanied by significant declines in the numbers of urban residents using public transportation facilities. For example, between 1950 and 1958 transit ridership in American cities decreased by 43 percent, from 17.2 to 9.7 billion trips per year (1). On the other hand, the number and use of private automobiles increased enormously.

The response to these transformations has been impressive. President Kennedy, for example, in a message to Congress, April 6, 1962, stated that:

> The national welfare, therefore, requires provision for good urban transportation with the proper use of private vehicles and modern mass transport to help shape as well as to preserve urban growth.

And, he requested Congressional authorization of grants for urban transportation totaling $500 million over a 3-yr period. There are also pending several ambitious rail rapid-transit plans including one in Washington, D.C. In the San Francisco-Oakland metropolitan area, voters have approved a bond issue for the financing of a 75-mi rapid-transit system having an estimated capital cost of nearly one billion dollars. The Los Angeles Metropolitan Transit Authority is ready to begin final design studies, contingent only upon obtaining adequate and low-cost financing, of a less ambitious project nicknamed "The Backbone Plan." The Los Angeles project has an estimated

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capital cost of $300,000,000 and consists of a 22.7-mi rail transit line, including 12 miles of subway. Although San Francisco and Los Angeles are the only cities having mass transit plans in such a state of readiness, proposals for new rail systems are being seriously debated in Pittsburgh and Atlanta. The National Capital Transportation agency has submitted to the President its report recommending construction of a rail transit system in Washington, D.C., at a cost of approximately $800,000,000 and a curtailment of the region's highway program (2). Moreover, Philadelphia, Boston, Chicago and New York are seeking Federal subsidies for expansion of existing rail facilities. One estimate of the next decade's capital requirements for mass transportation places them at nearly $10 billion (3). At the same time, the huge cost of urban highways is indicated by the $18 billion cost of the urban portion of the 41,000-mi Interstate System, which represents only a portion (although a large portion) of the decade's total urban highway expenditures.

As the report by the National Capital Transportation Agency proposing curtailment of Washington's highway program and substantial expansion of its public transit system indicates, highways and public mass transit are both competing and complementary Proponents of the rail solution would reverse or halt mass transit declines by making substantial improvements in transit facilities and perhaps by cutting back on construction of highway facilities. The $10 billion estimate of the next decade's public transportation capital requirements and the cost of the San Francisco and Los Angeles plans indicate the opportunity costs of the rail transit solution. If spent on further expansion of urban highways the $10 billion estimated capital costs would finance a sizable increase in the present urban interstate system. The $1 billion costs of the San Francisco-Oakland Bay plan might be used to finance many miles of urban expressway for the Bay Area. (Assuming lane-mile-costs from $0.5 to $1.0 million, between 1,000 and 2,000 lane miles could be constructed with the $1 billion, making no allowance for bridges, tunnels, and either public or private vehicles.)

Thus it is important to choose the right "mix" of these capital intensive facilities. The best mix depends to a large extent on the task confronting the local urban transportation planners. Some form of rail mass public transportation is probably best, in the sense of being most efficient or cheapest, if large volumes must be transported between high-density origins and destinations. Urban highways, with perhaps some exclusive rights-of-way for buses, may be more efficient than rail mass transit systems if low volumes and low-density origins and destinations must be served. The appropriate urban transportation investment policy is determined substantially by the spatial configuration of urban transportation demands which depends largely on the density of current and expected urban development.

If the projected increases in metropolitan populations result in increased densities and interchange volumes, considerable emphasis should be placed on rail mass-transit systems. If present urban densities are at their height and if most urban growth is to occur at low densities, emphasis should be placed on building up the highway system. If considerable uncertainty exists, a city should make an effort to emphasize flexibility so that the system can adapt to changes as they occur. In such a case, research to obtain information about future urban growth is necessary.

The debate about preferred solutions has been long and inconclusive. Assertions on both sides have been largely unsubstantiated and the evidence presented has often been contradictory. In large part this is because empirical information and evidence on urban location and development trends have been lacking.

The primary purpose of this paper is not to reach any final conclusions about alternative transportation policies or about an optimal mix of public and private transportation facilities, but to provide systematic empirical information on urban locational and development trends bearing on the appropriate mix. This will encourage and help make possible more factual and intelligent discussion of alternative transportation policies. This paper describes and evaluates locational trends common to most large metropolitan areas, not any particular metropolitan area. In this way, it is believed possible to identify the basic economic and technological forces prevailing in today's society and the commonalities of urban growth processes.

POSTWAR TRENDS IN URBAN POPULATION AND EMPLOYMENT

This section presents some descriptive statistics measuring postwar changes in the locational distribution of employment and population within the 39 largest Standard Metropolitan Statistical Areas (SMSA's). These areas are Akron, Atlanta, Baltimore, Boston, Buffalo, Chicago, Cincinnati, Cleveland, Columbus, Dallas, Dayton, Denver, Detroit, Ft. Worth, Houston, Indianapolis, Jersey City, Kansas City, Los Angeles-Long Beach, Louisville, Memphis, Miami, Milwaukee, Minneapolis-St. Paul, Newark, New Orleans, Oklahoma City, Philadelphia, Phoenix, Pittsburgh, Portland, Rochester, St. Louis, San Antonio, San Diego, San Francisco-Oakland, Seattle, Tampa-St. Petersburg, and Washington, D. C. New York City has been excluded from the sample because of its enormous size and other unique features. For wholesaling, only 38 cities were used.

Each metropolitan area is divided into two subareas, the central city and the metropolitan ring (the SMSA minus the central city). This is a rather crude geographical breakdown. Nevertheless, a comparison of the central cities and the metropolitan rings gives a rough picture of the contrasts between developments taking place in the older higher-density and the newer lower-density parts of metropolitan areas.

Table 1 gives the mean annual percentage changes in retailing, manufacturing, wholesaling and selected services employment and in population for the central cities and metropolitan rings for the 39 SMSA's. The statistics have been calculated for the intercensal time periods: 1948-1954, 1954-1958, and 1948-1958. The raw employment data used are actual counts reported by the Census of Business and Census of Manufactures. The population data are estimates made by interpolation of population counts obtained from the 1950 and 1960 Censuses of Population. The manufacturing data are for 1947 instead of 1948.

Table 1 indicates that the metropolitan rings are growing at considerably higher rates than the central cities on the average. Although it contains no particularly surprising information, Table 1 systematically overstates central city and understates ring growth because annexations have significantly increased the size of many central cities. Corrections of both population and employment data can be made to give a rough idea of the effect of annexations and of what the growth within constant areas has been. The 1960 Census of Population provides figures for the 1960 population residing within 1950 boundaries of the central cities. Data on population annexations by the 39 central cities were obtained (4). By assuming that population changed at constant percentage rates during the period 1950-1960 within each of these cities, estimates were made of the population within 1950 boundaries in 1948, 1954 and 1958. Employment data were corrected for annexations by assuming that the percentage of employment annexed in each category was the same as the percentage of annexed population.

TABLE 1

MEAN ANNUAL PERCENTAGE CHANGES IN POPULATION AND EMPLOYMENT

Item	Central City			Metropolitan Ring		
	1948-54	1954-58	1948-58	1948-54	1954-58	1948-58
Manufacturing	3.46	0.03	2.74	9.64	4.88	9.63
Wholesaling	1.76	1.74	1.92	10.42	12.43	13.76
Retailing	0.36	1.71	1.00	4.54	9.11	7.39
Services	2.75	5.68	4.42	9.28	10.86	12.32
Population	1.80	1.50	1.80	6.44	4.60	6.60

Formally, the annexation correction for the central city is of the form:

$$E^{cck}_{50i} = E^{cck}_{Li} - \frac{\left(P^{cc}_{Li} - P^{cc}_{50i}\right)}{P^{cc}_{Li}} \left(E^{cck}_{Li}\right) \tag{1}$$

in which E^{cck}_{50i} is the estimated employment within 1950 central city boundaries in the i-th year (i = 1948, 1954 or 1958) and for the k-th industry subgroup (k = retailing, wholesaling, selected services or manufacturing); E^{cck}_{Li} is the census employment of the k-th industry within existing legal boundaries of the central city in the i-th year; $(P^{cc}_{Li} - P^{cc}_{50i}) / P^{cc}_{Li}$ is the ratio of the difference between population in the legal and 1950 boundaries of the central city in the i-th year to the population within central city legal boundaries in the i-th year. The ring correction for annexations is identical:

$$E^{r}_{50i} = E^{r}_{Li} + \frac{\left(P^{cc}_{Li} - P^{cc}_{50i}\right)}{P^{cc}_{Li}} \left(E^{cc}_{Li}\right) \tag{2}$$

except the annexation correction is added instead of subtracted from the census employment statistic. As a side condition annexation corrections from the ring to the

TABLE 2

MEAN ANNUAL PERCENTAGE CHANGES IN POPULATION AND EMPLOYMENT, CORRECTED FOR ANNEXATIONS

Item	Central City			Metropolitan Ring		
	1948-54	1954-58	1948-58	1948-54	1954-58	1948-58
Manufacturing	1.9	-1.7	-0.6	13.2	7.0	15.0
Wholesaling	0.9	-0.2	0.7	25.4	16.8	29.4
Retailing	-0.6	0.1	-0.4	11.5	13.6	16.0
Services	1.6	3.9	2.7	18.2	16.8	24.4
Population	0.2	0.1	0.2	8.8	6.4	9.4

TABLE 3

MEAN ANNUAL CHANGES IN POPULATION AND EMPLOYMENT

Item	Central City			Metropolitan Ring		
	1948-54	1954-58	1948-58	1948-54	1954-58	1948-58
Manufacturing	477	-1,851	-454	2,237	564	1,568
Wholesaling	191	224	204	307	501	382
Retailing	-263	454	24	756	1,662	1,118
Services	452	1,002	672	399	611	483
Population (legal)	4,470	5,840	5,018	25,632	28,929	26,951

central city are not permitted to exceed one-half of the employment within the ring for a given employment activity.

The corrected data in Table 2 indicate that percentage changes calculated on the basis of the raw data seriously overstate the central city growth and seriously understate ring growth. Indeed, the corrected data actually show a percentage decline in manufacturing employment during the 1954-1958 period in the 39 central cities. Service employment is the only category with substantial central city gains. Moreover since the raw data indicate that the smaller central cities are experiencing more rapid growth than the larger ones, it is quite possible for the mean percentage change to be positive even though the 39 central cities might actually, on the average, experience declines in their levels of population and employment.

To investigate this possibility, Table 3 gives changes in population and employment during the three time periods in question. Increases in employment and population were greater in rings than in central cities in all categories except services. The differences between central city and ring growth are particularly significant for population and for manufacturing employment. Huge population increases are occurring in the rings, while the increases in the central city population are modest. Ring manufacturing employment increased in both periods, while the central cities have suffered large losses in manufacturing employment since 1954. Even so, the central city increases are overstated and ring increases understated, because of annexations.

Table 4 presents corrected changes in population and employment. As in the case of the percentage changes when corrected for annexations, the findings for the changes in Table 3 are magnified; only services exhibit significant central city growth—approximately 800 workers per year during the 1954-1958 period (Table 4). During the 1954-1958 period, large losses occurred in central city manufacturing employment, but employment in both wholesaling and retailing remained nearly constant. Central city population increases in both periods were very small, only about 300 persons per year. If Los Angeles and San Diego are deleted from the sample, the average change in central city population is actually negative. These two rapidly growing cities bias the mean upward; here rapid central city growth is attributable to the vast amounts of vacant land within central city boundaries, which absorbed a large proportion of the tremendous population increases occurring during the postwar period.

Further understanding of central city employment and population changes can be gained by examining the numbers of central cities which experienced declines in population and various categories of employment during each period. The pervasiveness of these central city declines is indicated in Table 5, which shows the number of declining central cities and rings in each employment and population classification. The frequency and widespread character of central city declines are indicated by the fact that during the first (1948-1954) period, retailing employment declined in 26 or two-

TABLE 4

MEAN ANNUAL CHANGES IN POPULATION AND EMPLOYMENT CORRECTED FOR ANNEXATIONS

Item	Central City			Metropolitan Ring		
	1948-54	1954-58	1948-58	1948-54	1954-58	1948-58
Manufacturing	159	-2,502	-809	2,168	1,214	1,821
Wholesaling	86	-2	51	415	739	544
Retailing	-479	6	-285	972	2,110	1,427
Services	373	786	538	479	827	618
Population	290	308	297	29,812	34,462	31,672
Population annexations	4,180	5,532	4,721	-4,180	-5,532	-4,721

TABLE 5

NUMBER OF METROPOLITAN AREAS HAVING EMPLOYMENT DECLINES IN CENTRAL CITY AND RING BY INDUSTRY GROUP CORRECTED FOR ANNEXATIONS

Item	Central City			Metropolitan Ring		
	1954-48	1958-54	1958-48	1954-48	1958-54	1958-48
Manufacturing	15	29	24	6	9	4
Wholesaling	15	18	13	3	0	1
Retailing	26	17	30	4	0	0
Services	7	4	3	1	1	0
Population (legal)	17	15	16	1	2	2
Population (1950)	21	21	21	1	1	1

thirds of the 39 central cities; manufacturing employment declined in 15 during the first period and in all but 10 during the second period; and wholesaling employment declined in 15 of 38 central cities during the first period; and in 3 more during the second. Some of the declines occurring in the second period may have been caused by the business cycle. This is particularly true for manufacturing. Only selected services, buoyed up by secular increases, avoided persistent central city declines. Selected services employment declined in 7 central cities in the first period and in only 4 during the second.

The number of population declines is also large; for the entire 1948 to 1958 period, 21 central cities decreased in population using 1950 boundaries and only 5 fewer had declines using legal boundaries.

The metropolitan ring did not escape declines entirely. The lessening importance of manufacturing employment in the economy, combined with especially large declines in a number of metropolitan areas, resulted in 6 ring manufacturing employment declines during the first period and 9 during the second.

AN ECONOMETRIC MODEL

The data indicate that central city manufacturing employment decreased on the average for the 39 metropolitan areas between 1954 and 1958, and that other types of central city employment, services excepted, also decreased in a large number of these cities. Central city population appears to have grown very little, and has actually declined in a majority of urban areas, i.e., 21 out of 39. One cannot help but wonder at the causal structure bringing about these changes. Econometric models provide a systematic and reasonably efficient way to study urban structure. An 11 equation recursive model has been formulated to assist in understanding the changes in population and employment currently taking place in American urban areas. This model includes 9 behavioral and 2 definitional equations. The parameters of the equation system are estimated from data for the period 1954-1958, using least squares regression techniques (5). The model (Fig. 1) includes 11 endogenous variables determined within the equation system, and 5 exogenous ones determined outside the system. The variables are as follows:

M_g^c = yearly changes in manufacturing employment in central cities of growing areas, i.e., defined as SMSA's having increases in manufacturing employment during 1954-1958.

M_d^c = yearly changes in central city manufacturing employment of declining areas, i.e., SMSA's with declines in manufacturing employment.

M^r = yearly changes in ring manufacturing employment in all areas.

P^c = yearly changes in central city population within constant 1954 boundaries.

P^r = yearly changes in ring population within constant 1954 boundaries.

W^c = yearly changes in central city wholesaling employment.

W^r = yearly changes in ring wholesaling employment.

R^c = yearly changes in central city retailing employment.

R^r = yearly changes in ring retailing employment.

S^c = yearly changes in central city services employment.

S^r = yearly changes in ring services employment.

M_g^s = yearly changes in manufacturing employment in growing SMSA's.

M_d^s = yearly changes in manufacturing employment in declining SMSA's.

P^s = yearly changes in population, all SMSA's.

V = the ratios of central city vacant land area to total central city land area.

A = annual annexations of population from the ring to the central city.

An assumption crucial to the structure of the model (Fig. 1) is that metropolitan area changes in population and manufacturing employment, the latter representing the most important form of base employment in most urban areas, are simultaneously determined.

Base employment refers to terminology used in economic base studies. Base employment may be thought of as the exogenous variable in an economic base model. It differs from nonbasic employment in that its output is exported and thus provides the area with income. Nonbasic employment or service employment is defined as that employment which provides goods and services for consumption within the area. For some time an effort has been made to estimate and evaluate the simultaneity problem between population and base employment. The treatment here is evidence that the results of this research have not yet been satisfactory and changes in both are treated as exogenous to the model.

Given changes in SMSA manufacturing employment and population, and the ratio of central city vacant land area to total land area, the yearly changes in central city population and manufacturing, wholesaling, retailing and services employment can be obtained using the model. The model can logically be separated into three parts or stages, and thus requires three discrete steps for solution and use as a predictive mechanism.[1]

Stage 1

Changes in SMSA manufacturing employment in declining areas are used to determine changes in central city manufacturing employment for SMSA's of declining manufacturing employment. Changes in SMSA manufacturing employment in growing areas and the vacant land ratios for growing areas are used to determine central city changes in manufacturing for SMSA's of increasing manufacturing employment. The central city changes in manufacturing employment for growing areas and those for declining areas are combined to obtain a weighted average of the central city manufacturing employment changes in both declining and growing areas. The weights used are the numbers of the areas in each class, divided by the total number of areas in the sample. The weighted average changes in central city manufacturing employment are then subtracted from the changes in SMSA manufacturing to obtain the change in ring manufacturing employment. The procedure of dividing SMSA's into growing and declining areas for the central city manufacturing equation requires some elaboration. This procedure is used because of an asymmetry for the manufacturing equation and the theory on which it is based. The vacant land variable is a constraint variable limiting the size and rate of central city manufacturing increases. The hypothesis assumed is that if significant tracts of vacant land within central cities exist, a sizable proportion

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[1] The model's 9 stochastic and 2 definitional equations together with the percentage of the dependent variables' total variances explained are as follows (all variables are statistically significant at the 5 percent level): $M_g^c = 1.510VM_g^s + 0.061A - 470$, $(R^2 = 0.70)$; $M_d^c = 0.623M_d^s + 0.105A - 992$, $(R^2 = 0.90)$; $M^r = M^s - M^c$; $P^c = 0.453VP^s + 0.650M^c - 2776$, $(R^2 = 0.50)$; $P^r = P^s - P^c$; $W^c = 0.032P^c + 0.022A + 91$, $(R^2 = 0.62)$; $R^c = 0.077P^c + 0.027A + 283$, $(R^2 = .65)$; $S^c = 0.031P^c + 0.023P^r + 0.022A + 201$, $(R^2 = 0.77)$; $W^r = 0.017P^r - 0.018A - 31$, $(R^2 = 0.56)$; $R^r = 0.053P^r - 0.049A - 5$, $(R^2 = 0.82)$; $S^r = 0.027P^r - 0.016A - 297$, $(R^2 = 0.79)$.

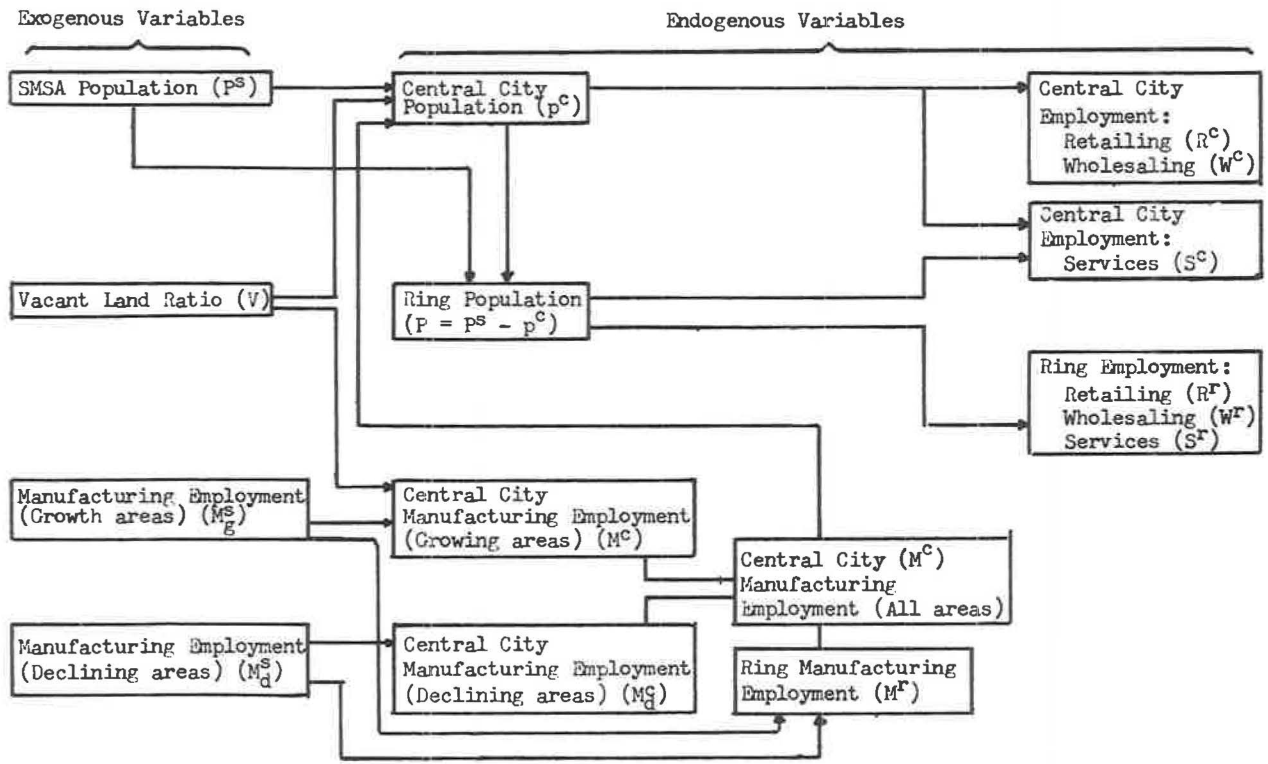

Figure 1. A model of population and employment changes.

of new manufacturing will locate there; if there is little vacant land, new manufacturing will locate on vacant land in the ring just adjacent to the central city. As this constraint is only meaningful in those areas where there are manufacturing employment increases, separate equations are estimated for increasing and decreasing areas.

Stage 2

The central city population change is obtained using the change in central city manufacturing employment (determined in Stage 1), and the predetermined values of the vacant land ratio and change in metropolitan area population variables. Ring population change is obtained by subtracting the central city population change from the metropolitan area population change. Because all except one of the metropolitan areas included in the sample increased in population in the period 1954-1958, the asymmetry characteristic of the manufacturing equation is not a problem in the population equation. Therefore, a single population change equation is used for all areas.

Stage 3

Changes in central city and ring retailing, wholesaling and services employments are obtained solely from variables determined within the model. Predictions of central city wholesaling and retailing employment changes depend on only central city population changes, while changes in service employment require as explanatory variables both central city and ring population changes. Both the central city and ring population change variables have positive and statistically significant regression coefficients in the central city selected services equation, although the coefficient of the change in ring population is somewhat smaller than that for central city population. This was expected, because people living in the ring will not purchase services located in the central city as often as those living within the city limits.

Changes in ring retailing, wholesaling and selected services employments are obtained using only ring population changes. Valid relationships between retailing and services employments and population are more probable than between wholesaling and population. It is assumed that the change in population is a fairly good proxy for changes in the distribution of the wholesalers' markets and thus a good wholesaling demand proxy. But the cause of wholesaling employment's rapid growth in the ring may be the lessening importance of centrally-located freight facilities resulting from more widespread use of trucks for moving freight. Consequently, no one should be surprised that the equations for wholesaling explain a smaller proportion of the total variation in the dependent variables than either the retailing or selected service trades equations.

PROJECTION AND PREDICTION

Having clarified to some extent the nature and causal structure of the model, it might be illuminating to use the model to predict what the typical metropolitan area would look like in 1965 and 1975 using various time paths of the exogenous variables. This procedure is carried out in two steps. Projections of the behavior of the exogenous variables over time are made. Then the changes taking place in the dependent variables during the time periods 1954-1965 and 1954-1975 are obtained by intergrating the model's equations with respect to time and evaluating the integrals.

To provide a basis for comparison, characteristics of an average or representative urban area in 1954 have been calculated. Table 6, giving the mean employment and population levels in both central cities and metropolitan rings, provides a description of a represntative urban area in 1954.

Manufacturing employment, which numerically outranks wholesaling, retailing and services employments combined, is clearly, in these terms, the most important type of employment in both central cities and metropolitan rings. Also, the growing areas seem to have fewer manufacturing employees than do declining ones. This is in part because the growing areas are, on the average, smaller. In addition, those metropolitan areas with very large proportions of manufacturing employment are strongly

TABLE 6

MEAN LEVELS OF EMPLOYMENT AND POPULATION, 1954

Item	Central City	Metropolitan Ring
Manufacturing (total)	98,718	70,918
Manufacturing (growing areas)	59,373	52,192
Manufacturing (declining areas)	132,442	86,969
Wholesaling	25,909	5,148
Retailing	48,753	23,626
Services	20,288	6,726
Total employment[a]	193,668	106,418
Population	724,315	656,052

[a]Does not take into account types of employment not included in the Censuses of Business and Manufactures such as construction, transportation and finance.

TABLE 7

PROJECTED ANNUAL CHANGES IN THE INDEPENDENT VARIABLES

Variable	Low Projection	High Projection (%)
Manufacturing employment:		
Growing areas	+3,083	+5.0
Declining areas	-1.1%	-0.5
Population	++2.6%	+3.5
Vacant land ratio	-5.9%	-5.9

oriented toward heavy manufacturing, which has declined secularly in the postwar period.

Table 7 gives the high and low sets of independent variable projections used for this paper. The low projections correspond with what actually happened, on the average, during the years 1954-1958. Since 1958 was a year of moderately severe recession, a higher set of projections incorporating more favorable developments in SMSA population and manufacturing employment is also included.

The projections of the vacant land variables are the same for both sets. The 5.9 percent annual rate of vacant land absorption is the mean obtained from a sample of 18 central cities during the postwar period.

Initial values of the vacant land variable are 0.271 in the manufacturing equation and 0.219 in the population equation. (These figures were obtained from land-use data collected by the authors from the 39 central cities included in the study.) A zero annexation level has been assumed when making the predictions, so the latter will refer to constant 1954 areas. Table 8 gives the predictions of cumulative changes over the periods 1954-1965 and 1954-1975.

Significant central city declines in manufacturing employment and population occur using the low values of the exogenous independent variables. The former are offset by increases in wholesaling, retailing and especially services so that total central city employment increases slightly. If the high set of values for the exogenous variables in each year is used, total employment consequently enjoys significant increases, as gains in the three employment categories again offset the moderate declines in manufacturing employment. Growth of the metropolitan rings is rapid using either the high or low values of the exogenous variables. The lower set of projections indicates small decreases in central city population, while the higher set entails slight gains. These

TABLE 8

PREDICTIONS OF CUMULATIVE CHANGES IN THE ENDOGENOUS VARIABLES IN BOTH CENTRAL CITY AND METROPOLITAN RING

Variable	Low Projections		High Projections	
	1954-1965	1954-1975	1954-1965	1954-1975
(a) Central City				
Manufacturing:				
Total	-12,568	-25,084	-5,238	-10,429
Growing areas	5,052	5,333	7,734	13,519
Declining areas	-26,273	-48,742	-15,327	-29,056
Wholesaling	803	1,240	1,385	2,358
Retailing	2,638	4,328	4,037	7,019
Services	12,639	27,034	17,229	38,780
Total employment	3,512	7,518	17,413	37,728
Population	-6,174	-20,974	12,002	13,971
(b) Metropolitan Ring				
Manufacturing:				
Total	13,536	28,210	34,692	88,873
Growing areas	28,861	59,410	74,824	193,992
Declining areas	1,617	3,943	3,479	7,115
Wholesaling	7,508	16,691	10,484	24,572
Retailing	24,415	53,961	33,694	78,532
Services	9,199	21,306	13,926	33,824
Total employment	54,658	120,168	92,796	225,801
Population	461,706	1,020,117	636,770	1,483,727

TABLE 9

PREDICTED PERCENTAGE CHANGES IN EMPLOYMENT AND POPULATION IN BOTH CENTRAL CITY AND METROPOLITAN RING

Variable	Low Projections		High Projections	
	1954-1965	1954-1975	1954-1965	1954-1975
(a) Central City				
Manufacturing:				
Total	-12.7	-25.4	-5.3	-10.6
Growing areas	8.5	9.0	13.0	22.8
Declining areas	-19.8	-36.8	-11.6	-21.9
Wholesaling	3.1	4.8	5.3	9.1
Retailing	5.4	8.9	8.3	14.4
Services	62.3	133.2	84.9	191.1
Total Employment	1.8	3.9	9.0	19.5
Population	-0.8	-2.9	1.7	1.9
(b) Metropolitan Ring				
Manufacturing:				
Total	19.1	39.8	48.9	125.3
Growing areas	55.3	113.8	143.3	371.7
Declining areas	1.8	4.5	4.0	8.2
Wholesaling	145.8	324.2	203.7	477.3
Retailing	103.3	228.4	142.6	332.4
Services	136.8	316.8	207.0	502.9
Total employment	51.4	112.9	87.2	212.2
Population	70.4	155.5	97.1	226.2

TABLE 10

HIGH AND LOW PREDICTIONS OF CENTRAL CITY AND RING EMPLOYMENT IN 1965 AND 1975 AND THE PERCENTAGE LOCATED IN THE RING 1954 BOUNDARIES

Area	Low			High	
	1954	1965	1975	1965	1975
	(a) Population				
Central city	724,315	718,141	703,341	736,317	738,286
Ring	656,052	1,117,758	1,676,169	1,292,822	2,139,779
SMSA	1,380,368	1,835,899	2,379,510	2,029,140	2,878,066
Percent in ring	47.5	60.8	70.4	63.7	74.3
	(b) Total Employment[a]				
Central city	193,668	197,180	201,186	211,081	231,396
Ring	106,418	157,076	226,586	199,214	332,219
SMSA	300,068	354,256	427,772	410,277	563,597
Percent in ring	35.5	44.3	53.0	48.6	58.9

[a]Manufacturing, wholesaling, retailing and selected services.

results seem to indicate that central city population may remain relatively stable in the near future. As in the case of employment, population growth in the ring is very rapid.

Table 9 permits comparison of the percentage rates of change in central cities and rings for 1954-65 and 1954-75. When both sets of the exogenous variables are used, central city total employment for the categories included in this study (representing approximately 60 percent of total non-agricultural employment) is estimated to increase considerably faster than central city population. Evidently the central city is more attractive as a place of business than as a place of residence. Again, ring growth is very rapid for population and all four categories of employment.

Table 10 gives the high and low predicted levels of total employment and population in 1965 and 1975 and the percentage of population located in the ring in each year. According to predictions, by 1965 at least 60 percent of the population of these 39 SMSA's will reside outside of the 1954 central city boundaries. In the same year, more than 44 percent of employment should be located there. By the year 1975, it is estimated that more than 70 percent of the population and more than 50 percent of total employment will reside outside of 1954 city boundaries. Thus, SMSA population and employment will become increasingly concentrated in the metropolitan ring.

TECHNOLOGICAL AND SOCIOLOGICAL TRENDS UNDERLYING THE MODEL

The model was based on the assumption that locational changes in manufacturing employment are the driving force behind shifts in land-use patterns that took place during 1948-1958. Today it is generally accepted that new production techniques based on continuous process methods and generally requiring single-story plants of large floor area are among the principal causes of manufacturing suburbanization. Single-story plants require large sites which are not often available in the central city (6). In addition, the growing need for parking space generated by the increasing percentage of workers using the automobile for journeys to work further increases industrial land requirements. There is just not enough vacant land in the central cities to even support present levels of manufacturing activity, let alone increase them. Furthermore, land, in part because of demolition and assembly costs, is much cheaper in the suburbs (6). Because many raw materials and finished products are now transported by motor truck, the bulk of light manufacturing is no longer forced to locate near railroad lines and yards. The same can be said for wholesaling.

Two different trends in population location, both leading toward suburbanization, stand out most clearly. The majority of the middle class seem to prefer low-density suburban living to crowded city life. Vacant land zoned for single-family residences has virtually disappeared in most central cities leaving room for expansion only in the suburbs. It is significant that an increasing proportion of city dwellers is composed of minority groups who are forced to live there either because of discrimination or low incomes. (The mean ratio of non-white to total population in the 39 central cities increased from 0.135 to 0.186 between 1950 and 1960.) People also prefer to live reasonably near their places of employment. Consequently, resident population follows manufacturing and other employment from the central cities to the suburbs. Wholesaling and retailing follow population in order to remain near their customers. The sequence of movement is likely to be manufacturing employment, population, retailing, and wholesaling. The latter probably does not move into an area until retailing is well established there. Only specialized kinds of services depending on customers from the entire metropolitan area find it convenient to locate near the city center or point of maximum access.

THE MODEL AS A FORECASTING TOOL

Before discussing the significance of these predictions for urban transportation policy and planning, there are some additional words of caution and qualification about the model. The predictions for 1965 and 1975 are obtained using constant parameters estimated from empirical information for only a single 4-yr period 1954-1958. Significant parameter shifts would invalidate or at least increase the error of the predictions. The extent to which the parameters would be expected to exhibit secular stability depends in large part on the extent to which the model includes structural relationships. The simple model presented in this paper obviously falls far short of a complete structural pattern of urban development. Still the model does have some structural characteristics. For example, the central city manufacturing and population equations based on the capacity theory of urban development do represent a beginning in terms of a more complete structural model. It is desired to construct an urban development model including the largest possible amount of structure.

The greatest single impediment to incorporating more structure into the models is the lack of data pertaining to what are thought to be the ultimate structural variables. Although the quality and quantity of data for urban areas have improved substantially in recent years, many gaps still exist. Growing awareness of urban development problems has led to the preparation and publication of an ever increasing quantity of statistical data on urban areas in a form that makes possible research of the type presented here. The 1960 Census of Population, for example, is much more useful for analysis of these problems than any previous edition. For the first time, census enumerators obtained information on the location of household members' workplaces as well as each worker's usual journey-to-work mode of transportation. Analysis of the wealth of information available from this new source will substantially enhance understanding of urban development and the interrelationships between urban development and urban transportation. Although the Census Bureau should be given the credit for these very large improvements in the 1960 census, it is desirable to expand and further develop this line of exploration. In the next census they should be encouraged to reduce the level of aggregation of the workplace data even further. Although the analysis presented here is a prima facia case for the proposition that highly aggregative data can be extremely useful and informative regarding metropolitan change, it suggests underutilizing existing sources of published information. It also suggests the tremendous gain that would be possible from greater geographic disaggregation.

As pointed out previously, the greatest weakness of the data used here is its relatively high degree of geographic aggregation; most of the statistics refer to central cities or to metropolitan rings. Thus, exact changes in employment and population levels within subareas of the central city and ring of any particular SMSA cannot be specified. This is less of a disadvantage for the cross-sectional analysis of several urban areas than if these changes for a single urban area were being described and analyzed. The metropolitan areas in the sample differ substantially in their population levels and characteristics, employment levels and distributions, growth rates, ratio of ring to central city area, etc. These differences between central city and ring characteristics and size make it possible to infer much about urban growth processes in both areas. This is particularly true of the results obtained using the more sophisticated multivariate statistical techniques. For the statistical analysis, the size of the geographic areas or the fact that they are not especially delineated is less important than whether the geographic areas differ or have significant statistical variation in the dependent and independent variables used. Geographic disaggregation only provides more information if it increases the homogeniety of the subarea and/or increases the variation between subareas. This is usually, but not always, the result of greater disaggregation.

The model's parameters for the 1954-1958 period rather than 1948-1954 were estimated because the earlier period contained too many disturbances and was too greatly affected by postwar adjustments to provide meaningful parameter estimates. This conclusion is strengthened by the fact that the results obtained for the first period, in estimating these and other relationships, are much inferior to those obtained for the second, i.e., the regression coefficients have less statistical reliability and the equations explain a smaller proportion of total variance.

The time paths assumed for the exogenous variables may be unrealistic. The estimate of the change in SMSA manufacturing employment, for example, may be too low or too high for use in a long-range projection of this kind. However, the projections of the independent variables were made wide enough apart so reality should lie somewhere in between for most of the 39 SMSA's. The predictions should be considered limits on what is likely to happen rather than exact forecasts for any specific city.

Another shortcoming of the model is that it does not include all types of employment. Construction, transportation, public utilities, finance, insurance, real estate, government, and a number of service trades (altogether about 40 percent of the civilian non-agricultural labor force), are not included because the necessary data are not available. Proprietors of unincorporated enterprises (especially important in retailing and the service trades) are also excluded from the model. It is possible that inclusion of these omitted employment groups might drastically change the picture of urban development suggested by the model's predictions and by the empirical data in Tables 1 through 5. Consequently, the empirical findings of this paper should be evaluated with these shortcomings in mind.

If these omitted employment groups are considered, however, only finance, insurance, some federal and state government employment, and some business services would, on the basis of other information, seem to be groups for which much different locational trends would be expected. Local government employment is nearly as much, or more, population oriented than retailing, as is a considerable portion of federal and state government employment, i.e., the post office, the social security administration, the department of motor vehicles, etc. Construction employment would be located where new construction occurs—predominantly in the new fringe areas. Much public utility and transportation employment is also population oriented. The greater use of motor trucks, piggy-backing, the rapid suburbanization of wholesaling and manufacturing, and finally the expansion of air transportation are all trends which suggest a rapid suburbanization of employment in intercity transportation.

The model is only a crude approximation and considerable extension and refinement of it will be necessary before it provides a highly accurate and reliable picture of the future development of urban areas.

Despite its limitations, the model suggests several significant trends. It demonstrates that the absolute levels of manufacturing employment and population in the central cities of slowly growing SMSA's are likely to decrease over time. Moreover, it exhibits the fact that very large increases in metropolitan population and employment are consistent with only moderate increases and perhaps even declines in central city population and employment.

SUMMARY

A considerable amount of empirical information bearing on the redistribution of employment and population has been presented. This information indicates that fundamental changes in the distribution of these categories have occurred during the postwar period. The empirical findings can be summarized by stating that the observed trends strongly indicate rapid growth in the levels of employment and population in the metropolitan ring and only slow growth in the central city. If the trends of recent decades persist, tomorrow's urban areas will have a considerably different appearance from those of the past. Metropolitan densities will become more uniform since growth in the ring is rapid compared to the central city.

Automation, continuous processing and other mass production techniques have tended to make outlying locations where cheap sites may be obtained superior to more central locations for the construction of the requisite one-level manufacturing plants. By the more widespread use of motor trucks, all but a few freight intensive employment activities have been freed from locations near rail lines, spurs, or deep water. Shifts in the composition of national output towards services and other non-manufactured goods have meant that less employment is freight oriented.

Increases in per capita incomes, improved credit availability, and the availability of a relatively cheap and ubiquitous mode of individual transportation have encouraged and made possible the consumption of low-density residential services by larger numbers of urban households. The evidence is substantial that many urban households with school-age children prefer the privacy and other amenities provided by single-family and other low-density forms of residential development and are willing to devote a larger portion of their budgets to their purchase.

Nevertheless, the predictions in Tables 8 and 9 indicate that in the future, employment in the central cities will increase faster than population. This implies that more journeys to work will be made between the central city and metropolitan ring. Consequently, the flow of traffic between these areas is likely to become heavier in all but the few slowest growing SMSA's.

Unfortunately, the analysis does not tell whether the increases will occur in the fringe areas or the CBD. In the former case, increased highway construction is likely to offer the best solution to the urban transportation problem. However, if there is considerable expansion of employment near and in the CBD, mass transit systems become more attractive. Clearly, more research needs to be done before the best mix of transportation facilities can be specified.

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Demand, Cost, Price and Capacity Relationships Applied to Travel Forecasting

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• SOME of the more recent travel forecasting research and studies have dealt with the feedback mechanism between trip distribution and capacity, and between route assignment and capacity. In other words, these studies have recognized the interdependencies among assigned or distributed volume, travel time (or travel "resistance"), and route or system capacity. A generalized form for the travel forecasting process which includes these feedback loops is shown in Figure 1.

To understand the interworkings of this forecasting model or process, and its implied interdependencies, it will be helpful to make use of some simplified capacity-demand-cost principles and relationships and to illustrate how these may in turn be used to relate explicitly the design variables. The value of this "conceptual" and "academic" exercise will be to indicate in more precise terms the nature and form of the information that will be required to make more accurate travel forecasts (or perhaps to reduce the computations involved).

GENERAL PRICE, VOLUME, AND DEMAND RELATIONSHIPS FOR FIXED CAPACITY SYSTEMS

For any particular system whose physical capacity or ability to accommodate traffic volumes is "fixed" (in the sense of having a definite number of roadways of specific widths, intersections of fixed approach widths and with specific control devices, etc.), the amount of capacity may also be described as its "supply." Although the system capacity is unchanging or fixed, the volume which uses the system at different times may, and usually does, change quite considerably. And from experience it is known that any particular system does not necessarily offer a fixed or constant level of service; in general, for a particular capacity level as the entering or input volume changes so does the resulting level of service. (The relationship between volume and speed on freeways is a well-known example.)

The level of service which the traveler experiences or must endure (at some particular level of volume for a given system capacity) shall be defined as the price of travel, where price is defined in terms of the combined difficulty of travel, required time for travel, hazard and discomfort of travel, and expense of travel as viewed by the traveler.

The price paid by the traveler need not be equal to the actual cost to provide that travel service and capacity. The price to the traveler may actually be less or more than that paid by the public at large for his using the facility. In order to predict how many travelers will use a particular facility, the actual cost of providing transportation is irrelevant; the only matter of concern is what price the motorist or traveler will have to pay if he travels (where price is stated in whatever terms the traveler imputes). Thus price of travel may be thought of as cost to the traveler and not as true cost. Also, price as described here includes much more than the out-of-pocket money expenses associated with travel.

A price-volume curve is used to show the relationship between actual price of travel and the volume using a particular facility or system of fixed capacity, and, generally,

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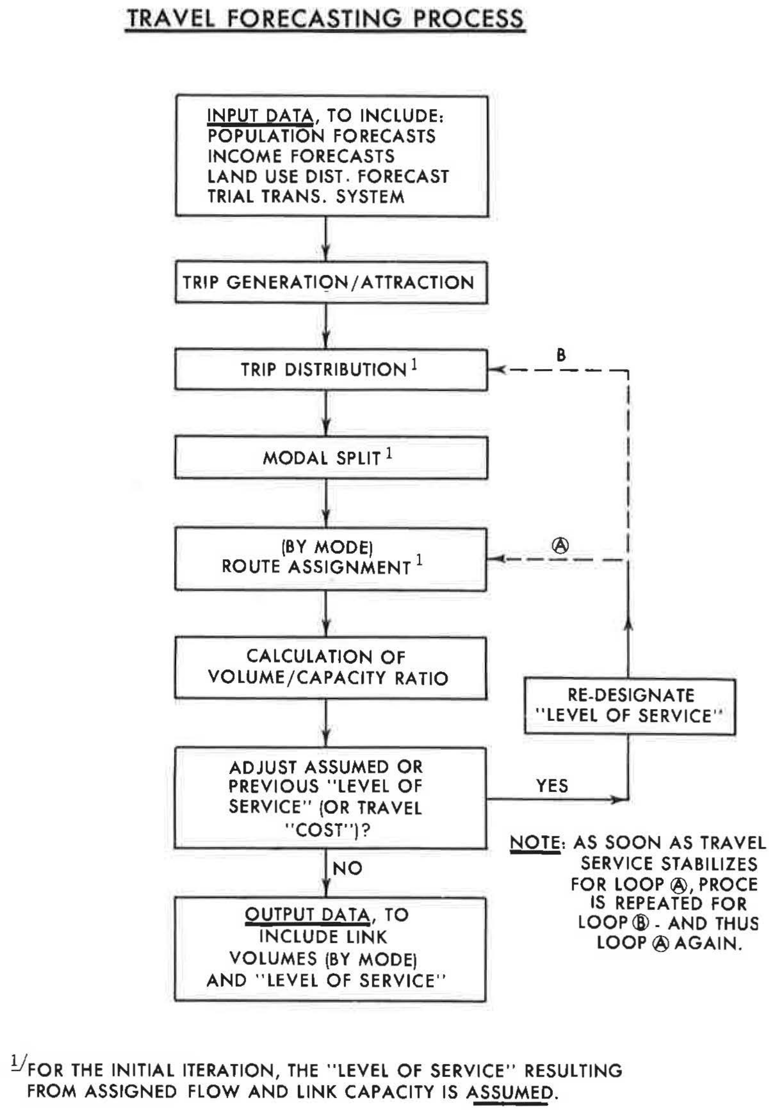


Figure 1.

the curve may be characterized somewhat as in Figure 2. This curve is just another way of saying: If the volume increases, the price of travel to the individual traveler will change as indicated. On the other hand, no information is provided or implied regarding how many travelers will use the facility or what the demand will be.

The solid curve (Fig. 2) shows the price-volume relationship for public highways operating under existing taxation methods. With these methods, the highway user and excise taxes paid by the individual traveler on using a particular facility do not vary with the construction and land acquisition cost of that facility or with the volume using the facility (except in almost negligible amounts). In such a case, the user and excise charges that the traveler pays are only a small fraction of the total price of travel; his vehicle ownership charges, time, discomfort and inconvenience costs outweigh his user charges by ten to twenty times.

On the other hand, it should be evident that such a single price system of taxation for facility construction, right-of-way, maintenance and administration (regardless of

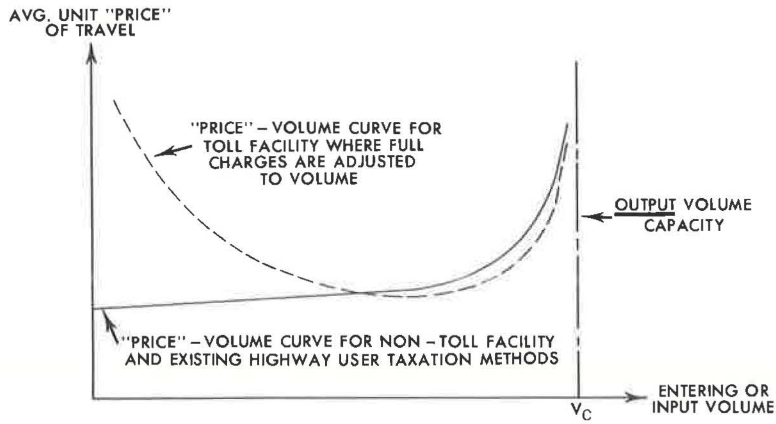


Figure 2.

the actual facility costs and regardless of the volume using the facility) produces some inequities. In short, it results in undercharging the users at low volume levels and overcharging them (for the facility costs) at high volume levels. The dashed curve (Fig. 2) indicates the price of travel for the case where the facility costs are adjusted to the particular volume using the facility. At low volume levels where the threshold or fixed costs are spread over a very low volume of traffic, the unit construction and right-of-way costs are quite high and are a major portion of the total price of travel paid by the motorist. As the volume rises these same construction and right-of-way costs are spread over a much larger volume; thus the unit cost for construction and right-of-way is reduced, and becomes a smaller portion of the total price of travel for the motorist (again, to include time, discomfort, inconvenience, etc.).

Both of the pricing systems are average cost pricing schemes; that is, at any particular volume level, the charge for facility construction and maintenance is the same to any motorist. But the latter scheme permits scale economies to be reflected in the charge to the user. Furthermore, the former scheme—where the user charge remains constant for all volume levels—is more characteristic of the present-day, public highway system and thus provides a more realistic description of the actual price of travel to the motorist. Thus the solid curve (Fig. 2) should normally be used in travel forecasting analyses. On the other hand, for toll facility forecasting, where the toll fee is adjusted according to the particular (long-run) volume level, the dashed curve would be the proper one.

Particular note should be made of the definition of volume level. The solid curve in Figure 3 demonstrates the relationship between price of travel and the entering or input volume for a facility or system of some fixed output capacity. As the arrival or input volume approaches (or exceeds) the output capacity, and is sustained at that level, the price of travel (that is, delay, etc.) becomes indefinitely large as the queue length on the approach ramps to freeways or on approaches to intersections continues to build up. A key word here is, of course, sustained. If, for example, the input volume rate exceeds the output volume rate only for a few minutes or for a fraction of an hour but then falls below the output volume rate for the remainder of the time, it is clear that the delay and thus price of travel will not become indefinitely large. Thus, it must be emphasized that the price-input volume curve is characteristic only for a given time period. If the time period changes, so will the shape of the curve, particularly as the input volume rate approaches the output rate (Fig. 4).

In all systems or on all facilities, regardless of the type of control, the arrival or input volume can and often does exceed the output volume; in fact, in urban areas evidences of this are seen almost every day during the peak periods. Traffic backs up on freeway ramps or connecting city streets; or queues build up along arterials or on ap-

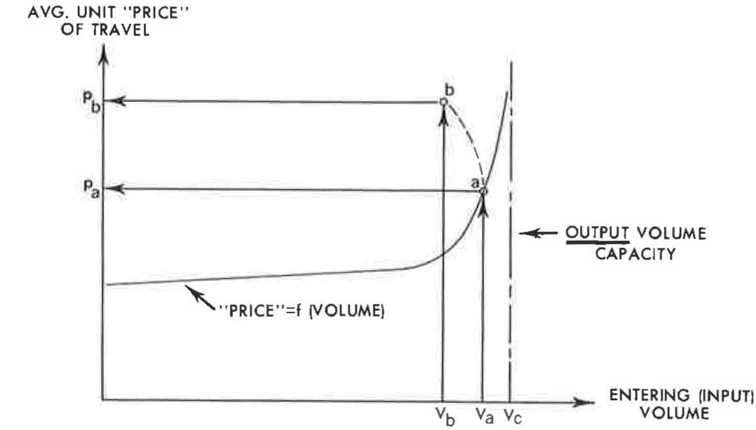


Figure 3.

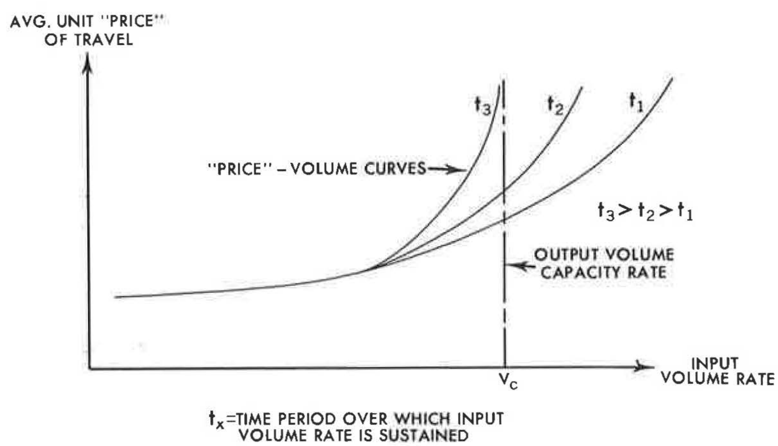
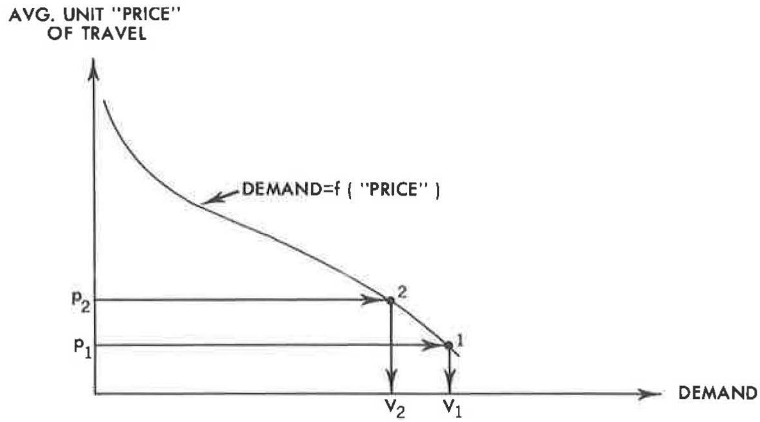


Figure 4.

proaches to intersections, etc. (While the traffic in many cases cannot actually enter the facility in question, but must wait on the side street, this analysis shall consider it as entering or input volume.) Frequently, though, it is suggested that such is not the case (that is, that input does not exceed output) by considering only part of the system rather than the entire framework. For example, in examining the flow actually passing through a tunnel or through the bottleneck area of a freeway, the phenomenon described by the dashed curve in Figure 3, or the so-called backward-bending curve, is often observed. One might be led to say that the demand was being reduced. On the other hand, such is not necessarily the case. This curve, in fact, only demonstrates the relationship between price of travel and output volume; furthermore, it indicates that the performance of the facility is such that the output volume capacity is being reduced because of shock action congestion. And, again, while the output volume is being reduced (from a to b), the input volume and its price of travel can still be increasing. The dashed curve therefore only provides price of travel for the output volume—and not for the input volume. The price for the input volume still increases indefinitely as the volume approaches and exceeds the output capacity. Since the output capacity is shifting to the left (from a to b), the price-input volume curve probably also shifts to the left.



NOTE: THE DEPENDENT AND INDEPENDENT AXES ARE REVERSED FOR THE DEMAND CURVES

Figure 5.

The two curves in Figure 3 suggest, of course, inefficiency in the network design or control. It is obviously more desirable to handle greater volumes at less price to the traveler (such as at point a) than less volumes at a higher price (point b). Studies on metering or monitoring traffic flow are directed at just this problem, that is, attempting to control the output volume and capacity and avoid the backward-bending case.

The solid curve is characteristic of conditions at facilities with controlled flow (such as signalized intersections), whereas the dashed curve is more representative of flow on facilities with little or no control, or of flow on expressways with more entering lanes than through lanes.

Thus far the capacity curve utilized (in Figs. 2 and 3, for example) has been explicitly described as a price-volume curve rather than a cost-volume curve. The difference is, of course, that a cost-volume curve would include all items of cost, whether or not the traveler actually had to pay the costs, whereas the price-volume curve only includes those items of cost which the traveler actually does pay (or thinks he pays). The distinction is of obvious importance in trying to predict whether or not travel is to be made, and on what routes, etc. And it is clear that the price curve is the relevant one for travel forecasting.

To determine how many travelers will use a facility or system, the demand curve is necessary. A demand curve is, in simple terms, a graphical statement showing the numbers of travelers who will buy or purchase travel at different levels of price. In other words, it states the value which different volumes of travelers are willing to place on making a trip; Figure 5 shows such a relationship (the dependent and independent variable axes have been switched to be consistent with the usual economic theory practice). The slope of the demand curve indicates the extent to which the demand is price elastic or inelastic. Furthermore, a particular demand schedule holds valid only for specified conditions of consumer preference (alternative uses of resources, etc.), incomes, population, etc.; thus shifts in the demand curve may take place as the result of a shift in the primary determinants (such as prices of other goods, population growth, and income levels). The demand curve indicates how many consumers are willing to pay (in terms of monetary expenses and the service costs of discomfort, inconvenience, travel time, etc.), and therefore indicates the value of travel to them (as a group). (In essence, then, this implies that equivalent monetary values have been determined for service variables.)

Given a pair of price-volume and demand schedules for travel on some particular facility or system, it would be possible to determine what volume of traffic would in fact use the facility, or, to put it another way, one could determine precisely what vol-

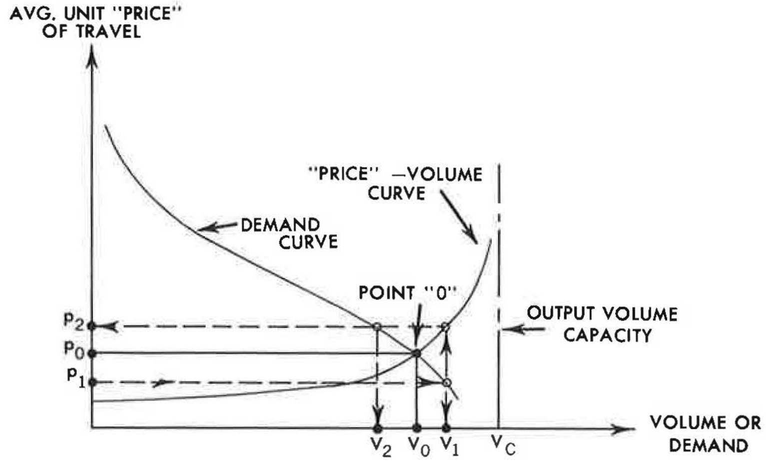


Figure 6.

ume would actually pay the price in time, discomfort, inconvenience, accident hazards, and expense associated with travel on that facility or system. Figure 6 places the price-volume and demand curves for a facility of fixed output volume capacity on comparable scales. Under the conditions shown, the resulting or actual input volume will be V_0 and will be operating at the average unit price of p_0. If, for example, a higher volume V_1 were to use the facility, this volume could only operate at the higher price level of p_2, and, at this price level, the demand schedule indicates that only volume V_2 would actually pay the price p_2—and so forth, until the volume and price stabilize as indicated by the intersection of the two curves.

It is clear that these curves should (to be realistic) include confidence limits; that is, some indication should be made of their variability. As noted, the curves are based on average unit price of travel over some time period (say, one hour, for example); during this time period the travel times, queueing waves, etc., will vary considerably around this average unit price. Thus the resulting (or expected) volume should be stated along with some estimate of the error or variability. This has been overlooked herein for simplicity.

It seems reasonable to expect that the actual volume will stabilize around the intersection point of Figure 6 fairly quickly and accurately. Travelers, on deciding whether or not to make a trip, on what route to make the trip, or what mode of travel to use, are guessing or estimating in advance of the travel two things: (1) What is the trip worth?; (2) How easy, cheap, and quick will it be to travel?

With regard to the last question, intuitively the traveler is guessing what the price-volume curve will look like, how many other travelers will be using it at the same time, and therefore how easy, comfortable, convenient, quick, and cheap the trip will be. (Thus one is guessing where the intersection point will be in relation to his position on the demand schedule.) If it is felt the trip will be too expensive, too time consuming, and too uncomfortable (that is, that the resulting price of travel will be higher than the value of making the trip) then he will not make the trip; of course, this is just another way of saying that the position on the demand curve is to the right of intersection point.

It seems fair to state that most of the time urban travelers estimate the intersection point reasonably accurately, and thus make rational trip-making decisions (at least in their frame of reference). Every now and then, however, someone finds he has misjudged the circumstances and learns to his sorrow that traffic congestion was much worse than expected. And the result of this misfortune may be that the traveler is "sorry" that he took the trip (or went that route, etc.). The price of travel forced upon him was higher than what he would have paid if he had known in advance about the service. Consequently, he is one of the people to the right of the intersection point, and by

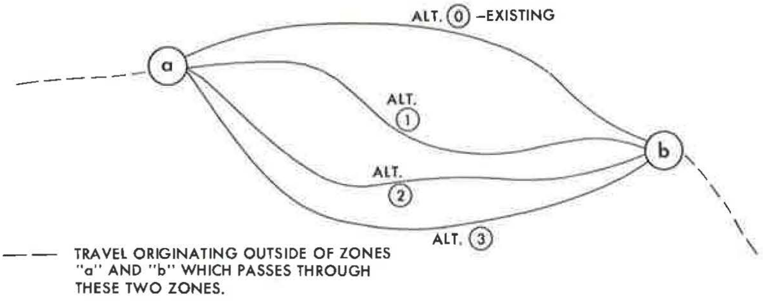


Figure 7.

virtue of having made the trip he has lost value (that is, paid an additional and what might be called an unreliability cost).

Careful examination of some recent travel forecasting models and procedures with capacity restraint features (1) will reveal that the feedback loops in these models merely provide a computational method of determining the point at which the demand and supply curves intersect; more specifically, the feedback and iterations are made to determine the actual volume and price level, such as volume V_0 at a unit price p_0 (Fig. 6). (In most of these capacity restraint models, travel time is used as the price determinant, though some recent ones permit inclusion of "out of pocket" expenses.) If through a feedback mechanism, the volume-demand levels do stabilize (or reach an equilibrium) with successive iterations, demand and price-volume curves are implied. Thus, it would seem that the point of intersection could be determined directly and uniquely without iterations.

The foregoing conclusion regarding unique determination of the actual volume using a facility (and its associated price of travel) will, however, hold true only for certain specific circumstances (though in some other instances the error introduced may be small enough to ignore). For example, in Figure 7, two trip generation zones have been isolated from the remainder of the region or community and four alternative routes for connecting these two zones are being considered (assuming one of these four is an existing roadway). If the travel originating outside of zones a and b which passes through these two zones were not dependent (or at least were dependent only to a negligible degree) on the travel conditions of the highway link between a and b, then it would be possible to make a unique and direct determination of the actual volume level and associated price of travel for each of the alternative links. For this idealized situation, it should be evident that a single demand curve for travel starting at zone a and ending at b (or vice-versa) will apply to all four alternatives; on the other hand, each of the four alternatives will (probably) have a different price-volume curve since the lengths of links will probably differ (and thus vehicle operating costs), and since travel times, discomfort, accident hazards, and travel difficulty will probably differ for each link. For this case, the existing user-charge taxation system has been assumed. Thus, differences in construction and right-of-way costs will in no way affect the price.

The effect is shown in Figure 8. The price-volume curves for the four alternatives have been plotted in terms of the total volume using each of the links between a and b, and they have been plotted with $Axis_1$ as the y-axis, or zero point for the abscissa. However, the demand curve for travel starting at zone a and ending at b (or vice-versa) cannot be superimposed directly on these price-volume curves without first shifting the y-axis, because the price-volume curves apply only to total volume on the link and the demand curve applies only to those trips with both ends of the trip at a and b and thus does not include the through volume. $Axis_2$ should be used for plotting the demand curve; obviously it will be necessary to shift the entire volume or x-axis while plotting this curve. Once the demand curve has been shifted, however, $Axis_1$ and the associated volume scale should be used for all calculations, because the original demand curve now includes the through travel as well.

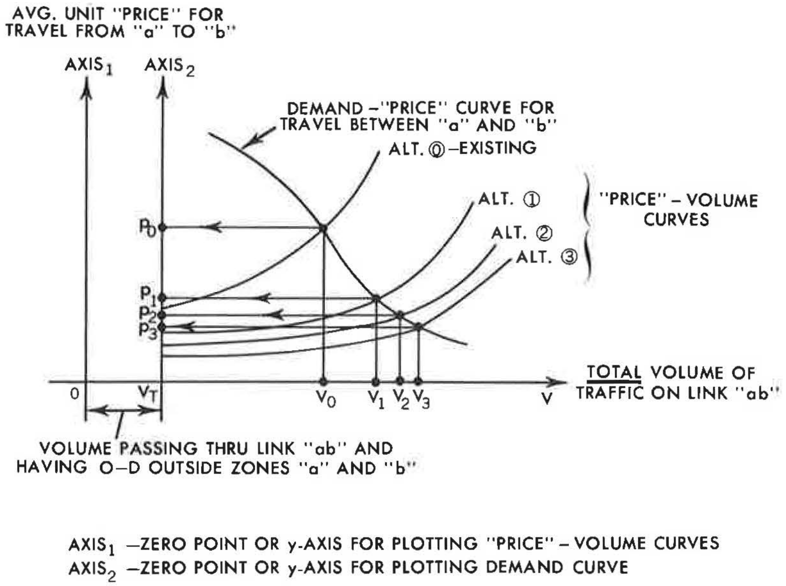


Figure 8.

The situation wherein the amount of through travel was considered independent of any changes in travel service or price may, of course, represent such an idealized case as to be of little use. But in these cases where corridors are sharply defined and particularly where the system has a limited number of links (that is, in rural or inter-city areas, or corridors where virtually all travel has common origins and destinations, and where there are few cross-linkages), application might seem more reasonable. Or to be more precise, the method becomes more and more useful as the demand for outside travel passing through the link becomes more and more inelastic.

An obvious question arises regarding the usefulness of price-volume and demand curves for forecasting urban travel. In the first instance, it appears that they would have application, at least in terms of explaining the forecasting process and the way in which the different prediction phases are interrelated. For example, in some of the more recent travel forecasting and modal split models, the capacity restraint feature insures a balance between link capacity and the volume that is assigned to that link, and insures that the assumed travel speed over that link is equal to the actual travel speed that can be maintained. The iterative process used to determine this balance between volume and capacity and between assumed and actual speed is analogous to determining the intersection point between price-volume and demand curves. But can the latter be substituted for the former in the travel forecasting process?

Figure 9 depicts on a small scale a region having five zones of travel generation or attraction and served by a simple right-angle transport system (but one of many links and possible travel paths). It is assumed that there is no traffic on the transport system which is external to the five zones of travel generation/attraction, and that the external-internal movement can be considered negligible.

For most present-day travel forecasting processes, the major steps are as shown in Figure 10. In step I, the number of trips generated and attracted by each zone is calculated. Unfortunately, though, in virtually every present-day forecasting process these trips are assumed to be independent of the travel conditions or price of travel (as previously defined); that is, travel starting or ending at a zone is considered to be perfectly inelastic. In some instances, though, the zonal trips'ends are regarded as a function of the transportation "accessibility," and thus this statement would be inaccurate. On the other hand, even in these instances, the total trip ends for the region as a whole are held constant; consequently, the criticism would still hold true but at a higher level.

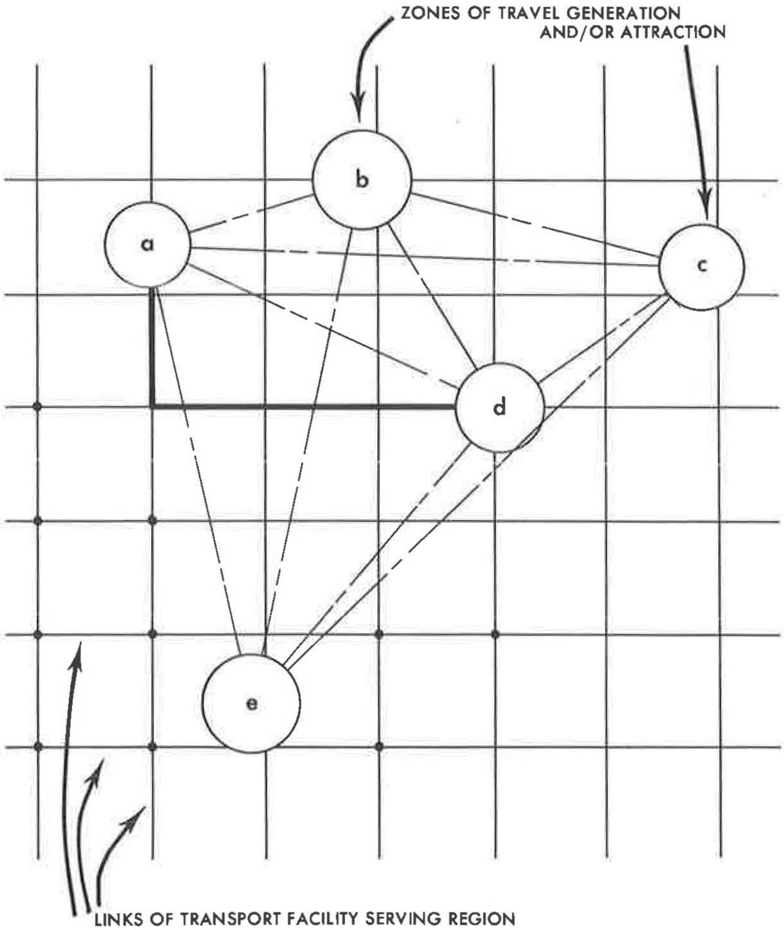


Figure 9.

Certainly, it might be argued that work trip ends are inelastic, and that the only problem is that of splitting work trip ends which start at zone a among each of the other zones and among each of alternative travel paths. It is difficult to imagine, though, that business trip ends, or shopping trip ends, for example, are not a function of the price of travel. Infinite cross-elasticity seems out of the question for all trip purposes, and it is suggested that a feedback link may be necessary between step V and step I (Fig. 10), at least for certain trip purposes.

Step II (Fig. 10) corresponds to the trip distribution phase, or computation of interzonal transfers between all pairs of zones. Often these transfers are calculated using a so-called gravity model, in which zone-to-zone travel time and zonal trip ends are usually the prime determinants for splitting the trips generated at zone a, for example, among each of the regional zones of attraction. In a very real sense, the trip distribution "gravity" model operates as a demand curve wherein the assumed travel times for the first iteration serve as estimates of the intersection point of price-volume and demand curves; successive iterations between steps V and II only refine the initial guesses. Such an analogy falls short, though, in that demand and price (or travel time for most models) are measured on a relative rather than absolute scale.

Step III (Fig. 10) is similar in many respects to the trip distribution phase; it serves to split the interzonal transfers (calculated in step II) for each interzonal pair among the alternative travel paths. For most studies, either the route travel time or the

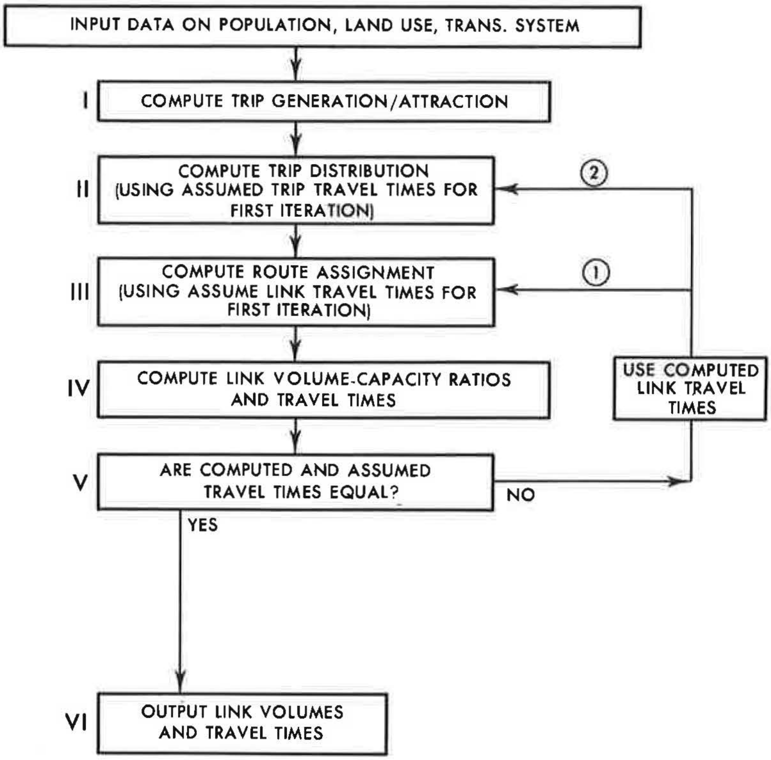


Figure 10. Simplified travel forecasting process.

route travel time plus terminal time is the prime (and only) determinant of the route splitting. Where the so-called capacity restraint feature, or feedback loop such as ①, is included as part of the travel forecasting process, individual link travel times are used and accumulated in computing route travel times and, in turn, in computing the assigned route volumes. Again, the route assignment procedure is somewhat analogous to the price-volume and demand curve intersection procedure, except that relative rather than absolute scales are used.

Step IV of the procedure differs distinctly from the other parts of the process. In essence, it is at this stage of the procedure that system capacity or price-volume relationships are introduced and related to the demand characteristics. There is an important difference, however, between price-volume curves for a simple link system such as in Figure 7 and those for a multiple link system such as in Figure 9. In Figure 7 (and the relationships previously described), the price-volume and demand curves can be reconciled; that is, the volume in both the price-volume curve and demand curve will represent the same travelers. In Figure 9, however, there are two problems: (a) the price-volume curve for travel between any pair of zones can only be represented by a series of price-volume curves; that is, by the accumulation of price-volume curves for the links between the pair of zones; and (b) the volume on any one or all of the links between the pair of zones will seldom be the same volume represented in the demand curve. Thus the two sets of curves cannot ordinarily be reconciled.

Considering the travel between zones a and d (Fig. 9), there is a certain utility associated with people traveling from zone a to zone d (or vice-versa)[1]; however, the

[1] Obviously the utility is not associated with the travel but with the arrival at a destination where desirable goods or services (in a broad sense) will be obtained; the utility or satisfaction or value received from the trip in a real sense depends on each individual, on his own value scale, on the nature of the trip purpose, and on the effort and/or cost expended at the destination to acquire the goods or services.

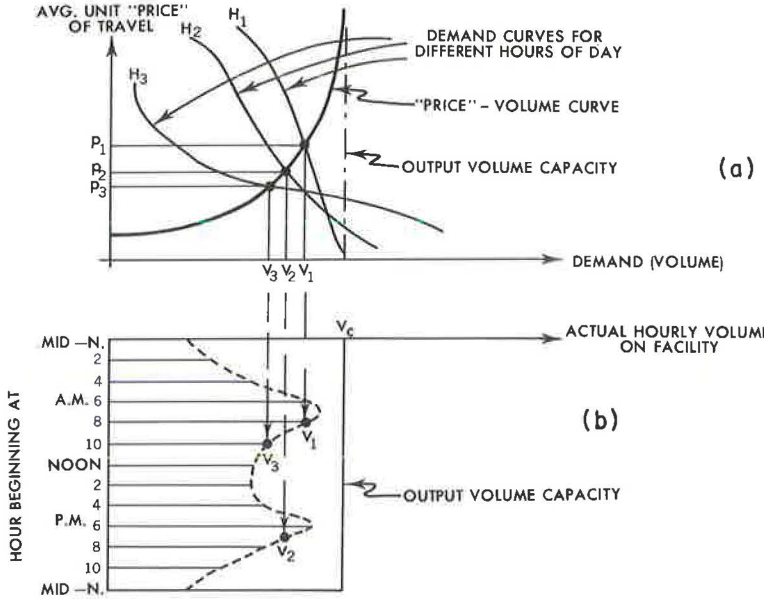


Figure 11.

net gain to the traveler from making the trip is a balance between this utility and the price of making the trip. As the price increases, there is decreasing net gain and thus decreasing demand. However, it must be recognized that the price of travel between zones a and d is not just dependent upon the amount of travel between these two zones (which, for example, takes place along the travel path marked by the heavy line in Fig. 9). It is also dependent on travel moving along this travel path or parts of it from other pairs of zones. In other words, travel between a and e, or between d and e, which uses portions of this travel path can also congest the travel and thus increase the price of travel between zones a and d, and thus affect the demand for travel between zones a and d.

From these remarks, one must conclude that when forecasting travel for networks, it is probably advantageous to use iterative procedures rather than to try and determine the intersection points for demand and price-volume curves by analytical or graphical procedures.

OTHER DEMAND-PRICE RELATIONSHIPS

In an urban society, it is seldom that any given facility or system or individual link of a system operates at just one level of volume and price, as suggested by the intersection point in Figure 6. Usually, volume and travel price will vary considerably throughout the day, with high service (or low price) during off-peak hours and low service (or high price) during peak hours. Essentially, this may be interpreted to mean that the demand-price relationship is changing throughout the day (the changes being the result of different trip purposes, and income levels, for example). Figure 11a characterizes one possibility for the changing demand-price curve, and helps explain the occurrence of several actual demand or volume points for a given facility during the course of a day. Assuming that there is an individual link of a system which can be isolated from the remainder of the region, and which can be represented by a simple price-volume curve, the varying demand curves can be interpreted to mean that different kinds of trips are made at different hours of day, and that these various kinds of trips have varying degrees of utility or satisfaction associated with them. The demand curve for hour H_1, for example, might represent the situation from 8:00 to 9:00 AM, when most of the travel is from home to work and therefore has high utility. (This is just another way of saying that these people will endure consider-

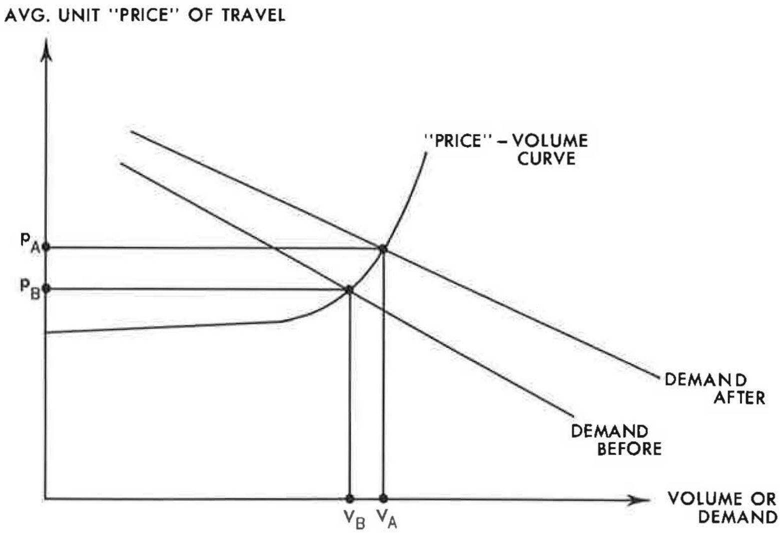


Figure 12.

ably more congestion than people whose trip purpose has less utility.) The other two demand curves might be applicable, for example, to 7:00 to 8:00 PM travel when many travelers are making social-recreational trips (curve H_2), and to midmorning 10:00 to 11:00 AM travel when trips consist mainly of business and shopping purposes.

The intersections between the price-volume curve and the three hourly demand curves have been projected on a volume-time plot (Fig. 11b). If all the 24-hr demand curves were available and if their intersections with the price-volume curve were similarly plotted, a distribution somewhat similar to that shown in Figure 11b might be expected.

At this point, it is useful to ask what changes might occur over time—that is, over the years—and how these changes might affect these relationships. First, with population increases it seems reasonable to expect shifts in the demand curves; that is, each year will have a higher volume of people willing to pay a given unit price for a particular trip, everything else remaining equal. As a consequence, the volume-time of day distribution (Fig. 11b) will gradually increase over the years. However, as the volume during the heaviest hour approaches the output volume capacity of the facility, further shifts in that demand curve may not occur but travelers may shift to other facilities, or may travel during other hours of the day. Indeed, a phenomenon often experienced in many urban areas is that over the years little increase is recorded during peak hours, and most of the increases occur during off-peak hours.

Similar shifts in demand curves may occur as a result of changes in consumer preference patterns, or perhaps as a result of real income increases. These changes may produce uniform shifts, but it seems more likely to expect disproportionalities. For example, income effects might shift the demand curve for shopping and business type travel to a larger degree than the demand curve for work trips.

These types of shift may be illustrated somewhat as in Figure 12, which includes demand curves before and after income and population increases. The net result of this increase would be a rise in the unit price of travel from p_B to p_A and in the volume of travel from V_B to V_A.

EFFECTS OF CHANGING SYSTEM CAPACITY

To understand the consequences of changes in capacity that result from improvements in the transportation system, Figures 13 and 14 are helpful. Figure 13 represents the relationship between the unit price of travel and the system capacity for a fixed or constant volume of travel. This curve depicts three things of importance:

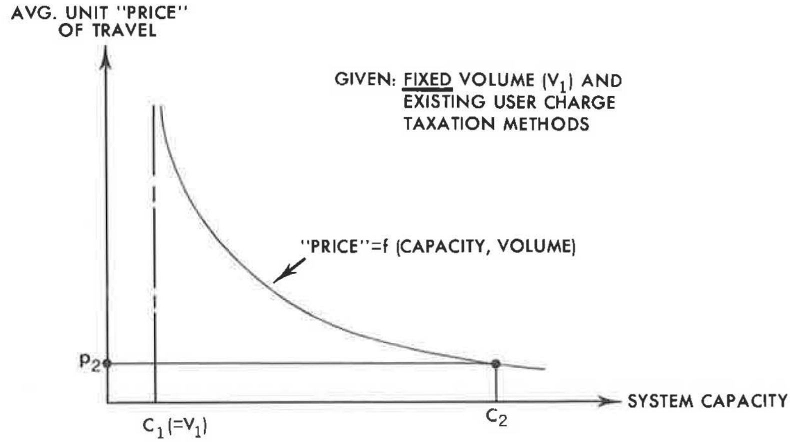


Figure 13.

1. It exhibits a general reduction in price as the system is improved (roads widened, radii increased, vertical curves lengthened, etc.).

2. Once the capacity is increased above a certain level (for example, C_2), further improvements to the system would have little effect on unit travel prices. Essentially, this describes the point at which this particular volume of traffic is suffering only a negligible amount of discomfort, the point at which the traffic is moving almost as fast as desired, the point at which the accident rate is extremely low, and the point at which substantial reduction in travel price can be achieved only by very large improvements or capital investment (such as installing an electronic highway-vehicle control system).

3. With a system capacity equal to or less than C_1, which is equivalent to the fixed volume of travel V_1, the unit price would be extremely large; in fact, with a sustained volume level which is equal to or greater than capacity, the unit price would approach infinity.

The effects of increasing system (or link) capacity can also be illustrated (Fig. 14). The price-volume $curve_1$ represents the relationships before improvement (or adding capacity), and $curve_2$ the situation after improvement. Such improvements will generally reduce the travel times, the accident hazards, discomfort, and inconvenience; also, under existing methods of taxation, and except for toll road travel, the price charged for the roadway construction, maintenance, and administration will remain virtually unchanged, thus the total unit price of travel will be reduced by the improvement.

In this illustration it is suggested implicitly that additional investments to increase capacity will generally lower the price-volume curve. One might argue, then, that since the unit price includes the costs for construction, maintenance, and administration, additional investment is always justifiable. However, recalling previous discussion, it was noted that the price-volume curves to be used in most of this paper would include only the costs of construction, maintenance, and administration which the user is actually charged under existing taxation methods. As a consequence, any additional capital or maintenance costs which are incurred to improve the facility are not included in the new price-volume curve (that is, $curve_2$), except for the user charges paid in by entirely new or additional travel. Thus, the curves (Fig. 14) by themselves will not permit any conclusions regarding the justification of improvement.

BENEFITS FROM IMPROVEMENT OF SYSTEM CAPACITY

Under the conditions in Figure 14, the volume of travel will increase from V_1 to V_2, while the unit price of travel will decrease from p_1 to p_2. The additional volume added after improvement (V_1 - V_2) represent travelers diverted from other facilities, those making more frequent trips, those switching from other modes of travel, or those mak-

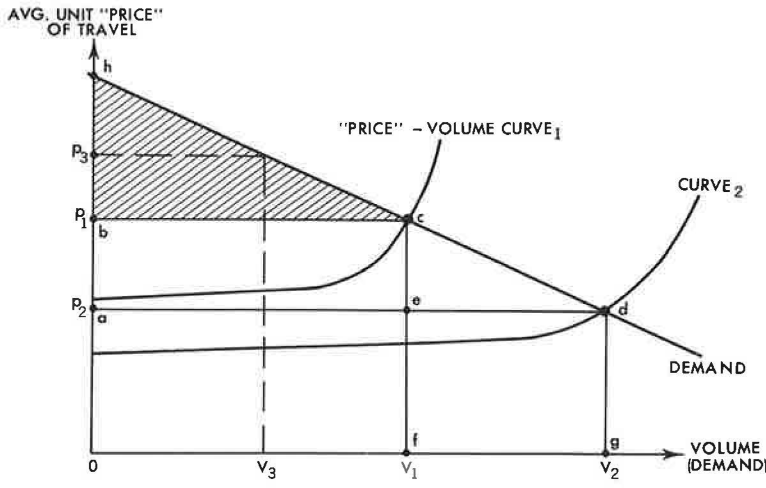


Figure 14.

ing entirely new trips. The existence of each of the new trips may be interpreted to mean that in each case the benefit achieved by virtue of making this trip is greater than that which can be obtained by an alternative use of the time, effort, and expense involved (which in this case would be p_2). In the sense used herein, benefit is defined as the difference between the value or satisfaction afforded the traveler (and described by the demand curve) and the unit price he must pay for the trip.

Certainly, each traveler using the facility must be receiving a benefit from the trip (exception for the trip at the margin), unless he misjudged the actual unit price he would have to pay. For example, prior to improvement, a traveler willing to pay a unit price of p_3 would experience a benefit of $p_3 - p_1$; after improvement, his benefit (ignoring any changes because of interpersonal comparisons) would increase to $p_3 - p_2$. Extending this to the entire volume V_1 using the facility before improvement, the total benefit of these travelers is equal to the shaded area, or triangle hbc. After improvement, the benefit to the volume V_2 would be represented by the triangle had. Thus, the additional benefit afforded these travelers by the improvement would be the difference, or area badc.

The extra volume ($V_1 - V_2$) added as a result of the improvement is handled differently than the original volume in computing additional benefit. The additional benefit for each traveler in the original volume V_1 is equal to price before p_1 minus the price after p_2 ($p_1 - p_2$); but the additional benefit for each extra traveler ranges from that same value ($p_1 - p_2$) down to zero, and on the average will probably be about one-half the additional benefit of each original traveler or $\frac{1}{2}$ ($p_1 - p_2$). The exact value, of course, will depend on the shape of the demand curve. One-half is suggested merely as an approximation. Study of some engineering economics reports will show that the entire difference is often incorrectly regarded as additional benefit for these extra travelers.

Finally, it must be emphasized that the additional benefit described does not represent net value added as a result of the improvement. First, any effects of traffic diversion and the additional benefits that might accrue to the remaining (and new) travelers on other facilities as a result of former travelers diverting to the improved facility have been ignored. Second, all the additional construction, maintenance, and administration costs required to improve the facility have probably not been included.

This paper is probably more notable for what it does not say, and for the variables and interrelationships that it does not treat, than for what it actually accomplishes. (For example, the intricate problem of handling modal cross-elasticities is scarcely mentioned.) Even so, it is hoped that some insight is provided and that perhaps a slightly improved way of examining and dealing with an old problem might result. Certainly, there is no intention or hope of solving the problem.

ACKNOWLEDGMENTS

Appreciation is expressed to Paul Roberts, A. Scheffer Lang, A. J. Bone, Richard Soberman, and Marvin Manheim for ideas, discussion and review in the course of developing these concepts. It should also be noted that this paper was initiated at the beginning of and as part of a research project at the Massachusetts Institute of Technology.

PERTing a Transportation Study

ROGER L. CREIGHTON, Director, Upstate New York Transportation Studies

•DURING the past ten years, organizations known as transportation studies have been created to prepare long-range, comprehensive transportation plans. Because the need for such planning is great (one index of need is the tremendous state and national investment in new transportation facilities), these studies have been well financed. Their budgets frequently run in excess of $1 million, and they employ hundreds of persons. Their size and cost create substantial management problems.

Size alone, however, is not the most pressing problem. Transportation plans must be produced rapidly. Road-building programs advance with considerable speed, although this may not always be apparent to the man on the street. Decisions to build are made far in advance, often on a project-by-project basis without any review against a comprehensive plan. Decisions then become salted down with investments in detailed plans, estimates, hearings, and public announcements. Each piece of construction and each commitment begets another. The building program is thus often fixed for five years into the future. Rapid production of plans for entire systems of transportation facilities is, therefore, a great need.

Size and speed demand skilled management, but many things make effective management unusually difficult. These difficulties may be grouped under three headings:

1. The number of different operations necessary for the completion of comprehensive plans. These include data gathering for land use, transportation facilities, and trip making; the coding of this information; machine processing; contingency checking; computing; analysis; specification of goals and planning principles; plan making; plan testing; and, the writing of reports.
2. The number of skills involved. To complete these operations, a wide variety of skills must be employed. These include economics, statistics, mathematics, city planning, traffic engineering, design engineering, sociology, geography, supervision of interviewers and coders, management of data processing machines, computer programming, supply procurement, accounting, typing, and the writing and production of reports.
3. The interdependency of work. The tasks which sum up to a completed transportation planning program are interdependent to an unusual degree. (See Fig. 8.)

All these things point to the need for new management tools which will permit a person or a management team to maintain control and direction over a project, rather than floating with the project and reacting to the pressures of events. This paper has to do with one such technique, Program Evaluation and Review Technique (PERT) also called the Critical Path Method.

PERT — AN AID TO MANAGEMENT

PERT is a programming device, designed to aid in the allocation of time, manpower, and skills to the various activities which constitute some larger work program. It consists of five basic steps: specifying events (the end products of each small part of a larger program); developing a network describing the relationships between events; estimating the time needed to accomplish each link in this network; determining the critical path; and, reviewing and revising the program.

Paper sponsored by Committee on Origin and Destination.

The essence of the PERT process is the use of a network diagram to describe a large number of products (events) and their relationships to one another. It would be extremely difficult and tedious to describe these events and their relationships in English. The PERT notation, like mathematical notation, is terse and clear; it is highly economical. It has, furthermore, the quality of being readily translated into computer notation so that some of the programming can be done by computer.

Although the basic idea of PERT is very simple and straightforward, actually doing the work is difficult. One reason for the difficulty — but a major advantage of the system — is that PERT requires a thorough and complete thinking-through of a major work program from beginning to end. PERT does not allow any pretense about what is to be done at each stage along the way. A second difficulty is that, despite its terse form and the precision of its statement of the problem, diagramming a complex production or research task can never be wholly complete. Some relationships must be left out, some tasks not included. The problem is to select the main elements with care, but to include all of these.

Specification of Events

The first requirement of PERT is the complete and exact specification of events which are to be programmed. An event is defined as the product or result of some kind of action. It may be a table, a set of specifications, a physical product, or a computer program. But the event is distinctly not the action or process which produced it.

Here there is a sharp contrast between PERT and the normal programming of research or planning work. Normally a planner thinks in terms of processes; for example, six months of O-D survey work, four months of coding, or two months for analysis of trip generation. By contrast, under PERT planning, these things would only be considered in terms of their outputs; for example, 20,000 completed home-interview forms, or a specific table of trip generation rates.

Concentration on product is especially important in research and planning work, where the process, for instance, the process of analyzing trip making, has tended to dominate the product. Analysis, research, and planning can very easily become nebulous operations. Hence the tough-minded approach of accenting the product is peculiarly important in this field.

Network Construction

Events can be listed, and then posted to boxes or circles drawn on a large sheet of paper or a blackboard (Fig. 1). The order of posting is not important, but the point of beginning is generally kept to the far left, the conclusion to the far right.

Once the events are posted, they must be connected by a series of lines which describe the relationships between events (Fig. 2). If, for example, a map is needed prior to field list, the map event must be at the base of the arrow which points from the map to the field list.

The preparation of lists of events and the placing and studying of the interrelationships between the events is best done by a small team consisting of those persons who will be doing the work. This enables them to participate in the project; it also produces a more complete specification of needs. Although group work is extremely helpful, there is always need for strong direction of the PERTing activity. Single direction provides a unifying element and the necessary decisiveness.

Time Estimating and Cost Estimating

Once the diagram of interrelationships has been prepared, time estimates of each activity must be prepared. The activity is represented by the line (arrow) connecting events; it is, in short, the work necessary to produce the event.

Single or multiple time estimates can be prepared. One manual recommends that three time estimates should be prepared, a shortest possible time, a "best" estimate, and a very conservative time estimate. The average value (computed by weighting the shortest time once, the best estimate four times, and the most conservative estimate

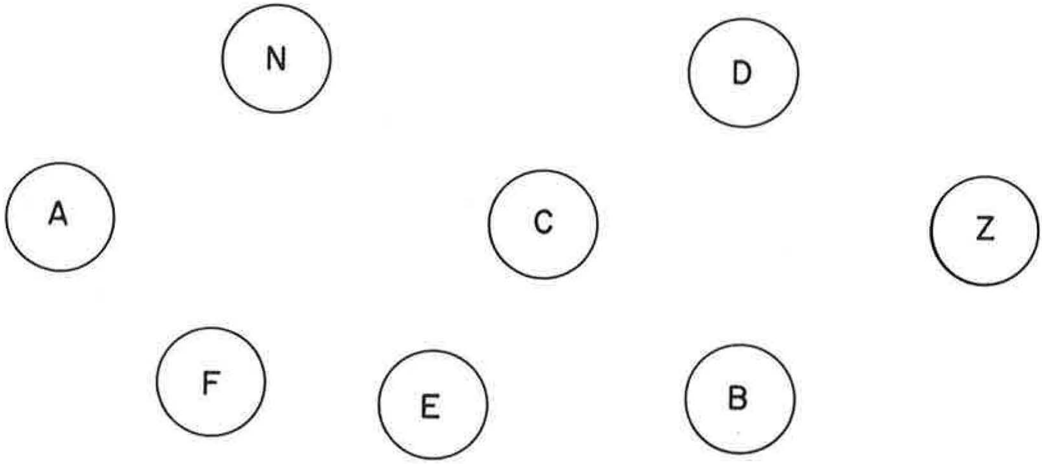


Figure 1. Events — a series of N events must be completed before final objective Z is achieved. Each event is defined.

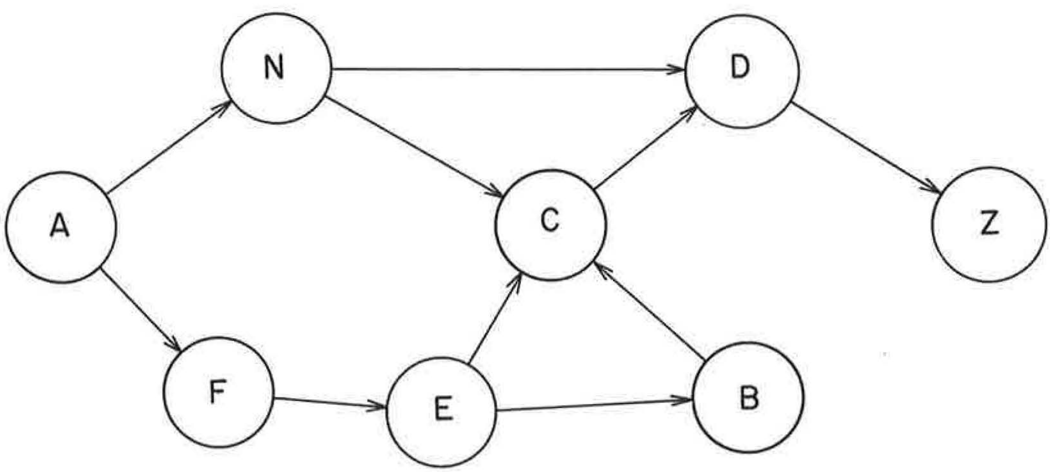


Figure 2. Relationships defined by network — lines are activities necessary to produce events; each event is an output of one activity and/or the input to another.

once) is posted on the "activity" line, below the other estimates (Fig. 3). It is desirable to make estimates randomly, so that there is less tendency to think of scheduling at the time the time estimates are made.

Determining the Critical Path

Once the time estimates have been made, the next step is to determine the critical path (Fig. 4). The critical path is simply the longest time path between the start of the project and its completion.

For networks of 100 or 200 nodes the critical path can readily be determined by hand. This is done using a hand posting technique developed from Moore's algorithm (1). The procedure is to start at the beginning of the network, posting the accumulated time at each node. At each node, a small arrow is placed, pointing backwards toward the origin along the longest time path to that point. Where two or more activities ter-

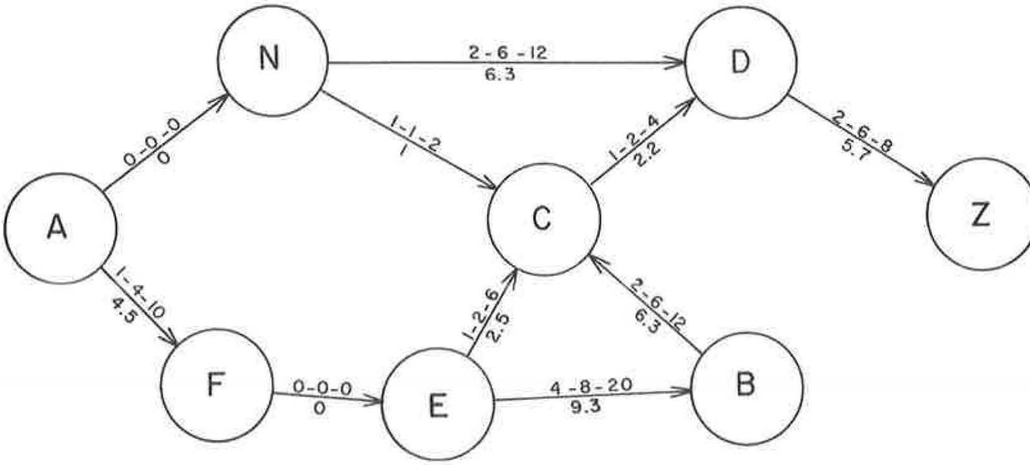


Figure 3. Times estimated — minimum, best estimate, and maximum time estimates are made for each link (e.g., 2-6-20); these time estimates are averaged for a working estimate (under line).

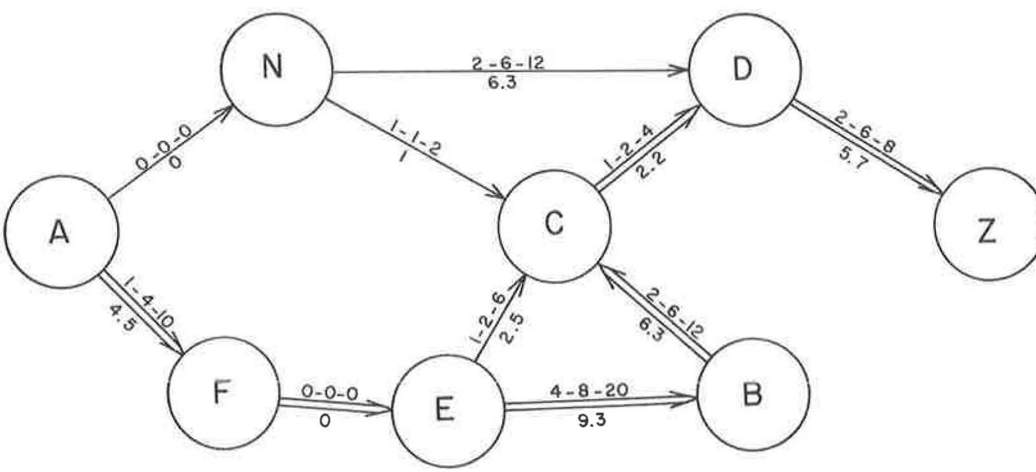


Figure 4. Critical path chosen — the critical path is that which takes the longest to achieve.

minate at a given node a choice must be made; the maximum accumulation of time to that node is noted, together with an arrow pointing backwards along the maximum time path. This can be done easily in one hour.

Computers can also be used to select the critical path. There are "canned" programs for this on a number of machines. The computers do many things besides calculate the critical path; they indicate earliest and latest start times for each activity, and calculate "float" times.

Review

Once the critical path has been determined, a review must be made to see where changes can be made to improve the situation. The review is the point where executive decision making is brought to bear. Methods or schedules can be changed, additional resources brought forward, or slowdowns ordered.

AN EXAMPLE OF PERT

A survey to measure and identify floor area in the central business district of Buffalo was conducted as part of the Niagara Frontier Transportation Study in August and September 1962. This survey was a small affair, involving direct costs of about $2,500. Nevertheless, it is a good example of the complexity of survey operations. It was decided to PERT this survey, and the final diagram, completed prior to the start of the survey, is shown as Figure 5.

One normally thinks of survey or inventory operations as consisting of field work and the coding of the results. As the PERT diagram forcefully shows, this is only part of the task. The critical path, far from being the direct line of making a study design, hiring and training people, and doing the inventory, actually winds far afield. In this survey, 15 percent of the total time along the critical path was spent in survey design, 23 percent in pre-survey work, 37 percent in the field work, and 25 percent in coding and other post-survey work.

Having prepared the PERT diagram in committee, decisions on several fronts were made in rapid order. Necessary card forms and supplies were procured, and their time requirements were understood immediately by the administrative personnel. Processes for control of records were set up, and key control points were noted.

If the survey had been longer, review of the PERT diagram would have indicated the desirability of running one or more operations in parallel; e.g., coding the early field work results before the whole field work had been completed.

Arraying PERT Diagrams by Organization and by Time

The basic PERT diagram can be redrawn to aid administrative decision making. Two forms and a combined form are possible.

The first form (Fig. 6) is to divide the presentation area by horizontal lines, each representing the area of responsibility of a particular group within a larger organization. It is easy, using this technique, for each responsible section or division head to see what projects are his, and how they key in with the work of other divisions or sections.

The second form (not illustrated) is to divide the presentation area by vertical lines, each representing a week or other time unit on a calendar. The events can then be arrayed in their chronological sequence. The placement of each event may be fixed (as in the case of events on the critical path) or there may be some degrees of freedom. Here is where earliest and latest "start" times, as calculated by a computer, can be of great advantage. It can be seen that the placement of events having degrees of freedom can be dictated by some new criterion, such as the minimization of cost or the desire to minimize changes in employment.

A third form (not illustrated) would be a combination of both the preceding two forms.

Diagramming Technique

There appear to be two different diagramming techniques which can be used for PERT or the Critical Path Method. In one technique (used in this report) the event is the point of emphasis and the event's title is posted within a circle or box. In the other, the process is the point of emphasis and its title is posted along the arrow which represents the work activity leading to an event (2). In both cases event (node) numbering is the same and critical path computations by hand or computer would appear to be identical.

Although either technique could be used, the one employed throughout this paper was selected because of its focus on the event or product. It also appears to have some advantages of neatness, and undoubtedly has greater flexibility of presentation. However, a review of the CBD Survey PERT diagram (reproduced here in its form of August-September, 1962) led to a modified diagramming technique. The purpose of the change is to increase clarity and reduce the possibility of making mistakes.

The technique illustrated in the CBD Survey problem places an event in every node (represented by a circle). This leads to the certainty that two or more arrows — each

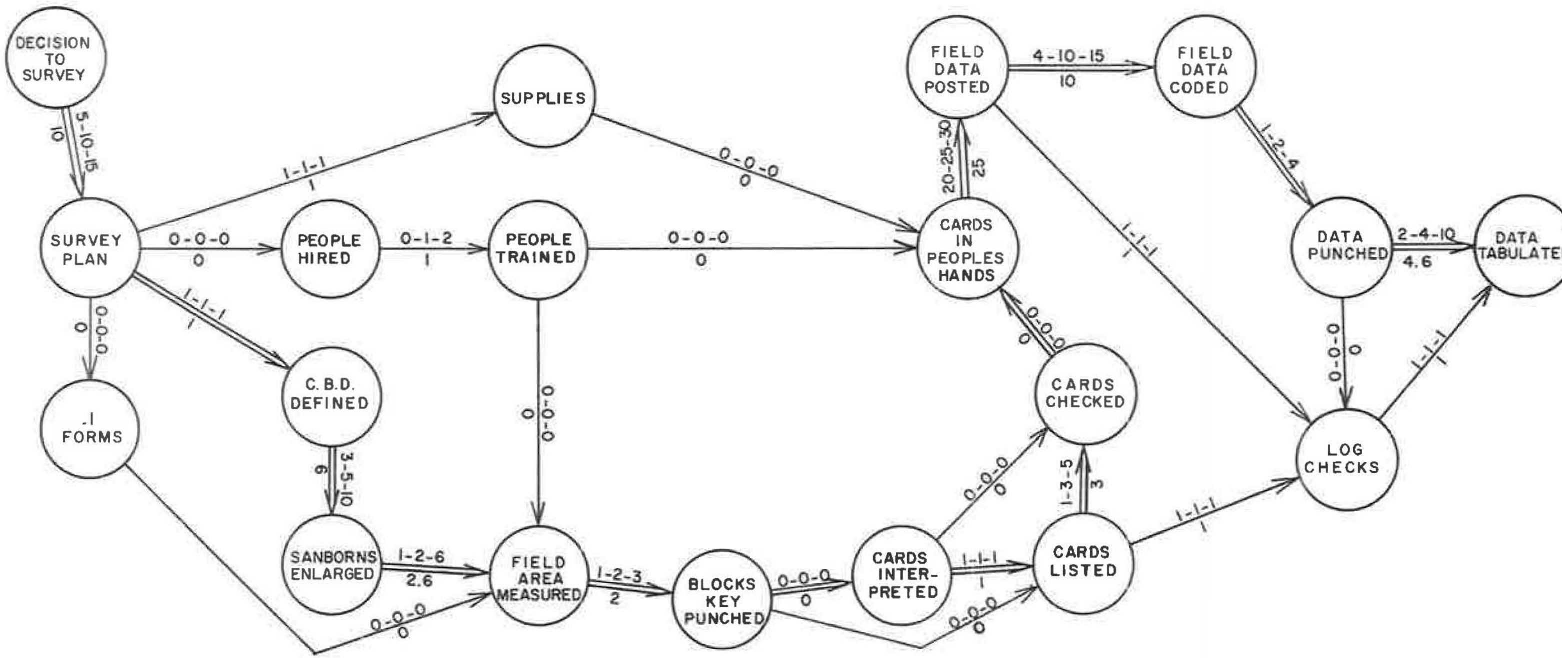


Figure 5. PERT program for CBD survey (all time estimates in days).

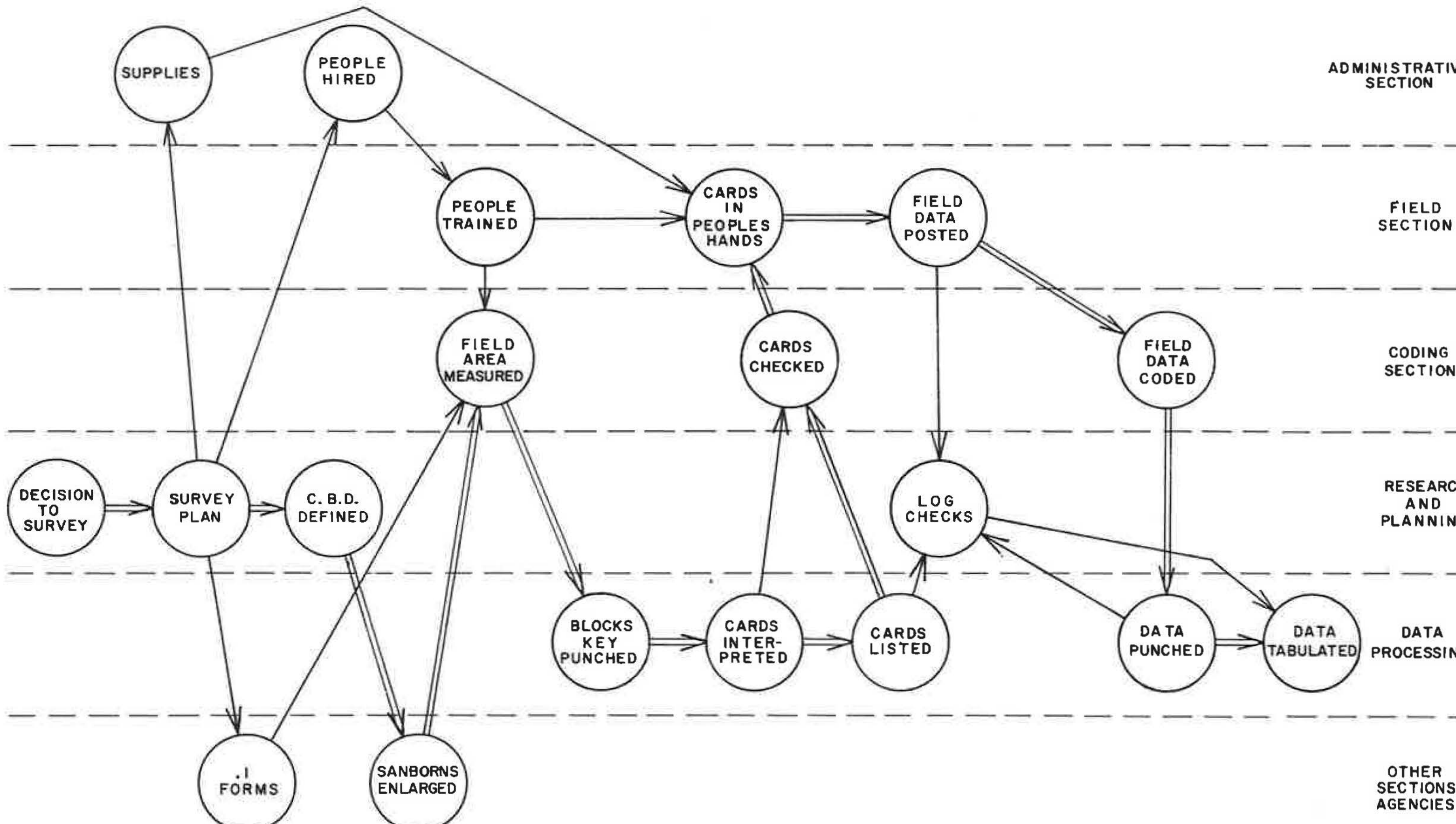


Figure 6. PERT program for CBD survey arrayed by section responsible for events.

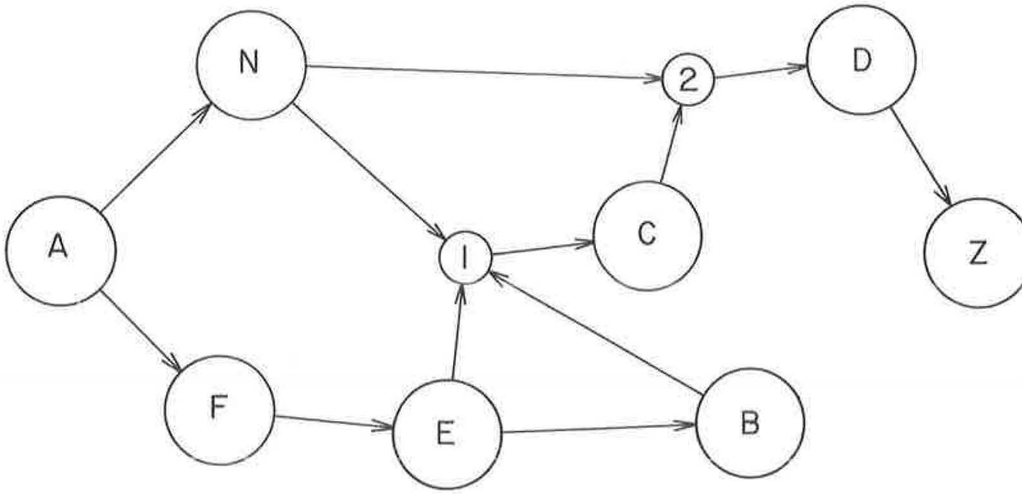


Figure 7. Modified diagramming technique — numbered nodes are assembly nodes; lettered nodes are event nodes. Only one activity (arrow) may lead to an event node. Assembly nodes indicate required availability of two or more events before a new activity may begin.

representing an activity — will terminate in a single event. It does not seem logical for two activities to have a single product.

To get around this problem, the author has used, in subsequent PERT diagrams, two types of node symbols. The first, called an "event node," is diagrammed using a large circle. Such event nodes can only be the terminal of a single arrow representing a single activity. The second type of node is called an "assembly node" or "dummy node" and is used as a junction point where two or more previously completed events are brought together so that a new operation or activity may commence (Fig. 7).

This diagramming technique adds perhaps a third more nodes, but increases clarity and diagramming ease. It has been used subsequently in the PERT diagram for the entire transportation planning process.

PERTING A COMPREHENSIVE TRANSPORTATION STUDY

A PERT diagram for an entire comprehensive transportation study is shown in Figure 8. This diagram, although prepared specifically for a transportation study for the Rochester (N. Y.) metropolitan area, is sufficiently general so that it could be used in any major metropolitan area.

A list of events, with minimum requirements for each, is given in Table 1. Numbering of the events corresponds with the numbers on the block diagram.

The diagram and its accompanying list of events has evolved through about six drafts, with many minor amendments. The nature of the PERT process dictates that it will continue to be subject to constant change and amendment. Figure 7, therefore, cannot be considered final.

In all, 150 events are diagrammed in Figure 8. Of these, 31 are "assembly nodes" and 119 are "event nodes." Over 200 activity lines or arrows connect these nodes; about 40 percent of the arrows are dummy activities, with zero times. Not counting zero activities, the median duration of each activity is between three and four weeks. This appears to be a reasonable unit for management and reporting purposes in a transportation planning program.

Major Work Areas and the Critical Path

As the PERT diagram for the entire transportation planning process was prepared, the various events began to fall into a series of major work areas. This was partly

TABLE 1

EVENTS AND MINIMUM REQUIREMENTS FOR COMPREHENSIVE TRANSPORTATION STUDY

Node Number	Title	Minimum Requirements
1	Study design	Report describing surveys, analyses, forecasts, objectives, planning and testing processes, together with organization, time, cost, manpower, space and equipment requirements.
2	Transit study design	A plan describing methods for mass transportation survey and planning operations.
3	Travel survey design	A report describing the time, duration, sample size, and other features of the travel inventories to be undertaken including the home interview, the truck-taxi, and the external surveys.
4	Contractor hired	A firm retained on contract to undertake all, or portions of, the home interview, the truck-taxi and the external surveys.
5	Administrative procedures	The steps necessary to obtain (a) interviewing personnel and to train them, (b) field office, (c) payment procedures, (d) vehicles, and (e) incidental equipment.
6	Arterial selection criteria	A set of criteria for determining which roads shall be included in the network of arterial streets to be coded and used for planning purposes and computer assignment.
7	Land-use manual	A plan for obtaining land-use data using one or a combination of (a) existing data, (b) assessors files, (c) air photos, and (d) field list. This includes a plan for parcel and block numbering.
8	Map resource list	List giving coverage, scale, date, and contents of all maps and aerial photographs available for the study area.
9	Census tracts and political units maps	Maps showing up-to-date political unit and census tract boundaries.
10	Gridded regional map	Map showing study area with precise location of a half-mile grid with CBD at point x = 500, y = 500.
12	Zones and districts	The mapped location of analysis zones, which are the area units into which the study area is divided for planning purposes. Zones are grouped into districts which combine into rings or sectors arrayed by distance and direction from the CBD of the urban area.
13	Arterial numbering manual	A plan for numbering the arterial network.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
14	Home-interview manual	A manual describing in precise terms how the home-interview survey is to be conducted.
15	Truck-taxi manual	A manual describing in precise terms how the truck-taxi survey is to be conducted.
16	External manual	A manual describing in precise terms how the external survey is to be conducted.
17	Truck-taxi sample	A sample of truck registration numbers drawn from official registration sources, keypunched, and printed on interviewers' daily work sheets, together with letters to truck owners and operators.
18	Transit maps and schedules	Maps of all mass transportation systems in the metropolitan area showing route locations together with schedules for buses and rail rapid transit trains.
19	Coded transit network	The transit network coded for computer representation including length, seating capacity, service and other characteristics of each segment of the network.
23	Land-use data source	All available sources giving existing land use. May be existing land-use maps, assessors' cards, field lists, or aerial photographs.
24	Assessors' files	A card or tape copy of assessors' files including (a) account number, (b) address, (c) area of land, (d) land-use code (if available), and (e) other data.
25	Large-scale maps with grid and block numbers	Maps at 800 ft = 1 in. to 2,000 ft = 1 in. with grid and all block numbers added.
27	Selected arterial system	A map showing all streets divided into three classes (a) local streets, (b) expressways and (c) arterials.
29	Parcels identified	All parcels of land, as defined, numbered within or referenced to each block.
30	List of blocks	A list of each block in the study area, numbered by its x-y position.
31	Field list	A list, or a corrected list, of addresses within numbered blocks showing (a) number and location of each dwelling place and (b) land use.
32	Block list keypunched	Keypunched list of all blocks in study area, numbered with x-y notation.
33	Streets numbered	A list of all streets in the study area with a four digit number for each.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
34	Arterials numbered	Each segment of the arterial network within the study area, plus existing expressways, numbered to permit its being represented in a computer.
35	Street list keypunched	The street list in punched card form.
36	Block list checked	Block list checked against maps to insure completeness.
38	Sample selected	A sample of addresses, properly stratified and day-dated, printed on interview assignment forms and printed on "dear householder" letters.
40	Street address guide	A printed address guide, giving address ranges for each block face in the study area, and the proper block and street numbers pertaining thereto.
41	Screenline counted	Mechanical and hand traffic counts made on each crossing of one or more screenlines dividing the study area.
42	Transit network tabulated	Bus and other mass transportation service summarized to provide, as a minimum, seat miles of service by route segment.
43	Arterial network keypunched	The arterial network keypunched.
44	Arterials contingency checked	Contingency checks performed on the arterial network to insure completeness of the network.
46	Land use identified	Land use of each parcel coded onto forms or mark sensed on cards. Includes reference to street face identified by number.
47	Screenline data summarized	Summarizations of screenline crossing by vehicle type, by hour of day.
48	Transit computer program	A computer assignment program permitting transit trips to be assigned over a mass transportation network, simulating zone-to-zone movements.
49	External survey completed	All interviews completed on the cordon line surrounding the study area.
50	Truck-taxi survey completed	Interviews completed for all truck and taxi sample registrations.
51	Home interview completed	All home-interview sample addresses interviewed.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
52	Road network survey	The following data, as a minimum, coded and keypunched for each arterial street: length, speed limit, pavement width, right-of-way width, type of cross-section.
53	Sample of streets	A sample of local and arterial streets selected for machine or manual counting.
54	Land use measured	Each parcel measured and noted on forms or mark sensed on cards. Includes street areas.
58	Sample of buses	A sample of buses selected from schedules to permit a sample survey to be conducted of person miles of travel.
59	Person miles of travel survey	A survey conducted on bus and (if in operation) rail rapid transit systems to ascertain the volumes of passengers using each segment of the transit network.
60	Person miles of travel data coded	Data obtained in the person miles of travel survey, coded and keypunched.
61	External survey coded	All external interview forms coded and ready for keypunch.
62	Truck-taxi survey coded	All truck-taxi forms coded and ready for keypunch.
63	Home interview coded	All home-interview schedules coded geographically and numerically.
64	Road network coded, punched	All data for the arterial network punched and contingency checked.
65	Road volume counts made	Counts (either short-count manual or machine) made of traffic volumes on sampled arterials and local streets.
66	Contingency check on person miles of travel data	Person miles of travel surveys checked and corrected.
68	External travel survey keypunched	Coded travel survey data keypunched.
69	Truck-taxi survey keypunched	Coded truck-taxi data keypunched.
70	Home-interview survey data keypunched	Coded data from the home-interview survey keypunched.
71	Land use keypunched	Land-use data keypunched.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
73	Land-use contingency checks completed	Land-use contingency checks completed. Includes (a) block list check for completeness, (b) area checks for scale correction, (c) map printouts, and (d) miscellaneous checks.
74	Volume data coded and punched	Manual or machine counts coded and keypunched.
75	Road network contingency checked	Contingency checks performed on the road network and corrections made so as to insure a perfect file.
76	External contingency checks	Contingency checks performed on all external survey data and corrections made.
77	Truck-taxi contingency check	Contingency checks performed on all truck and taxi cards and corrections made.
78	Home-interview contingency checked	All home-interview cards machine contingency checked and corrections made.
80	Person miles of travel tabulations	Tabulations of person miles of travel giving, as a minimum, the volumes on each segment of the mass transportation network and person miles of travel by analysis zone.
81	Volume data contingency checks	Contingency checks data performed on volume cards.
83	Land-use tabs	As a minimum, area totals for each major land-use type by analysis zone.
84	Zoning data	Existing zoning measured, as a minimum, for commercial, residential and industrial categories, for each analysis zone. (It may be desired to incorporate this within the land-use survey.)
85	Land-use forecast model	A computer program, based on a reasonable theory which will (a) distribute population, labor force, and vehicle ownership to analysis zones by 5-yr increments, and (b) indicate future uses of land in each analysis zone.
86	Travel data factored	Home interview, truck-taxi and external travel data factored.
87	Travel tabulations	Tabulations of travel data obtained from the home interview, truck-taxi, and external survey giving, as a minimum, person and vehicle trips by purpose and separately by land use by analysis zone. Also, standard Bureau of Public Roads tables of population and zone-to-zone trip movements.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
88	Person trip data	Tabulations of person trips by mode within land use, by analysis zone.
90	Transit computer assignment	An assignment of current transit trips to the existing transit network to determine whether current travel over bus and rapid transit network can be simulated reliably.
91	Volume and vehicle miles of travel data	Volume data presented, at a minimum, in flow diagram form; VMT data by street type by analysis zone.
92	Road network data tabbed	Tabulations of network data including, as a minimum, arterial and expressway capacity, mean speed, and length, by analysis zone.
94	Historic PEV data	Historic data on population, economic growth, and vehicle ownership of the study area.
95	Independent trip generation data	Trip generation data from other cities obtained for the purpose of simulating trip making independently from travel survey data.
97	Simulated trip data	Person trip and vehicle trips simulated by applying trip generation rates from other cities against current land-use data.
98	PEV forecast model	A computer program for estimating aggregate population, economic, and vehicle growth for the study area, by 5-yr increments.
99	PEV forecast	An estimate of (a) aggregate population for the study area, (b) labor force, by industry type, (c) income, (d) industrial output, and (e) vehicle registrations, all by 5-yr increments.
101	Vehicle trip data	Tabulations of vehicle trips giving, as a minimum, automobile and truck trip destinations by land use and separately by purpose, for each analysis zone.
102	PEV data	Tabulations of population, economic, and vehicle ownership data obtained from travel surveys giving, as a minimum, population for each analysis zone with breakdowns by age group, by income, and by vehicle ownership for each district.
103	Land-use forecast	An estimate, by 5-yr increments, of the distribution of population, labor force and vehicle ownership and of the uses of land, in each analysis zone.
104	Trip forecast model	A computer program which will estimate future truck trips, automobile trips, and person trips made by mass transportation, for each analysis zone, by 5-yr increments.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
105	Trip generation rates	As a minimum, person and vehicle trip generation rates per acre by major type of land use, within district.
106	Road computer program	A computer assignment program capable of estimating zone-to-zone movements and assigning them over a road network with the option of restraining traffic flows by relating volume to street capacity.
108	Actual assignment	A computer assignment performed using trip data recorded from the travel surveys and assigned over the existing network.
109	Transit assignment evaluated	The assignment of transit trips compared with volumes measured on each link of the mass transportation network as measured by the PMT survey.
111	Simulated assignment (roads)	An assignment of vehicle trips to the existing network using simulated trip ends.
112	Transit sketch plans	One or more plans for mass transportation facilities.
113	Coded transit plans	Transit plans coded for computer assignment.
114	Trip forecast	An estimate of truck trips, automobile trips, and person trips by transit for each analysis zone for each 5-yr planning period.
115	PMT survey and mass transportation network report	A published report giving the amount and distribution of service provided by mass transportation systems together with the use which is made of these systems.
117	Assignment evaluated	Actual and simulated assignments compared with data on traffic flows and vehicle-miles of travel so as to calibrate the computer program to reproduce present traffic flows reliably.
118	Revised transit computer program	The transit computer program calibrated.
119	Physical factors	Mapped locations of both physical (topographic) and cultural (expressways, rail lines, housing developments, cemeteries, parks, etc.) features which influence the planning of future transportation facilities.
120	Objectives	A statement of the objectives and values which are to be sought in urban planning, with particular focus on transportation objectives. These objectives are to be used as a basis for measuring the performance of each plan.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
121	Planning guides	A statement giving general guides or principles for the planning of transit, rail, and road networks.
122	Optimum spacing	Formulas for estimating, in preliminary fashion, the best spacing of future road systems.
125	Arterial plans	A set of plans giving the proposed locations and numbers of lanes of arterial (major) streets, taking into account future trip making, physical factors, planning guides and optimum spacing.
126	Expressway plans	One or more plans giving the proposed generalized locations of expressways to serve travel demands of a future population.
128	Sketch road plans	The combination of expressway and arterial plans.
130	Revised computer program (roads)	The computer program revised and calibrated as a result of the evaluation of actual and simulated assignments.
131	Coded road plans	One or more road network plans coded for computer assignment.
134	Transit computer assignment	An assignment of future transit trips to a transit plan.
135	Road computer	A computer assignment using future estimated trips over a planned road network.
136	Transit evaluation	An evaluation of more than one transit plan including, as a minimum, estimates of (a) construction costs, (b) operating revenues, (c) passenger time, and (d) other evaluations in light of the objectives.
137	Road plan evaluation	A review and study of the computer assignment resulting in (a) estimate of construction and operating costs, (b) a list of portions of the network which are overloaded and underloaded, and (c) a general evaluation of the network in light of the objectives.
138	Final road plan	A road plan adopted as a result of the review of assignments to a number of plans.
139	Final transit plan	A final plan for mass transportation facilities indicating recommended locations for bus and rail lines and estimated use of each such line.
141	Final plan	A final, comprehensive transportation plan showing recommended locations for new arterials, new express roads, additional bus service, and additional transit lines as required.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
142	Schedule	A recommended schedule of priorities for the construction of new transportation facilities and for the operation of new transit services, by 5-yr increments.
143	Financial study	A study indicating the relationship between the costs of constructing and operating new transportation facilities and the ability of the Federal, state, and local governments to pay for such improvements.
144	Final report	A report containing the final plan, the justification for this plan and a recommended schedule for its construction.
145	Trip forecast report	A published report giving the estimated numbers and locations of truck trips, automobile trips, and mass transportation trips.
146	Land-use forecast report	A published report giving estimates of the distribution of population, vehicle ownership, and land use for the target year.
147	Road network and volume report	A published report giving the results of the surveys of road facilities and the use made of these facilities.
148	Travel report	A published report giving the findings obtained from the surveys of travel.
149	Land-use report	A published report on the distribution of land use by type within the study area.
150	Stop	

the influence of previous experience and partly the result of the evolution of the diagram as it was drawn. (Much of the diagram was drawn backwards, starting from the final plan and asking the question "what do I need to have on hand to produce this particular event?")

Nine major areas of work evolved:

1. Mapping and listing controls;
2. Land-use survey;
3. Road facilities and use survey;
4. Travel survey;
5. Transit facilities and use survey;
6. Land use and trip forecasting;
7. Assignment calibration;
8. Planning and testing; and
9. Final reports.

One major work area has been omitted: the study of goods movement. A program for this is now being developed by the UNYTS staff for the Niagara Frontier Transportation Study. It will be fitted into the overall diagram at an early date.

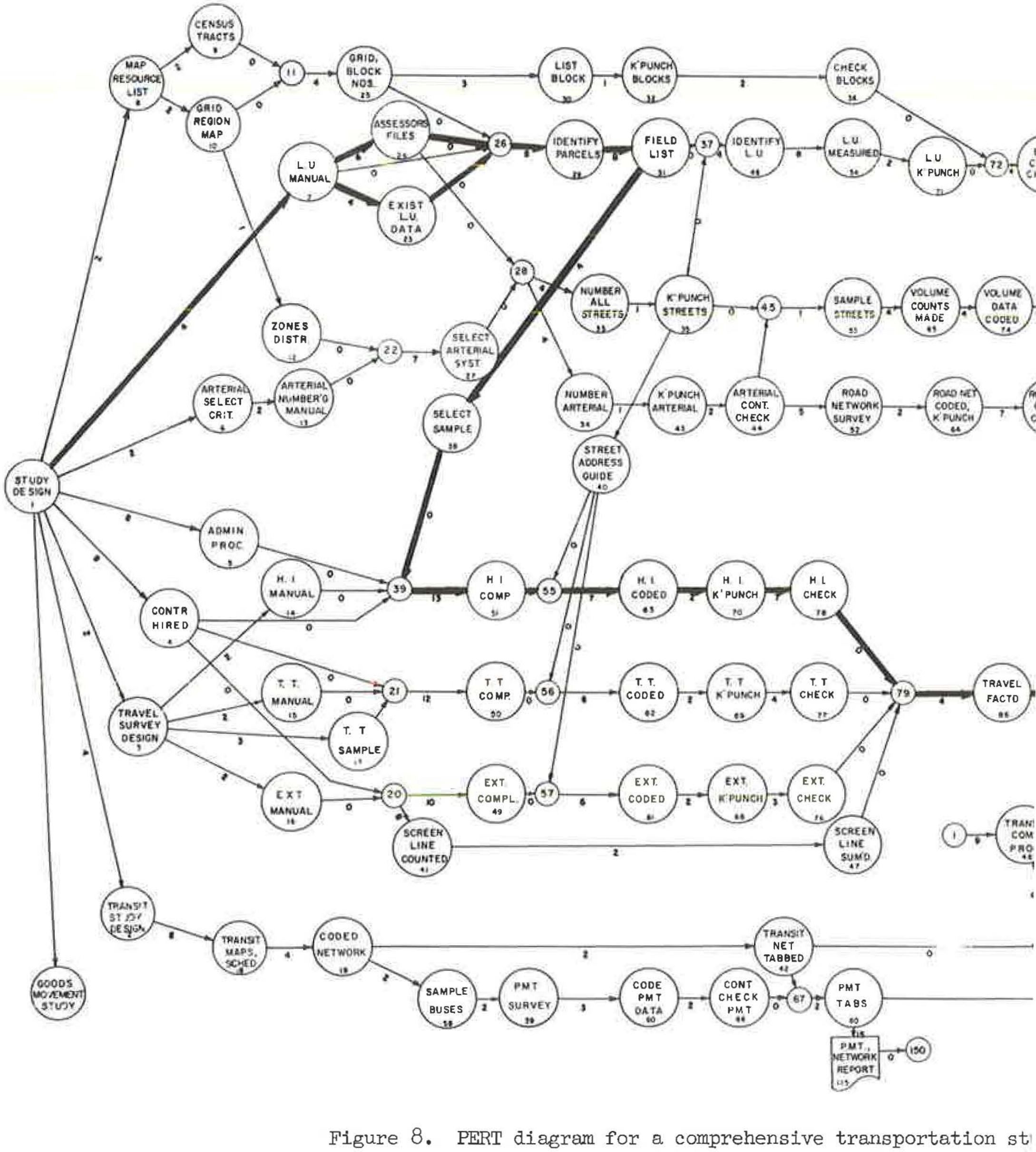


Figure 8. PERT diagram for a comprehensive transportation st

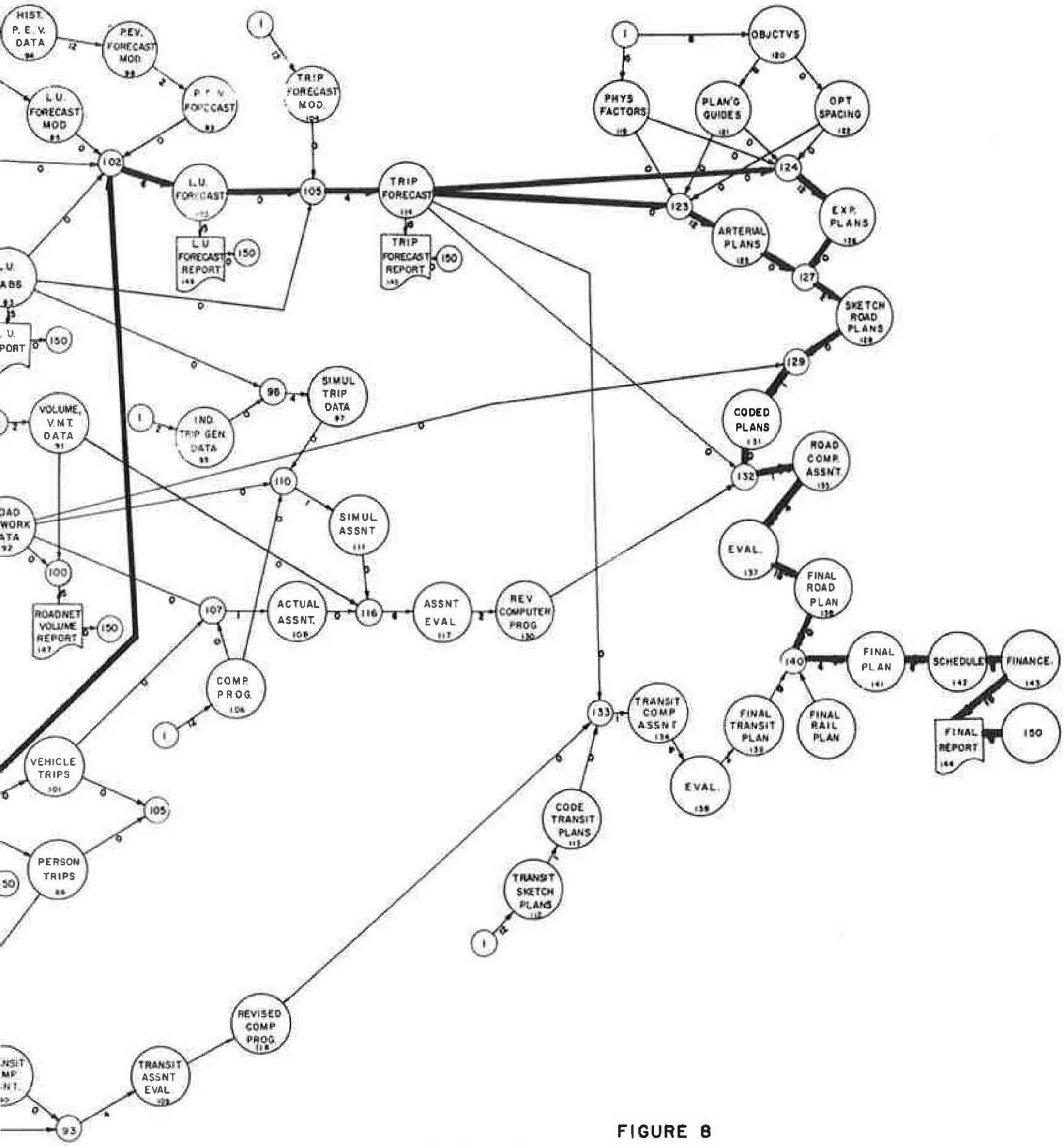


FIGURE 8

PERT DIAGRAM FOR A COMPREHENSIVE TRANSPORTATION STUDY

TIME IN WEEKS — CRITICAL PATH

gures on lines represent time in weeks; heavy lines, critical path.

The critical path runs through (1) mapping and listing, (4) travel surveys, (6) land use and trip forecasting, (8) planning and testing and (9) final reports.

The critical paths, determined objectively on the basis of time estimates prepared randomly (so as to be influenced as little as possible by previous scheduling), turn out to be very much the way one would expect.

The critical path, as estimated from this diagram, is 148 weeks, or 2.8 years. This length of time can undoubtedly be reduced, but probably not much under two years. The breakdown of this critical path is as follows:

From Start Event	To End Event	Duration
Go	Sample selected	28 weeks
Sample selected	Travel tabs	37 weeks
Travel tabs	Trip forecast	10 weeks
Trip forecast	Final road plan	38 weeks
Final road plan	Final report — Stop	35 weeks
Total		148 weeks

The two final sections of the critical path (from final road plan to final report — stop) can be shortened. Much of the planning work will be done ahead of the time when trip forecasts have been made. Also, studies of scheduling and financing the plan can be undertaken ahead of time, and not in series as shown on the diagram.

Evaluation for Time Reductions

Having displayed the transportation study process in PERT diagram form, the obvious question is "How can the planning process be modified to reduce time and/or cost?" This is a proper question, provided that one is assuming a constant quality of plan output. It would certainly be unwise to conduct a race to see who could conduct transportation studies the fastest, because a major plan takes time to mature and its quality must be very high.

One must insert the precaution that the time estimates shown in Figure 8 are based on given manpower, machine power, and experience. The UNYTS staff now has the experience of data gathering for one major metropolitan area. Manuals have already been prepared which, with slight modification, are ready to be used in other metropolitan surveys. An inexperienced staff would naturally take much longer to do the same job.

There are certain obvious ways in which to make reductions in time, not necessarily derived from the PERT process. Some of these have already been put into practice in the Niagara Frontier study, others will be used in the Rochester study.

1. Cut interviewing time to 3 or 4 months. Indications are that urban travel is sufficiently regular so that long interviewing periods are no longer necessary.
2. Increase manpower in coding operations. Provided that good coding instruments (coding guides, maps, and generator files) are available, and within the limitations of management capability, it is worthwhile to increase the number of coders, since an hour's coding work costs as much one month as it does the next.
3. Increase machine power. High-speed data processing equipment probably costs less per unit of output than low-speed equipment, even including programming time.

In terms of delivering a product sooner there is no comparison. Hence more powerful machines provide a clear way toward cutting time.

4. Running operations in parallel. Within the limitation of the time of the professional staff, it is naturally desirable to run operations in parallel rather than in series. In the Niagara study this has been accomplished by starting the formal planning work at an early date — working out statements of objectives (Event 120), planning guidelines (Event 121) and preparing maps of the key physical factors (e.g., topography, land uses, transportation facilities) which influence planning. Traffic assignment computer programs are available which will be ready in time to run, and these have, in fact, been tested so that there is a proven capability for computer assignment.

Besides these more obvious means of reducing the total time of a transportation study, examination of the PERT diagram (Fig. 8) leads to other possible ways.

1. Increased use of simulation techniques. A large part of the critical path (23 weeks) is employed in testing and re-testing plans (Events 131 to 138). Plans can be prepared almost from the start of a study, but the problem is how to test them without the availability of travel data. The answer lies in improved simulation of trips and improved forecasting techniques — both made completely dependent on the computer. The only new data needed (at least for preliminary testing purposes) would be the results of the land-use survey.

2. Improved maps and field list data. A large part of the work needed to get ready for surveys of travel and land use is absorbed in preparing adequate maps and lists of houses. Numbering of blocks and obtaining reliable land-use data are also lengthy tasks. Such activities may require 12 to 15 weeks, assuming that one is willing to get by with less than the best. A sure way of reducing the time needed for such preparatory work is to have the data already available in the proper form. An excellent combination of source data appears to be assessors' data combined with land-use data from the city planning commission, with both of these keyed to accurate photogrammetric maps. Such data, organized on punched cards or on magnetic tape, can greatly reduce land use, block numbering, sample selection, and other costs and time expenditures.

3. Shortening the forecasting operations. Much of the time required to make forecasts is eaten up in the preparation of models for forecasting population, economic growth, vehicle registrations, land use, and trips. Once these models have been prepared, in sufficiently generalized form so that they can be applied in more than one metropolitan area, there will be a considerable reduction in the overall planning processes.

4. Shortening the planning operations. Whereas survey work for comprehensive transportation studies is well understood, this same situation does not obtain in the field of plan preparation. Currently it is a major effort to select and assemble the key factors influencing a transportation plan for roads, mass transportation and good movement, and to use these in molding a plan. Hopefully this work, which has tended to be highly intuitive and individual, will become sufficiently regularized so that it will not take so long.

Goals

A PERT diagram proceeds from a start point to a single ending point, and thus carries with it the danger that the single destination may become a fixation, to the exclusion of all other goals. The single goal in Figure 8 is a comprehensive transportation plan, embracing roads, mass transportation systems and other forms of transportation as may be required.

This single plan, however, must be viewed along with other goals. These include the conduct of successful research work, the development of increased public understanding, and the accomplishment of the plan itself. Accomplishing a plan depends, of course, both on the existence of a careful and responsible plan and on public understanding of the plan and its means of development.

Of the three additional goals, only one makes its way into the block diagram describing the transportation study. This is the development of increased public understanding — through the reports which the study staff must prepare. These reports are shown by standard report symbols which take off from certain events on the diagram. There are six such reports which can be prepared and distributed in the second year of a transportation study's life.

Clearly, the additional goals besides the goal of the plan itself must be kept constantly in mind. They must, moreover, be acted upon if the fullest use is to be made of the plan once it has been prepared.

CONCLUSION

PERT offers the manager or management team of a transportation study a number of substantial advantages in return for the investment in time which the technique requires. Several of these advantages are as follows:

1. Accurately defined work targets.
2. A concise means of representing processes that are too complicated to store in one's head.
3. A technique which helps to remove bias from time estimating.
4. A technique that objectively points out the critical work areas.

This paper has shown how the PERT process is being applied to a comprehensive transportation study. A diagram and a list of events have been presented. Several implications have been drawn from this evidence — ways in which transportation studies can be shortened, and critical areas where work is needed in the development of new methods.

It is clear, however, that a great deal more can be done with PERT. Three areas of possible improvement are as follows.

1. Computer display. It is quite possible (if it has not already been done) to program a computer so that the output of the PERT problem is not merely a list, but a diagram like the original input, with the events positioned according to certain rules. One rule would be to position each event vertically according to the organization doing the work and horizontally according to, say, the earliest possible start time.
2. Computer scheduling. It should be possible for the computer to consider the events and the size of the organization involved and to schedule the work according to various rules. One rule might be to minimize changes in employment; that is, to keep the work load as even as possible, within a given overall project time.
3. Cost considerations. PERT/COST is a technique which brings cost as well as time into the picture. This should be applied to transportation studies, since the trade-off of time for money can assume large proportions.

Any management work requires a considerable investment of time and skill. PERT is no exception to this rule. PERTing a comprehensive transportation study takes, initially, a month of concentrated work, and beyond that many hours of drafting, coding, and checking before it can be put on a computer. Constant revisions and corrections must be made. The return lies in increased certainty and speed and this outweighs the investment.

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Development of a Model for Forecasting Travel Mode Choice in Urban Areas

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•WITHIN an urban area a great many people travel in pursuit of their daily activities. This large person movement is made mainly with the help of private automobiles and taxis, public transit and commuter trains.

The basis on which people choose among the various means of transportation available in different parts of an urban area is of utmost importance to the transportation planner.

Citywide estimation of potential passengers attracted to a new transit facility is sufficient only for broad planning purposes. With ever increasing cost of operation and construction, the selection of a location and determination of adequate capacity of a new traffic facility requires a reliable framework of references necessary to forecast the probable usage of such a traffic facility.

Hence the objective of the studies reported in this paper was to determine the major factors affecting the travel mode choice and to construct reliable framework of references (modal split) necessary in travel movement forecasting for specific transportation planning purposes. This was done on the basis of empirical evidence of how people actually traveled from origins to their destinations. Such a model has a direct application in the estimation of the relative demand for mass transit and/or expressway facilities, on an area to area basis, area basis or citywide basis.

Basic studies of factors affecting peoples' choice of travel mode were carried out in Toronto in 1960 and 1961. In subsequent studies in 1962 of peoples' travel behavior in Washington, D.C., the established framework of relationships was enlarged and finally corroborated by studies of O-D surveys conducted in Philadelphia.

CONCEPT OF MODAL SPLIT RELATIONSHIPS

The total number of people moving during a certain time period from an origin zone (O) to a destination zone (D), may be thought of as the total travel market existing between the O and D in question. The various modes of travel available for moving from O to D are competing for a share of this market, and each will win a portion of it, depending on its competitive position with the others. In this analysis the comparative advantages and disadvantages of each of the two major types of travel mode (public transit and private automobile) are measured by the time, cost, and convenience criteria. The other criteria, such as economic status and trip purpose, may be thought of as market characteristics which affect user reaction to the first three criteria.

To isolate the effects of the five determinants on market reaction (i.e., relative usage of transit and autos), it is necessary first to calculate the value of relative travel time, relative travel cost, and relative service describing the relative competitive position of public transit and the private automobile between every O-D pair under consideration. It is also necessary to determine the average economic status (income category) of travelers proceeding from O to D. Next the percentage of travelers proceeding from

Paper sponsored by Committee on Origin and Destination.

O to D using public transit and private automobile is determined for each trip purpose and is related to each of the other four determinant factors.

If these five factors explain completely the modal choice process, one would expect that all O-D pairs with identical values of time, cost and service ratios, and user income level would each display the same percentage of work trips made via public transit. The factors should produce the same percentage of non-work trips made via public transit for O-D pairs with identical values of the factors. However, this percentage would in general be different from the percentage of work trips made via public transit. This is, in general, what is observed, although there is, as would be expected, a scatter in the observations, owing to various sources of random variation.

FACTORS DETERMINING CHOICE OF TRAVEL MODE

The five basic factors considered are as follows:

1. Relative travel time via public transit and private automobile.
2. Relative travel cost via public transit and private automobile.
3. Relative excess travel time via public transit and private automobile (also known as relative level of service or convenience).
4. Economic status of trip makers (income per worker).
5. Trip purpose.

These five factors were selected on the basis of multiple regression analysis as having more independent significance than any others studied, to explain peoples' propensity to use public transit.

Among the factors considered originally were: trip length, population density, employment density, transit seat capacity, and orientation of the trip with regard to the central business district (CBD). However, they were found to be linearly dependent on at least one of the four determinants, time, cost, service, and income. Consequently, the degree of orientation of the trip with regard to the CBD is not included. Previous modal split studies (1) have shown that difference in transit usage of people traveling to CBD and non-CBD areas is adequately explained by differences in the five factors.

Usually there are more than two modes of travel available to most trip makers in urban areas. However, it is believed at this stage of development work, that the division of these travel modes into two main types, public transit and private automobile, is sufficient to account for the basic differences in the properties of the main types. Public transit is characterized by fixed routes and schedules, while private automobiles may be used flexibly whenever desired by the traveler.

Relative usage of alternative submodes within each of the main types (bus, subway, commuter train within the public transit mode; private auto or taxi within the motor vehicle mode) can be shown to depend on similar determinant factors.

Relative Travel Time

Relative travel time is expressed as a time ratio: door-to-door travel time via public transit divided by door-to-door travel time via private automobile. Figure 1 shows how the percentage of trips made to work by transit varies with travel time ratio. Diversion curves of this nature have been developed by a number of research workers for different cities with similar results. Time difference has also been used as a measure of relative travel time, but was not used in this project because the time ratio seems to produce a more well-defined relationship.

Relative Travel Cost

Relative travel cost is also defined as a ratio: the out-of-pocket travel cost via public transit divided by the out-of-pocket travel cost via private automobile (Fig. 2). Transit travel cost in this ratio is defined as the total fare paid during the trip; automobile travel cost is defined as operating cost (gasoline, oil, lubrication), one-half parking cost, and bridge tolls if any. Automobile depreciation, licensing and insurance costs

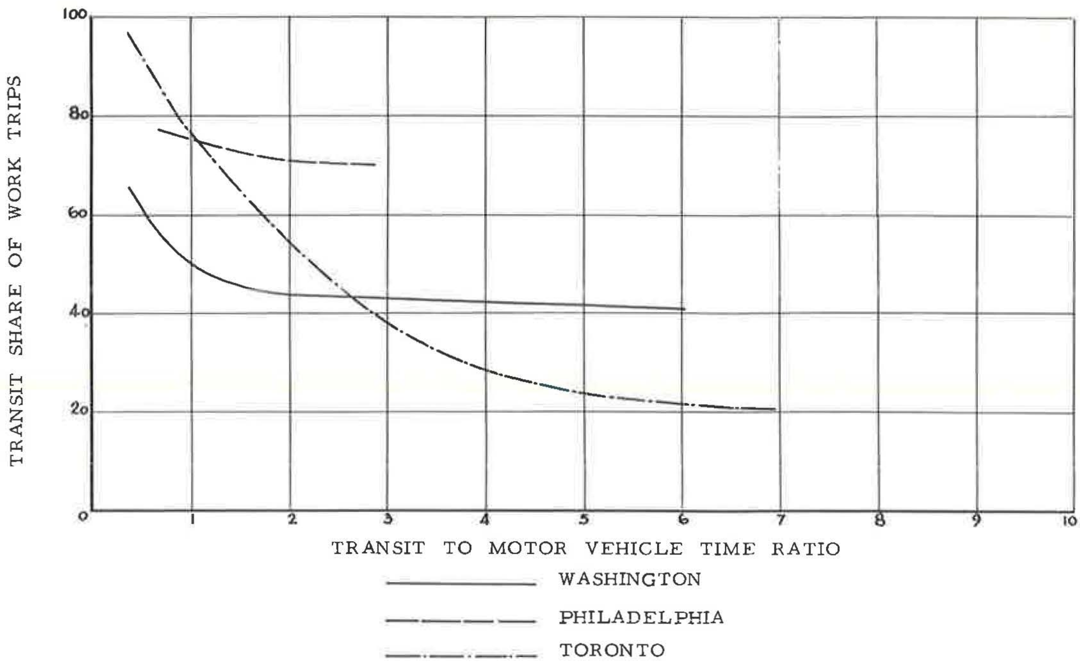

Figure 1. Travel time ratio diversion curve for work trips in peak periods (no. of trips in 1,000's).

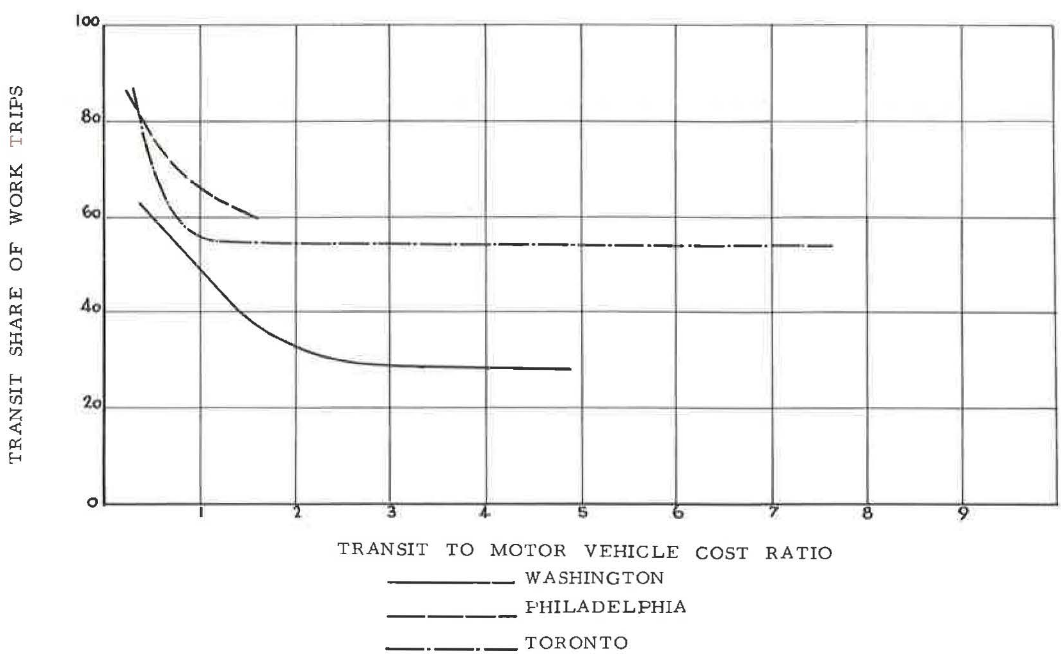

Figure 2. Cost ratio diversion curve for work trips in peak periods (no. of trips in 1,000's).

are not included, on the assumption that most automobile drivers do not consider these costs in connection with each trip made (2). For this study the travel costs via private automobile are divided evenly among all occupants of an automobile, based on the principle of cost sharing which usually exists in car pool arrangements.

Relative Travel Service (Convenience)

Obviously, a number of factors affect the level of service offered by each mode of travel. Among these are a clean bright appearance of the travel vehicle, a pleasant view from the window, a reasonable temperature within the vehicle, a comfortable seat, uncrowded conditions, a smooth ride, flexibility of departure and arrival times to suit the desires of the traveler, and convenient transfers from one vehicle to another, if this should be necessary. Many of these factors cannot be easily or meaningfully expressed in quantitative terms, and cannot therefore be included explicitly in these relationships.

The relative level of service has been expressed as a ratio: the excess time when traveling by public transit divided by the excess time when traveling by private automobile. Excess time is defined as the time spent outside of a vehicle while en route. In the case of public transit this is the time spent walking from point of origin to the nearest transit stop, plus the time spent waiting at the stop for the transit vehicle, plus the time (if any) spent transferring from one vehicle to another during the trip, plus the time spent walking to the point of destination from the nearest transit stop. For private automobile the excess time is the time spent walking to or from the parking place at O and/or D plus the time spent parking or "unparking" the automobile at either end of the trip. Clearly, the ratio of excess times is one measure of the relative convenience of the two modes (Fig. 3).

Another convenience-comfort index which can be expressed quantitatively is the load factor for public transit; that is, the ratio of total passengers in a transit vehicle to the number of seats in the vehicle. It has not been possible to treat this factor explicitly in this study because of the difficulty of obtaining data. When such data become available it will be possible to include the effect of transit load factor directly in the modal split relationships, and therefore in the forecasting process in which they are used. The load factor during peak hours is apparently limited by similar regulations for the three cities. This factor is therefore implicit in the relationships and it can be said that any travel movement forecasts based on the relationships assume such a a load factor level.

Economic Status of Trip Makers

It might be expected that increases in income would increase the elasticity of demand for transit. In the first place, prosperous people expect good service for their money and will tend to avoid a transit system which does not provide good service. Augmenting this is the fact that those with high income can afford the capital outlay necessary for private automobile ownership. The overall effect of trip maker's income (per worker) on relative transit usage (Fig. 4) will become clearer when the stratified relationships are described. It will be seen that high income is not necessarily a deterrent to transit usage, provided the time, cost and convenience are competitive between public transit and private automobiles.

Trip Purposes

For many trip purposes, such as selling to widely separated clients or shopping for week's groceries, the use of an automobile is all but mandatory. For trips, such as work trips of office staff, the choice is open and will depend on other factors. For other trips, such as many school trips, transit is the only choice because of travelers' inability to driver or own an automobile. It is logical to expect, therefore, that modal split relationships based on the four determinant factors described above will vary somewhat, depending on trip purposes.

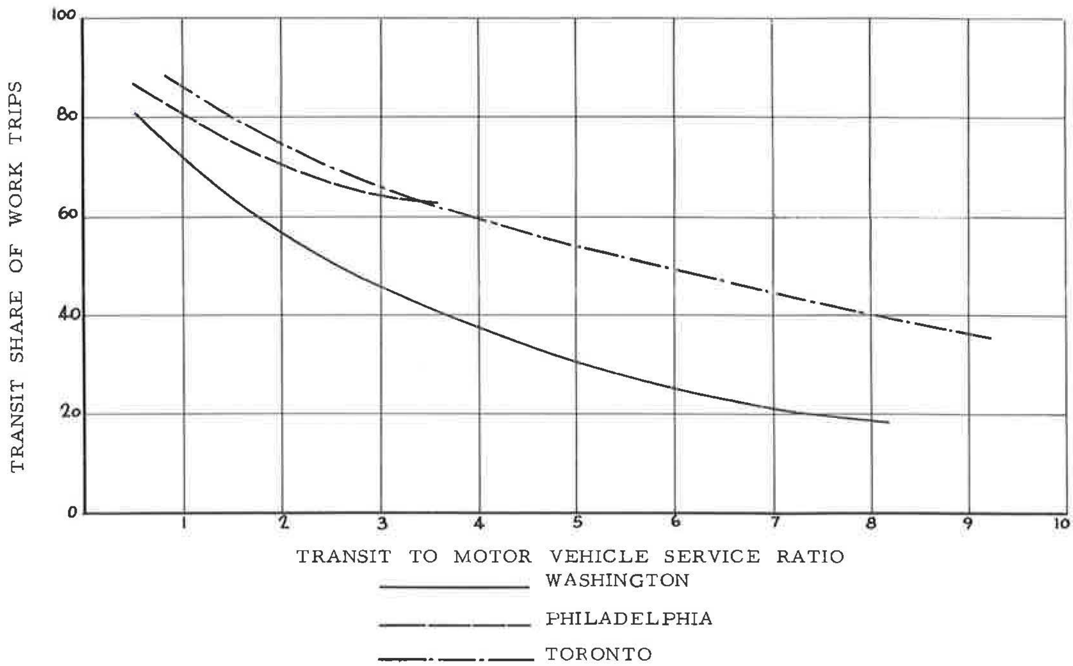

Figure 3. Service ratio diversion curve for work trips in peak periods (no. of trips in 1,000's).

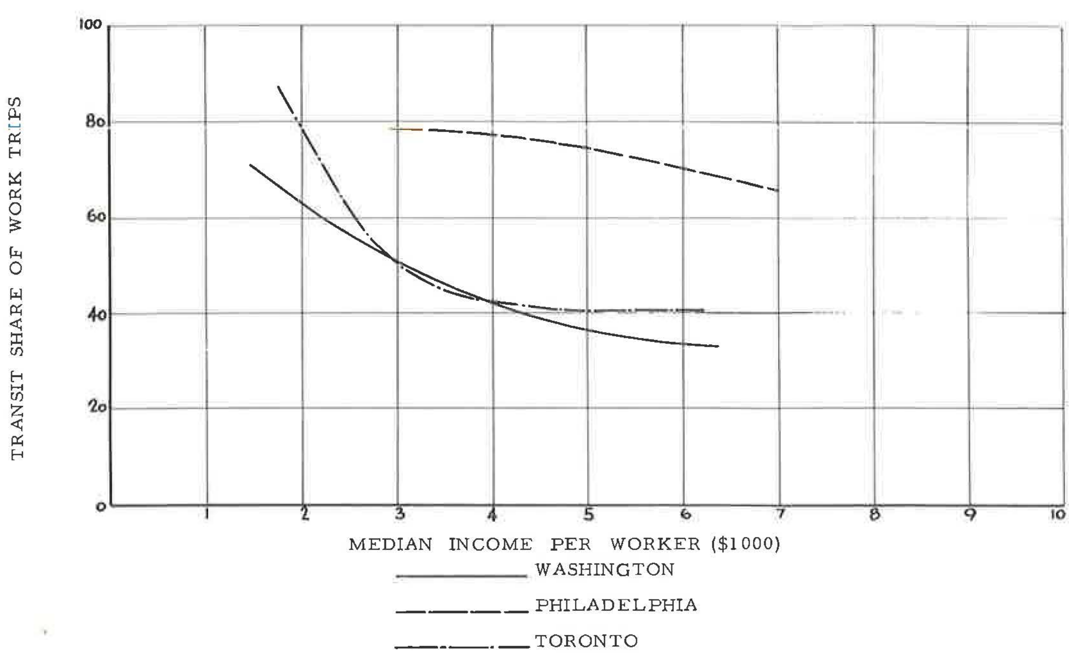

Figure 4. Income diversion curve for work trips in peak periods (no. of trips in 1,000's).

Figures 1 to 4 show the unstratified relationships determined from the three-city work trip data. Differences in slope and intercepts of the relationships are generally due to the interactance of the remaining factors which vary from city to city, i.e., low transit fares in Toronto and Philadelphia relative to auto costs, compared to higher transit fares in Washington relative to auto costs and the effect that rapid transit facilities have on modal choice behavior in Philadelphia and Toronto, but not in Washington, due to an entire bus-streetcar system. The relationships once stratified by the remaining factors demonstrate less significant differences.

SOURCES OF DATA

The major source of information concerning travel mode in metropolitan areas was O-D surveys, reporting how people actually traveled from their origin to trip destination when faced with the relative time, cost and convenience of competing modes of travel. The analysis was not based on interviews asking people how they would like to travel.

To relate the observed travel mode to the five determining factors, supplementary data of parking surveys, published mass transit route schedules outlining headways and fares, and the census providing population and household characteristics were necessary to augment the O-D survey data. Although supplementary information was obtained from independent sources it was generally considered representative for the sample trip interchanges, where the survey sample was chosen according to random selection procedures.

The following surveys were the major source of data for each of the three metropolitan areas:

1. Toronto journey to work survey, 1954: a survey reporting how workers actually traveled.
2. Washington home-interview O-D destination survey, 1955: a survey reporting how people traveled, their trip purpose, trip start and arrival time and type of parking facility used by auto drivers.
3. Philadelphia home-interview O-D survey, 1960: a survey reporting how people traveled, their trip purpose, trip start and arrival time, type of parking facility used by auto drivers, toll bridges crossed and trip maker's income.
4. Washington Federal employee journey to work survey and Washington private employee journey to work survey, 1961: surveys reporting how workers traveled to CBD areas, trip start and arrival time, transit fare of transit passengers, parking cost to auto drivers, walking times at the trip O and D and income grade.

Generally, survey trips are reported for the individual modes of travel, or combinations of the following: (a) auto driver, (b) auto passenger, (c) railroad, (d) elevated subway, (e) bus, (f) streetcar or trolley, (g) taxi passenger, and (h) truck passenger. Trips involving transfers between different modes were linked and assigned the mode code of highest priority. The mode priorities were as follows: (a) railroad, (b) elevated subway, (c) streetcar and subway, (d) bus, and (e) auto, auto passenger.

The mode stratifications were different between surveys. However, this was disregarded where the basic distinction between the two main types of travel mode was maintained. Grouping of travel modes reported in the surveys were made in order to comply with the two main types of travel modes.

Transit share of O-D traffic was calculated from the data thus grouped for the three metropolitan areas. The transit share expressed as percent of the total O-D interchange volume was correlated with the basic determinants which were calculated using the survey or supplementary information.

Travel Times

Departure and arrival times were reported for each trip of the surveys with the exception of the Toronto survey, thus providing all the information needed for the time determinant for both mass transit and motor vehicular trips. Portal-to-portal travel times of the two modes were calculated by differencing the two times.

In the case of Toronto, procedures were implemented to estimate the travel times by mode from each zone centroid to all other centroids. Knowledge of the relationships between travel speeds and prevailing traffic flows was used to estimate travel times by auto for each O-D worker movement. Travel times on the public transportation facility, not including waiting or transfer times, were based on scheduled speeds as recorded by the Toronto Transit Commission for their service in operation in the Metropolitan Toronto Area. Using a minimum path algorithm, travel times were calculated for each O-D interchange. Terminal times were added to the travel times to provide an estimate of the portal-to-portal time.

Travel Costs

Mass transit fares were generally determined from transit fare schedules. In those cases where different fares applied for railroad and other transit travel, weighted average fares were computed which were dependent upon the observed percent usage of the submodes. In the single case of the 1961 Washington journey-to-work trip surveys, the costs of transit trips were reported and therefore could be used as the source.

Automobile operating costs were calculated based on empirical formulas derived by Bevis (3) and May (4) which show average fuel consumption as a function of average speed. Average speed for each O-D pair was based on average travel distance data and automobile running time data (portal-to-portal minus estimates of terminal time). Appropriate cost per gallon of fuel was determined for each city to give fuel costs. To the fuel costs were added the proportion of oil and lubrication costs determined for a motor vehicle trip.

Average automobile parking costs were obtained for zones comprising the study areas by determining the average rates of commercial, private (government if applicable) and street facilities and the utilization thereof. The average parking costs were computed by weighting the rates of facilities according to the number of drivers serviced by each facility. With the exception of the 1961 Washington journey-to-work surveys where parking costs were reported, parking costs were derived in this manner. Since one-way trips were the basis of the study, parking costs were divided by two to give one-way parking costs.

In the case of Philadephia, toll charges were a component of some motor vehicle trip costs. When calculating motor vehicle trip costs, therefore, a toll cost for crossing the Delaware River was included. An average toll cost per O-D motor vehicle interchange was determined by combining information of percent usage of each bridge and the toll cost.

Thus the average automobile travel cost for each O-D pair was obtained by summing the (one-way) parking cost at the O or D, bridge tolls and the one-way operating cost based on average travel time and distance, and dividing this cost by the average automobile occupancy figure for the O-D pair in question, as reported by the survey.

Taxis and truck passenger trips were a small proportion of total motor vehicle trips. Consequently, automobile costs were assumed as representative of the costs of the general motor vehicle. Any discrepancies due to taxis and truck passenger trips were considered to be negligible.

Service Times

With the exception of the 1961 Washington journey-to-work survey, no information about excess transit times (walks, waits, and transfers) was reported. Walk times were reported in the particular Washington survey, but other excess times (waits and transfers) were not given and had to be computed by reliable estimating procedures.

Average wait and transfer times were determined by a procedure of tracing O to D transit routes and computing average times from the many route combinations. Experts of the transit system generally considered the results representative of the actual situation. Average walking times to and from transit stops in each zone were determined in a systematic manner based on geometric formulas. The formulas were based on the postulation that the average walking distance to transit stops was related to the following factors:

1. Developed land area serviced (acres);
2. Number of miles of transit routing;
3. Stop spacing (miles); and
4. Location of transit in developed area with respect to population centers.

Walking times to parking facilities plus the delay at the facilities were taken as a measure of convenience of motor vehicle travel. Such times were considered negligible at the home end of the trip but significantly important at the non-home end of the trip. Walking times were generally determined from the available O-D survey data. Average walking times were obtained by converting walking distance data of a parking survey, on the basis of a walking speed of 3 mph. Estimates of parking delay times were generally based on knowledge of lot and garage operation. These aggregate totals were considered representative of the total excess time for travel by auto.

Economic Status

Income-per-worker data were derived from population and household statistics of the 1950 and 1960 censuses (1951 in case of Toronto). This derivation was employed in the case of Washington and Toronto. However, income data for Philadelphia were taken from the home-interview survey and converted to income-per-worker data.

Comparative analysis of modal choice behavior in various cities necessitated expressing income data in terms of the real buying power in a base city. The Washington dollar of 1961 was chosen as the basis. Both Philadelphia and Toronto income data were adjusted to express incomes in terms of 1961 Washington constant dollars; i.e., real buying power as compared to the buying power of a dollar in Washington.

DERIVATION OF MODAL SPLIT RELATIONSHIPS

The comparative analysis of modal choice behavior in different cities was conducted exclusively with work trip data. The conclusions reached concerning the three-city work trip relationships generally should apply in the case of non-work trips, excluding school trips. The modal split of school trips will be governed by the policy of school boards with regards to location of schools to population centers and provision of school bus service. The modal split described for work trips naturally does not take such extraneous factors into account.

All types of non-work trips (excluding school), if considered, would be grouped together as one category, because the peak-hour period of time is of immediate interest for travel movement forecasting studies and such trips make up less than 25 percent of total trips at that time.

Relationships must be determined from trips made in a specific period of the day, either the rush hour or off-rush hour, as travel time and transit services differ significantly between the two periods. It is expected that differences in travel mode choice are completely explained by the differences in these two determining factors, therefore, either may suit analysis purposes. However, the rush-hour period is most suitable because of the concentration of work trips in that period. Time ratio diversion curves stratified for the remaining factors were determined for the AM rush hour (7:00 to 9:00 AM) from the three-city data, to demonstrate trends of transit usage among workers.

Stratification of Data

The unstratified curves in Figures 1 to 4 would be unsuitable for travel movement forecasting purposes because they show on a given curve the effects of one determinant only, while the effects of all other determinants are submerged in each curve. These unstratified curves are useful to indicate the overall effect of each determinant, but for forecasting purposes it is necessary to stratify the observations further so that the effects of each determinant may be seen explicitly.

In order to stratify the modal split relationships based on these data properly, it was necessary to define meaningful ranges of the factors which were to be stratified. These ranges were chosen such that each covered a roughly equal variation of the factor in question.

The cost ratios were subdivided in the following 4 ranges: (a) transit trip is cheaper; (b) equal trip costs; (c) transit is more expensive; and (d) transit is 50 percent more expensive.

The service ratios were divided into the following 4 ranges: (a) equal service time; (b) transit service time is higher by a factor of 4; (c) transit service time is higher by a factor of 6; and (d) transit service time is much higher.

The economic status was subdivided into the following 5 ranges: (a) low income; (b) intermediate income; (c) moderate income; (d) high; and (e) very high.

O-D data were stratified for each type of trip, into 80 categories, depending on which range of each of the three stratified factors applied to each O-D pair. Then for each group, a curve was determined by regression analysis and plotted showing percentage use of public transit as a function of travel time ratio. For each city data, there is a set of about 80 time ratio transit diversion curves, one curve for each combination of cost ratio, service ratio and economic status.

Grouping of Data

Individual stratified O-D observations were not plotted. A grouping procedure was carried out to remove random scatter in the data before determining the modal split curves.

Upon grouping O-D observations which fell into equidistant time ratio intervals, weights were assigned according to the total interchange volume, and the weighted average transit usage was calculated for the average point in each time ratio interval. Next, the grouped data were plotted on graph paper. Linear, and in a few cases curvilinear, curves were drawn as best fit through the plotted data, which generally agreed with the least squares fit to the ungrouped data.

In a few instances the best fit to the grouped data did not agree with the least squares fit to the ungrouped data. However, the least squares fit to the grouped data was within the confidence limits of the relationships based on ungrouped data. Also the fit to the grouped data was more consistent with known trends as indicated by data from the same source and by data of other cities. Consequently, it was concluded that the best fit to the grouped data would be more reliable in travel movement forecasting.

Observed Modal Choice Behavior

Figures 5 to 9 show observed modal choice behavior among workers, expressed for the four determining factors. Relationships based on selected survey data from each sample survey and for each metropolitan area are demonstrated.

Within each set of stratified relationships the effects of time, cost, service, and income can be seen quite clearly. Generally, it can be seen that the slope of the curves increases for increasing values of cost ratio, service ratio and economic status. That is, as public transit becomes relatively less and less competitive in terms of travel time, demand for its use falls off more quickly among prosperous people and those paying relatively low transit fares continue to use transit in fairly large proportions. By the same token, these curves show that high percentages of travelers are using public transit for trips in which it is fairly competitive with the private automobile in terms of travel time and excess time, even though transit is relatively expensive and/or the travelers in question are of high economic status.

STATISTICAL VALIDITY OF RELATIONSHIPS

Most of the points comprising the curves (Figs. 5 to 9) have a number beside them representing the number of thousands of observed trips on which each point was based. Points with no number were based on fewer than 500 observed trips. Points representing large numbers of observed trips have more statistical significance than points representing small numbers of trips, and the more significant points have been given more weight in drawing the curves. Each point shown actually represents the average of a number of points which were grouped together when they fell within a small range of the independent variable of the curve (time ratio).

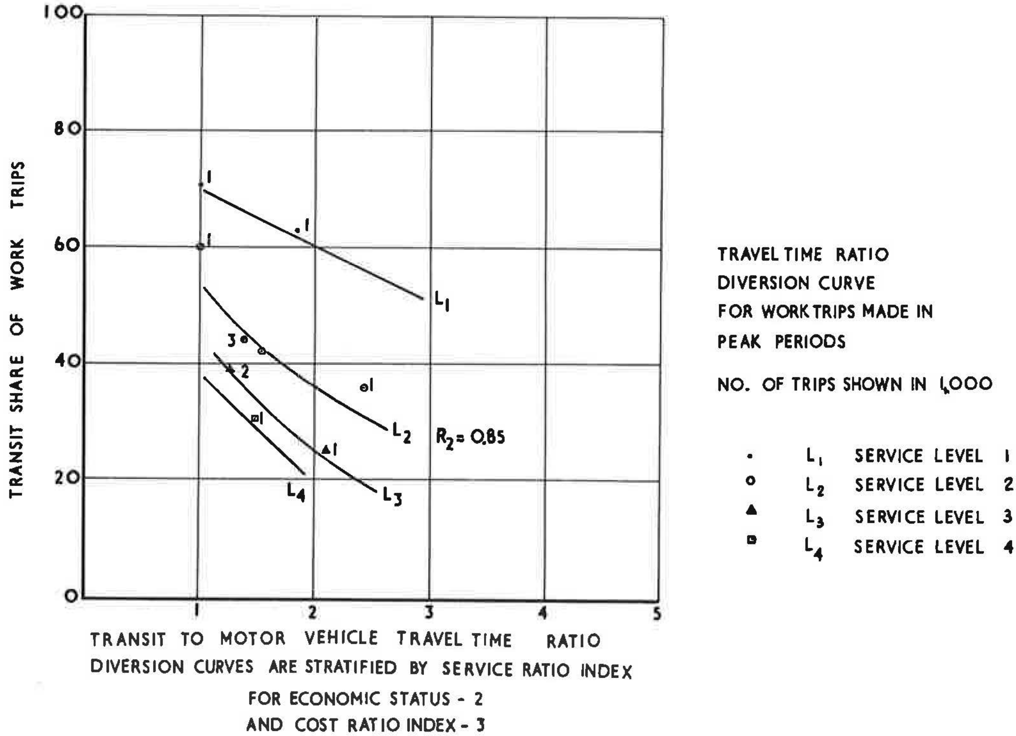

Figure 5. Home-interview survey data, Washington Metropolitan Area Transportation Study, 1955.

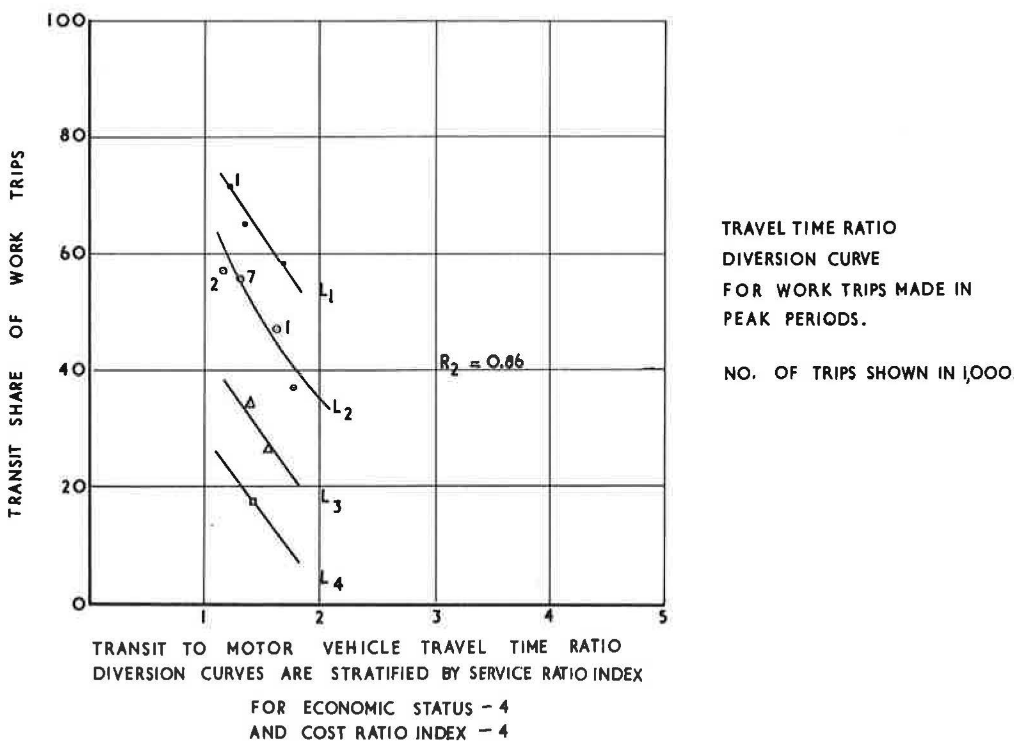

Figure 6. Federal employee parking and transportation survey data, 1961.

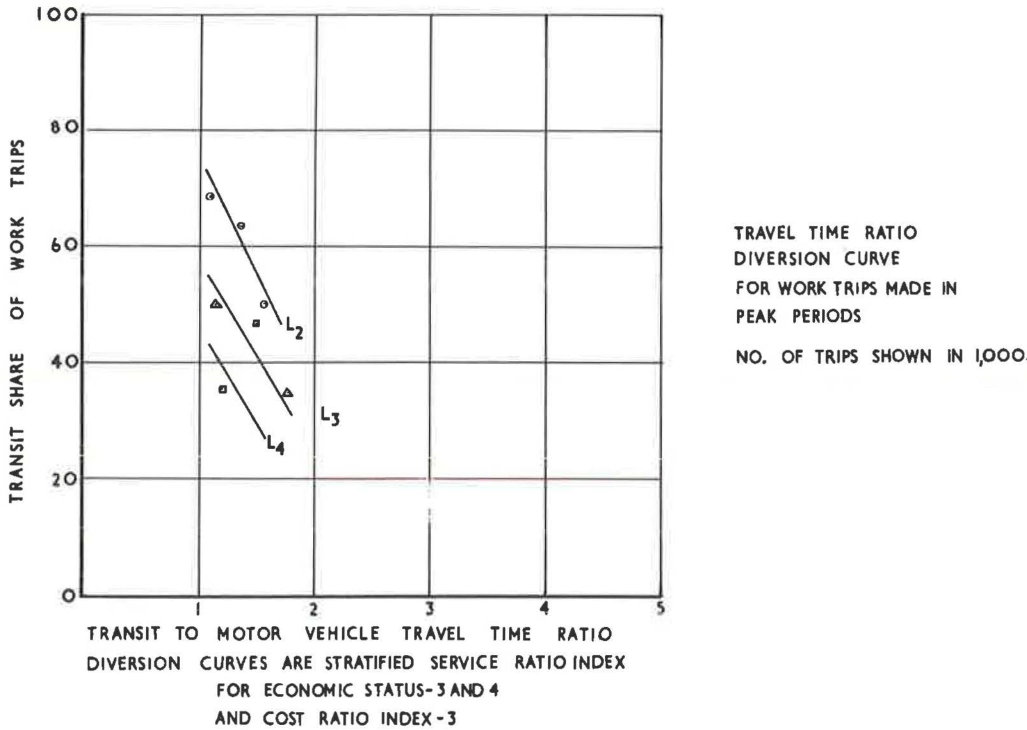

Figure 7. Private employee work trip survey data, National Capital Transportation Agency, 1961.

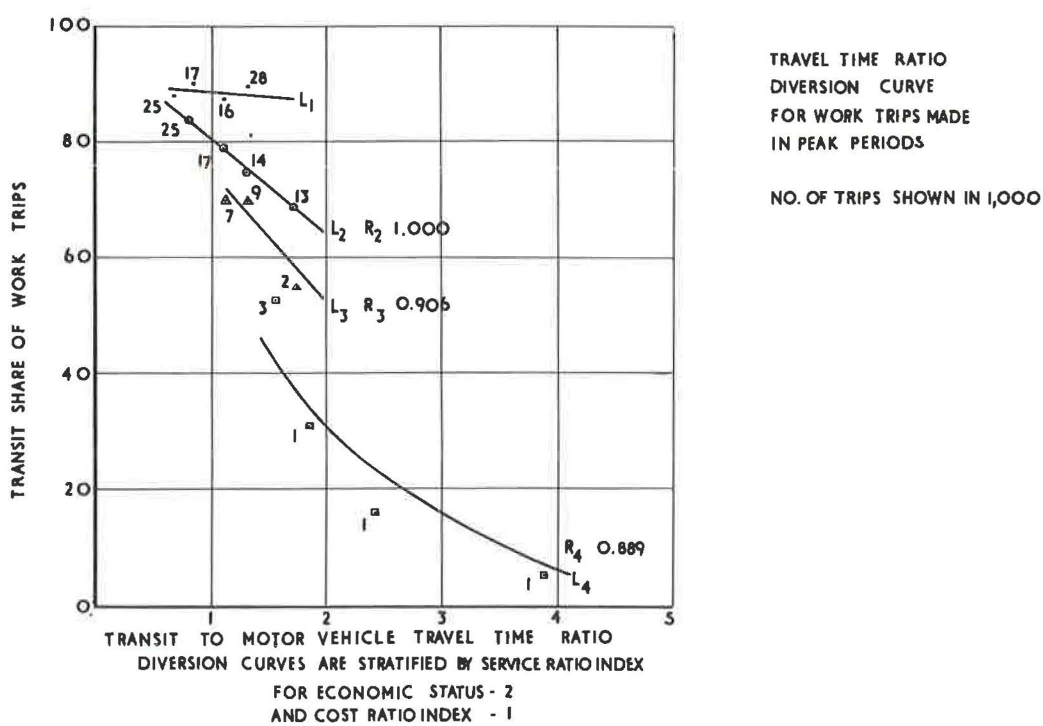

Figure 8. Worker survey data, Metropolitan Toronto Planning Board, 1954.

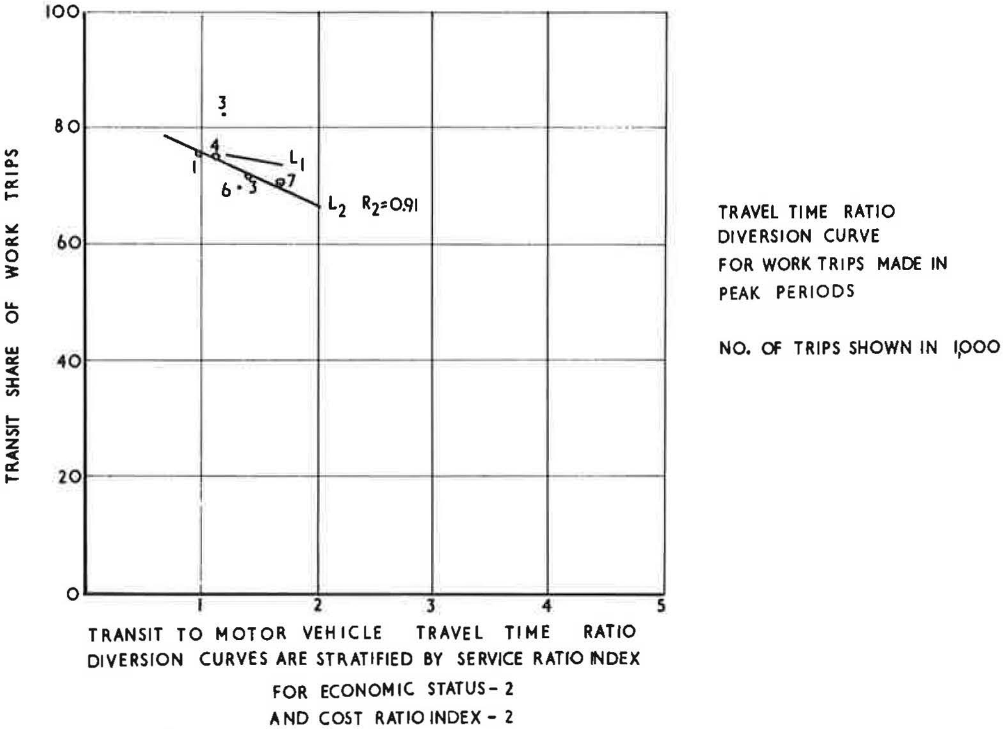

Figure 9. Home-interview survey data, Penn-Jersey Transportation Study, 1960.

Individual observations were subject to random variances. The random variances were mainly due to two factors: survey sampling error and the effect of zone size.

Survey Sampling Error

The magnitude of sampling error is a function of the observed number of person interchange trips. The more people who report trips, the greater is the confidence that the sample is representative of the whole population. Consequently, survey sample size regulates the magnitude of this component of random variation. A theoretical approach to estimating this error is based on the theory of the binomial probability distribution.

For the case of a 1-in-20 sample survey, Table 1 shows the dependency of one standard deviation of percentage usage on differing expanded trip interchange volumes V and different mean usage P.

TABLE 1

ONE STANDARD DEVIATION FOR VARIOUS VALUES OF V AND P
(Sample Size of 1-in-20)

V \ P	10	25	50	75	90
40	21	29	35	29	21
80	14	20	24	20	14
160	10	14	17	14	10
200	9	12	15	12	9
320	8	10	12	10	8
400	7	9	11	9	7
600	6	7	9	7	6
800	5	6	8	6	5
1,000	4	5	7	5	4

Effect of Zone Size

In order to simplify data handling, trip ends are grouped into O and D zones or districts which are in some cases of considerable size. The travel time, cost, and service between a pair of such zones must, of necessity, be average values which describe the trips between them as well as possible. However, the average values of these determinants will be lower than the values for trips starting and ending at extreme opposite sides of the two zones and higher than the values for trips between the near edges of the two zones. This will cause the trip makers to split between travel modes in different proportions than will average travelers between the two zones, leading to scatter in the observations. Similar scatter will be caused by the fact that inhabitants of most zones are not homogeneous as regards income, and yet must be treated as if they all had the average income for each zone.

These two sources of error are to some extent in conflict because a reduction in zone size, to decrease averaging errors, leads to an increase in sampling errors unless the relative sample size is increased substantially. Although there is a scatter in the observations when O-D pairs with like determinants are grouped together, the scatter is within expected limits, and the relationships between modal choice and the five determinants show up clearly.

The standard deviation of the ungrouped points around the grouped point, with regard to the dependent variable, is a good indication of the validity of the grouped point. The standard deviations of these groups have been calculated and have been found, in general, to be less than what was expected from the two sources of random variation. Clearly, each of the grouped points in Figures 5 to 9 are truly representative of actual travel behavior.

The next step in assessing statistical validity was to examine the degree of correlation, as shown by the grouped points, between the percent transit usage and the time ratio.

For each curve based on more than three grouped points, a value of R, the coefficient of correlation, is given. This quantity is defined as follows:

$$R = \sqrt{\frac{\sum_{n} (y - \overline{y})^2 - \sum_{n} (y - Y)^2}{\sum_{n} (y - \overline{y})^2}}$$

in which

y = observed percent transit use as shown by a grouped point for a given value of the time ratio;

$\overline{y}$ = average percent transit use of all grouped points for curve in question (i. e., for all values of time ratio);

Y = fitted percent transit use from curve itself, for each value of time ratio for which a grouped point exists; and

n = number of grouped points on which curve is based.

The coefficient of correlation provides a measure of the relative portion of the variation in the values of the percent transit use which is explained by dependence on time ratio. That is, if y remains nearly constant for all values of time ratio, the coefficient of correlation R will be small or zero. If, on the other hand, y varies clearly and systematically with time ratio, and there is little scatter of the observed points around the fitted curve, then R will be close to 1.00, its highest possible value.

Figures 5 to 9 show that R is generally high enough to show a clear dependence of percent transit use on the various determinant factors.

COMPARISON OF MODAL SPLIT RELATIONSHIPS FOR THE THREE CITIES

Investigations of modal choice behavior within a metropolitan area and between metropolitan areas demonstrated a similarity of trends of transit usage.

Submodal choice behavior was shown to be similar when expressed by the five basic determining factors. These findings supported the statement that the various modes of travel can be divided into two main types. Such evidence appears to be sufficient for travel movement forecasting where empirical observations of travel behavior are based on small sample surveys.

The use of transit for CBD and non-CBD oriented travel, use by government and private employees, and use by workers over a six-year period (1955 to 1961) were shown to be statistically similar. This further confirmed that no differentiation has to be made for CBD and non-CBD oriented travel other than to reflect the differences in time, cost and service. Most important, the relationships apparently demonstrate a stability between types of workers and especially a stability over a period of time.

Statistical tests and visual comparisons of modal split relationships conclusively showed that transit use by workers in the three cities was similar when expressed by the four determining factors.

Statistical Tests of Significance

The student t-test was used to test the similarity between the corresponding sets of data. For each set, the slope of the line of best fit and its intercept on the vertical axis were calculated and compared with the slopes and intercepts of other sets. The level of significance of the difference between sets of data was obtained from t-distribution tables. The assumption is made here in conducting these tests that there is a linear fit to the data. Generally, a linear fit to the three-city data seemed to apply; in a few dissenting cases where curvilinear fits were indicated because of points with small weights at opposite ends of the scale. such data were deleted before the statistical comparisons.

The general form of the t-ratio was

$$\frac{m_1 - m_2}{\sqrt{s_1^2 + s_2^2}}$$

in which

m = the variate to be tested; and
s^2 = the variance of each set of data.

Because of the heterogeneous nature of the survey data, it could not be presumed that each set of data would have equal standard deviations. In applying the formula, and in calculating the corresponding degrees of freedom, solutions were incorporated which make provision for this heterogeneity (5, 6, 7).

The criteria for evaluating the results of the t-tests were:

1. A level of significance equal to or greater than 0.05 indicated no significant difference between the sets of data.
2. A level of significance between 0.05 and 0.01 was inconclusive of whether any significant difference did or did not exist.
3. A level of significance less than 0.01 indicated that there was a statistically significant difference between the sets of data.

Tests of Significance of Submodal Behavior

It has been stated that the relative use of alternative submodes within the public transit mode is also dependent on similar determinant factors: time, cost, service, and economic status. Using Philadelphia data, a statistical evaluation was carried out to offer some insight to this consideration.

All railroad trips were assigned appropriate time, cost, service, and economic status data for the calculation of representative determinant factors. Likewise the determinant factors were calculated for public transit trips, referred to here as transit not involving travel by railroad. In each case the usage of the submode was shown as a percentage of total O-D trip interchange. Consequently, the use of submodes was directly comparable.

Where sufficient comparable data were available T-tests of coincidence were conducted for the submodal relationships. In all but one case the tests showed that differences in slopes and intercepts were insignificant at the 5 percent level. In one case the level of significance was greater than 1 percent, hence the results were inconclusive as to whether any difference did exist (Table 2).

TABLE 2

PUBLIC TRANSIT SUBMODAL TIME RATIO DIVERSION CURVES DATA STRATIFIED BY EC, CR, SR (Rail vs Transit)

EC	CR	SR	Slope t-Ratio	Level of Significance	Intercept t-Ratio	Level of Significance
3	2	1	0.81	0.40	0.32	0.70
3	2	2	1.62	0.10	0.20	0.80
3	3	2	0.47	0.60	2.15	0.03*
4	2	1	2.02	0.10	2.05	0.10
4	2	2	0.18	0.80	0.54	0.50
4	3	2	0.11	0.90	0.62	0.50
4	3	3	2.91	0.05	3.10	0.05

*Inconclusive results.

Similarity of Modal Choice Behavior Within a Metropolitan Area

The similarities of modal choice behavior between CBD oriented and non-CBD oriented travel, between government and private employees and between workers over a 6-yr time period were confirmed by statistical tests of significance, based on survey data of the Washington Metropolitan Area.

1. 1955 CBD Work Trips vs 1955 Non-CBD Work Trips (Table 3a). —In all cases tested, the level of significance between these sets of data was greater than 0.05, indicating that on a statistical basis there was no significant difference between the sets of data.

TABLE 3

SIMILARITY OF MODAL CHOICE BEHAVIOR WITHIN A METROPOLITAN AREA

E	C	L	Slope t-Ratio	Level of Significance	Intercept t-Ratio	Level of Significance
(a) 1955 CBD Work Trips vs 1955 Non-CBD Work Trips						
1	3	2	1.19	0.25	1.46	0.10
2	3	2	0.33	0.70	0.60	0.50
2	3	4	0.41	0.60	0.16	0.80
3	3	4	0.28	0.70	0.16	0.80
3	4	4	0.84	0.25	0.46	0.40
(b) 1955 CBD Work Trips vs 1961 Federal Survey						
3	3	3	1.88	0.05	2.13	0.05
3	4	2	1.45	0.10	1.08	0.25
3	4	3,4	0.10	0.90	0.10	0.90
(c) 1961 Federal Survey vs 1961 Private Survey						
3,4	2	2	0.54	0.60	0.86	0.40
3,4	2	3	1.03	0.40	1.23	0.40
3,4	2	4	1.24	0.20	0.93	0.30

2. 1955 CBD Work Trips vs Federal Survey (Table 3b). —In all cases tested, the levels of significance between the paired data were in the range that indicated no statistically significant difference existed between the sets of data.

3. 1961 Federal Survey vs 1961 Private Employees Survey (Table 3c). —In all cases tested, the comparison indicated no significant difference between the sets of data.

Similarity of Modal Choice Behavior Between Metropolitan Areas

T-tests of concidence of relationships were employed to determine if significant differences of modal choice behavior (for work trips) existed between metropolitan areas which were not explained by the four major determinants. The tests generally showed that differences were statistically insignificant at the 5 percent level and were otherwise generally inconclusive at the 1 percent level. On the basis of such tests, it was concluded that the relationships were statistically similar. Any dissimilarity was definitely less than the variation within the survey data. Either large sample surveys or special market research type surveys would have to be carried out to disclose the nagnitude of dissimilarities, if they do exist.

It was not possible to make a comparison between all O-D trip data of each metropolitan area because of a different distribution of data over the time, cost, service ratio and economic status scales. The median worker income for Toronto was in the range of the second economic status level, whereas the median incomes for Washington and Philadelphia were in third economic status level. Although there were ample data for low cost ratios in the case of Philadelphia and Toronto, there were no such data in the case of Washington. Large variations of service ratio existed in all three cities, so that direct comparisons were possible for service ratios over the complete range.

Of the 17 groups for which comparisons were made, 11 indicated no significant differences for either slope or intercept. One comparison indicated significant differences and the remainder were inconclusive on the slope comparison and or intercept comparison (Table 4).

TABLE 4

TIME RATIO DIVERSION CURVES; GRAPHS STRATIFIED BY EC, CR, SR

Comparison	EC	CR	SR	Slope t-Ratio	Level of Significance	Intercept t-Ratio	Level of Significance
Philadelphia	2	1	1	1.05	0.30	0.61	0.50
vs	2	1	2	1.25	0.40	1.23	0.40
Toronto	3	1	1	1.96	0.10	1.61	0.10
	3	1	2	2.87	0.01*	2.38	0.025*
Washington	2	2	1	0.64	0.50	0.86	0.40
vs	2	2	2	0.10	0.90	0.91	0.30
Philadelphia	3	2	1	3.72	0.005**	3.99	0.01*
	3	2	2	3.77	0.001**	4.51	0.001**
	3	3	2	0.38	0.70	0.18	0.80
	4	3	3	0.88	0.40	0.12	0.90
Toronto	2	2, 3, 4	1	0.50	0.60	0.51	0.60
vs	2	2, 3, 4	2	2.22	0.02*	0.60	0.50
Washington	2	2, 3, 4	3	1.62	0.10	0.17	0.80
	2	2, 3, 4	4	2.39	0.02*	1.60	0.10
	3	2, 3, 4	1, 2	1.86	0.05	2.28	0.02*
	3	2, 3, 4	3, 4	1.73	0.05	0.43	0.60
	4	2, 3, 4	3, 4	0.19	0.80	0.15	0.80

*Inconclusive results.
**Significant differences are apparent.

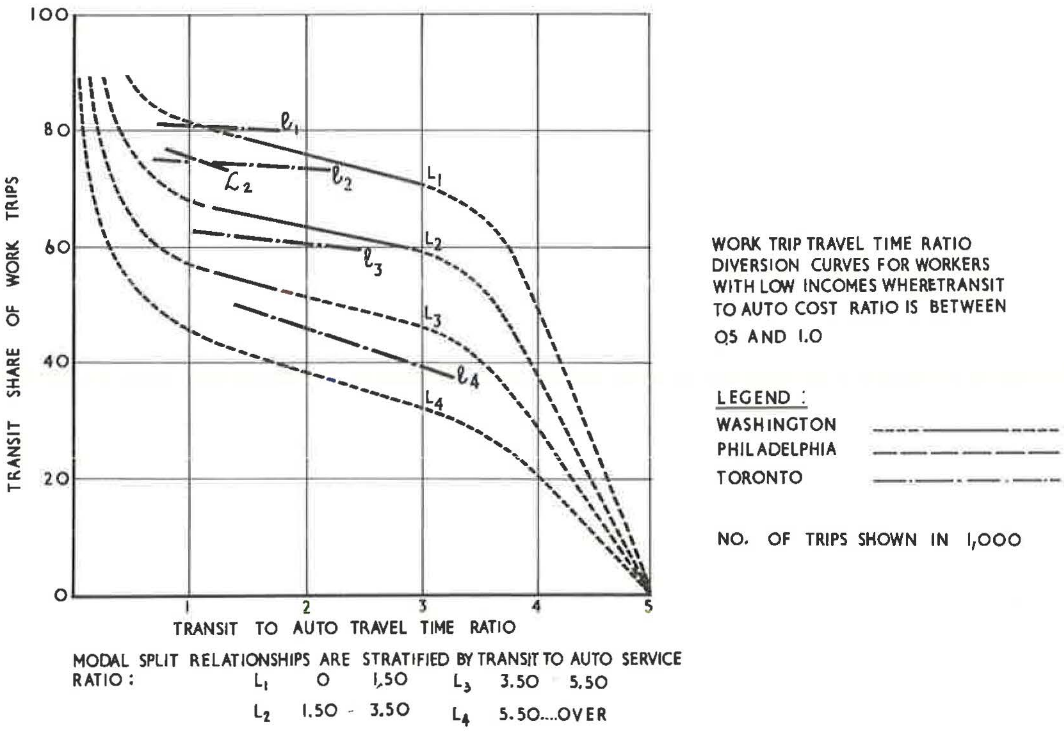

Figure 10. Direct comparison, Philadelphia, Washington and Toronto.

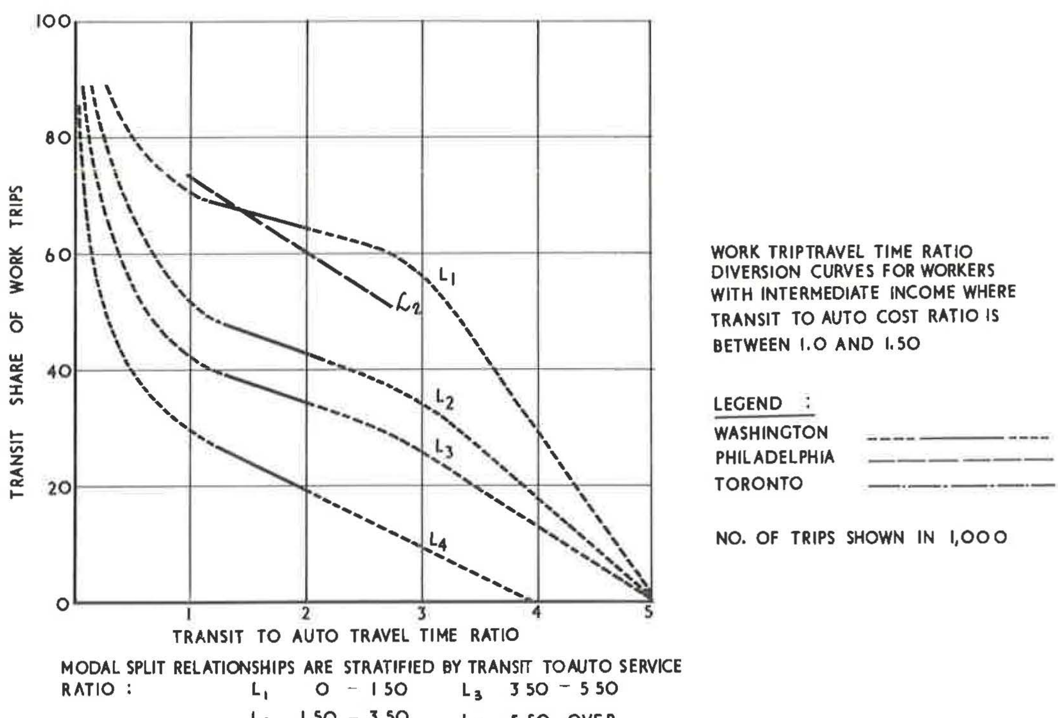

Figure 11. Direct comparison, Philadelphia, Washington and Toronto.

The findings were encouraging, as modal choice behavior was apparently similar between cities. Modal split relationships of cities such as Philadelphia and Toronto can be employed to augment the Washington relationships for those situations where no local supporting survey data are available, etc. This does not mean a direct substitution of relationships, but only an extrapolation of known trends in the most probable direction of occurrence as indicated by corroborative data from the other cities.

In addition to the statistical comparisons, this conclusion is borne out by visual comparison of the three city relationships (Figs. 10 and 11).

CONCLUSIONS

Based on the above comparisons it may be concluded that travel mode choice behavior for trips to work, as related to the four basic factors, time, cost, service and income, is stable over time and is similar in Philadelphia, Washington and Toronto.

A major difficulty in these comparisons is that stratification of data into 80 groups, although necessary to isolate the effects of the determinant factors, has the result of reducing the number of survey reported trips in some of the stratified groups to levels for which statistical sampling variance can be quite large (Table 1). Comparisons between data for three cities have removed most of these uncertainties because similar trends have been established for the three cities. Similar reassurance may be gained from the fact that forecasts using these relationships will focus attention mainly on heavily traveled corridors where the large numbers of trips involved tend to cancel out statistical variances. Further analyses and comparisons of travel mode choice behavior, based if possible on large sample surveys, are desirable to increase knowledge in this important area. Meanwhile, modal split relationships derived for each metropolitan area and verified by comparative analyses for the remainder, may be used with confidence for urban travel movement forecasting studies.

In particular the relationships have been incorporated into a modal split model which is being used for travel movement forecasting in Washington (8) and in Toronto (9).

Relationships for non-work trip purposes were derived from the Washington data and were a component of the Washington model. Although, unsupported by other city data at that time, they were considered adequate for the purpose of travel movement forecasting.

Although the comparative analyses have demonstrated statistical similarity between the modal split relationships for Washington, Philadelphia and Toronto, the transportation planner who may choose to use directly these relationships for travel movement forecasting in another city is cautioned concerning their direct use. Ten percent differences in absolute usage exist in some cases between the three sets of relationships. These differences are probably due to random variation, inherent in the data of small sample surveys, and perhaps also due to other factors characteristic of the population and or transportation system, which have not been included in the model. Since a measurable range of random variance is expected in the survey data which generally exceeds the 10 percent difference between curves of the three cities, it is difficult to determine other sources of difference from the basic data alone. Special large sample surveys or surveys of a market research type are required to determine these sources.

This 10 percent difference in absolute usage reflects a significant difference between estimates of demand for a transportation system. The differences could influence a transportation decision regarding the number of freeway lanes or capacity requirements for public transportation facilities.

It is recommended that some analysis of survey data for a city be conducted to determine precisely the intercepts and positioning of the curves on the usage scale. Although the slopes should generally agree with those of Washington, Philadelphia and Toronto, the intercepts may disagree by 10 percent. The derivation of new relationships from sample survey data and comparative analyses with other city data will give the transportation planner the assurance he requires to apply modal split relationships in travel movement forecasting.

The investigations described in this paper have been essential and exploratory research into the factors which motivate people in their choice of mode. The finely stratified data presented here in the form of time ratio diversion curves lend themselves to careful scrutiny of partial effects and comparison with data from different sources.

Following the careful examination of the role of the determinants in mode choice and the numerous interrelationships, investigations are now proceeding to determine whether mathematical functions will adequately describe modal choice behavior as explained by the stratified diversion curves.

ACKNOWLEDGMENTS

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Application of a Modal Split Model to Travel Estimates for the Washington Area

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•THE National Capital Transportation Agency (NCTA) is an independent Federal agency established in 1959. The Congressional act establishing the agency required that a report be prepared for submission to the President on November 1, 1962 (1) setting forth financial and organizational recommendations for urban transportation in the region.

The Washington Metropolitan Area Transportation Study (WMATS) is a continuing organization sponsored by the highway departments of the District of Columbia, Maryland and Virginia in cooperation with the Bureau of Public Roads.

The Traffic Research Corporation is a private organization which provides consulting services in the fields of transportation planning and traffic research.

In order to maximize the use of technical personnel and techniques and to insure a coordinated technical approach to transportation planning for the region, the technical forces of NCTA and WMATS were combined late in 1961. The major objectives were to prepare forecasts of peak and 24-hr person travel for two land-use plans and to test the modal split implications of various highway and mass transit systems proposed for the two plans. The gravity model method of trip distribution was used for both forecasts (2).

This paper is concerned with the modal split phase of the joint program and more specifically, the application of a model which was developed by TRC (3), under contract to NCTA, for use by the joint group.

Adequate estimation of alternative mixes of transit and highway usage was a critical element in the study of the region's transportation requirements. Washington has a large central area employment with 350,000 today and over 400,000 estimated by 1980. These jobs are situated such that a great majority of them could be served by a rapid transit system. Furthermore, there is evidence that the postwar trend toward low-density development has been arrested. Last year, 62 percent of all dwelling units constructed in the Washington area were in multifamily buildings. These are but two of the several facts that make Washington one of the few American cities which seriously has a wide range of modal mix alternatives. Most other cities are either too small, too dispersed, or already have rapid transit systems receiving heavy use; any of these situations limits the range of future possibilities.

MODAL SPLIT MODEL

The modal split model applied during these studies consists of two parts: (a) empirical relationships describing how travel mode choice behavior is related to basic factors in a number of cities; and (b) a computer program designed to forecast future travel mode choice behavior, based on these relationships.

Paper sponsored by Committee on Origin and Destination.

Stratified Modal Split Relationships

It is apparent that such a model is a valid forecasting tool only if the relationships on which it is based can be shown to be stable. That is, the relationships must show how propensity to choose one travel mode in preference to another is related to basic motivating factors that are not likely to change over time, or from one city to another. These criteria have been tested for the relationships on which this model rests.

The two travel modes to which the model applied are public transit and the private automobile. These modes have fundamentally different properties. Public transit is characterized by fixed routes and schedules, whereas private automobiles may be used flexibly for door-to-door travel at whatever time the traveler desires. It therefore seems reasonable to assume that travelers' choice of two modes will depend in part on the effects of these different properties, and the evidence bears this out.

Following multiple regression analysis of a larger number of variables, five factors were selected as having more significant correlation with propensity to use public transit than the other variables tested. These five factors are defined as follows:

1. Relative travel time: door-to-door travel time via public transit divided by door-to-door travel time via private automobile.
2. Relative travel cost: the out-of-pocket travel cost via public transit (i.e., the fare) divided by the out-of-pocket cost via private automobile (i.e., gasoline, oil and lubrication costs for the trip plus parking cost, if any).
3. Relative excess travel time: time spent walking to and from transit stops, waiting for vehicles and transferring between vehicles when traveling via public transit, divided by the time spent walking to and from parking areas and waiting to park or "unpark" the auto when traveling via private automobile. (This ratio, also known as the service ratio, provides a measure of the relative level of service or convenience supplied by the two travel modes.)
4. Economic status of trip makers: the income range within which each zone falls, as regards median income of resident workers.
5. Trip purpose: the destination purpose, such as work or school, for which each trip is made.

To isolate the effects of the five determinants on relative use of transit and autos, it was necessary first to calculate the value of the travel time ratio, travel cost ratio and service ratio describing the relative competitive position of public transit and the private automobile between every O-D pair under consideration. It was also necessary to determine the average economic status of travelers proceeding from the O to the D. Then the percentages of travelers from the O to the D using public transit and private automobile were determined for each trip purpose and related to each of the other four determinant factors.

This was done by stratifying the observations for each trip purpose into 80 groups, according to the particular cost ratio, service ratio and economic status applying to each origin-destination pair. The analysis was carried out for two trip purposes (work and non-work) so that 160 groups of data were obtained. For each group, the percentage use of public transit was plotted against the travel time ratio for each O-D pair in the group. The final result was 160 transit-use diversion curves, each one showing how relative use of public transit varies with relative travel time for the travelers experiencing a particular level of cost ratio, service ratio, economic status and trip purpose.

Five O-D surveys, for the years 1954, 1955, 1960 and 1961, were analyzed in this manner during the model development and it was found that the derived modal split relationships were similar from one year to another during this period. These surveys represented travel data from three cities, Washington, Toronto and Philadelphia, and again it was observed that the modal split relationships were quite similar from one city to the next.

Comparison of the three sets of Washington work trip relationships showed that, when all three sets were expressed in terms of 1961 Washington dollars, the stratified relationships were similar enough to allow amalgamation of the three sets of data, producing one composite set of Washington modal split relationships for work trips (Fig. 1). A similar set was developed for non-work trips. The Toronto and Philadelphia sets of modal split relationships for work trips, also expressed in terms of 1961 Washington dollars, were then compared with the composite Washington work trip relationships, both visually (Fig. 1) and statistically. It was shown that the modal split of work trips in the three cities is strongly similar when stratified by the four factors, time, cost, service, and income.

A word of caution is necessary, however, regarding the application of modal split relationships developed in one city for forecasts in another city. Comparison of the Washington curves of Figure 1 (solid lines, with dotted lines where the curves have been extrapolated to low and high travel time ratio values) with the curves from Philadelphia (dashed lines) and from Toronto (dash-dot lines) shows that some significant differences occur for some of the curves. It would therefore be unjustified, considering the present state of knowledge in this field, to use curves developed in one city for forecasts in another, except for the roughest estimates of modal split. The Philadelphia and Toronto curves were not used directly in the Washington forecasts, but were derived rather to corroborate the Washington relationships and to provide evidence for the extrapolation of Washington curves. General similarity from city to city is very pronounced; however, any city contemplating the use of this model for detailed forecasts should carry out some analysis of local travel data as the primary basis for modal split relationships, rather than applying the Washington relationships without verification for local conditions.

Each of the 20 graphs in Figure 1 shows transit use diversion curves as a function of travel time ratio (TTR) for all trips in the city which fall within a certain range of travel cost ratio (CR), economic status level of travelers (EC), and travel service ratio (L). All five graphs in each vertical column of Figure 1 pertain to one value of CR. Similarly, all four graphs in each horizontal row pertain to one value of EC. Finally, within each of the 20 graphs there are four separate curves for Washington, each referring to a particular level of L. (There are fewer than four curves in each graph for each of the other two cities because of lack of data for some levels of service.) The ranges of values defined by each level of CR, EC and L are given in Table 1.

Examination of Figure 1 indicates the effects that the various factors have on propensity to use transit. First, the curves within each graph show the effect of relative travel time: as the time ratio increases, transit use decreases. Second, the effect of cost ratio is indicated by comparing each column of graphs with the next: generally, as cost ratio increases (moving from left to right) transit use decreases. Third, the effect of economic status is indicated by comparing each row of graphs with the next: generally, as user income increases (moving from top to bottom) transit use becomes more sensitive to poor service. And fourth, the four Washington curves in each graph indicate the effect of service ratio: as service ratio increases (moving from L_1 to L_4) transit use decreases. When interpreted in the light of the four factors, it can be seen that these effects appear to be entirely reasonable, strongly suggesting rational modal choice behavior on the part of the traveling public.

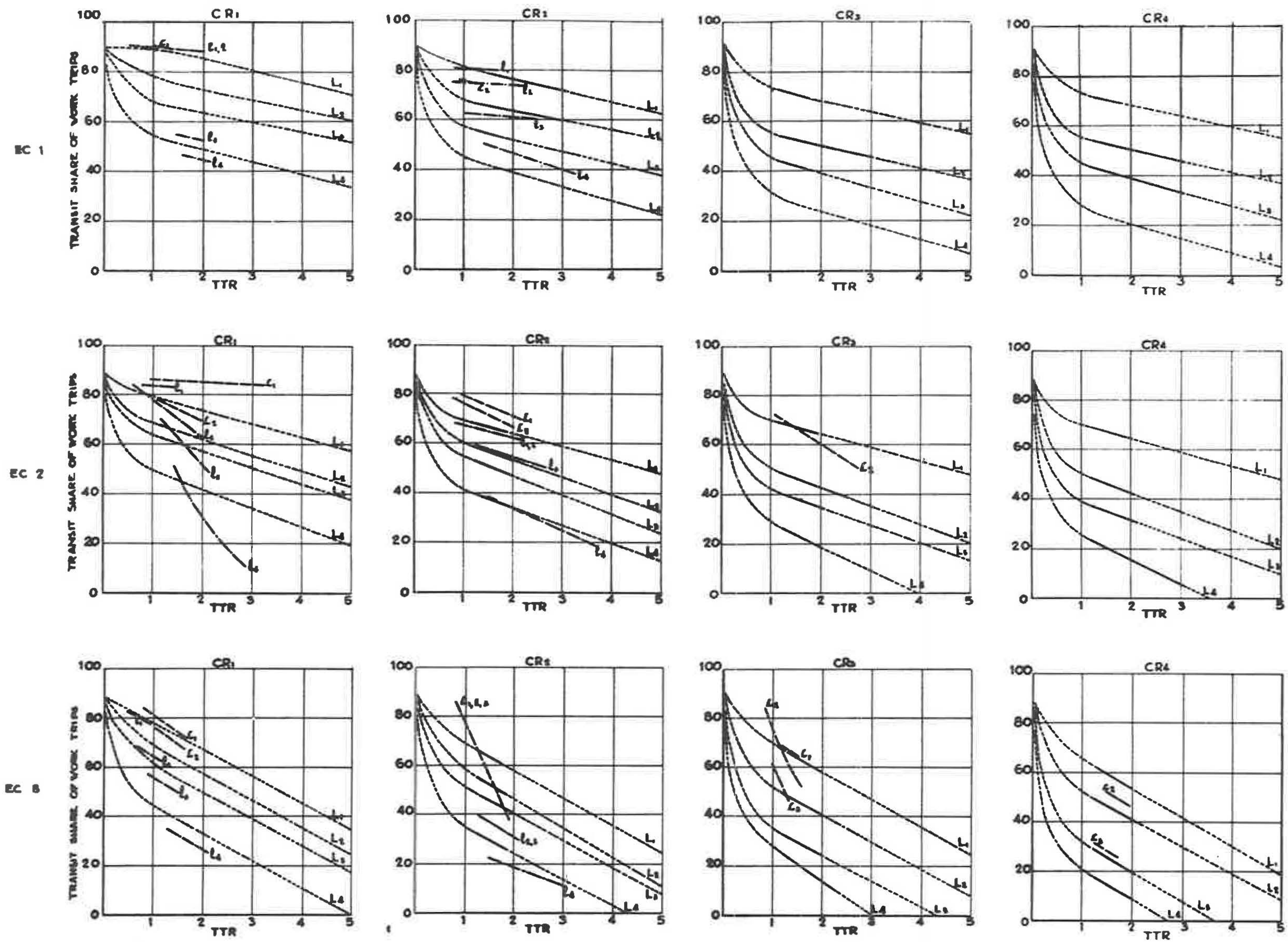
The details of the modal split analysis, its statistical validity, and the compar-

TABLE 1

STRATIFICATION LEVELS FOR COST RATIO (CR), ECONOMIC STATUS (EC) AND SERVICE RATIO (L)

CR_1	= 0.0 to 0.5
CR_2	= 0.5 to 1.0
CR_3	= 1.0 to 1.5
CR_4	= 1.5 and over
EC_1	= \$0 to \$3,100 per annum
EC_2	= \$3,100 to \$4,700 per annum
EC_3	= \$4,700 to \$6,200 per annum
EC_4	= \$6,200 to \$7,500 per annum
EC_5	= \$7,500 per annum and over
L_1	= 0 to 1.5
L_2	= 1.5 to 3.5
L_3	= 3.5 to 5.5
L_4	= 5.5 and over

Note: TTR is plotted as a continuous variable, the abscissa of each graph in Figure 1.


EC 1
EC 2
EC 8
CR1
CR2
CR3
CR4
TRANSIT SHARE OF WORK TRIPS
TTR

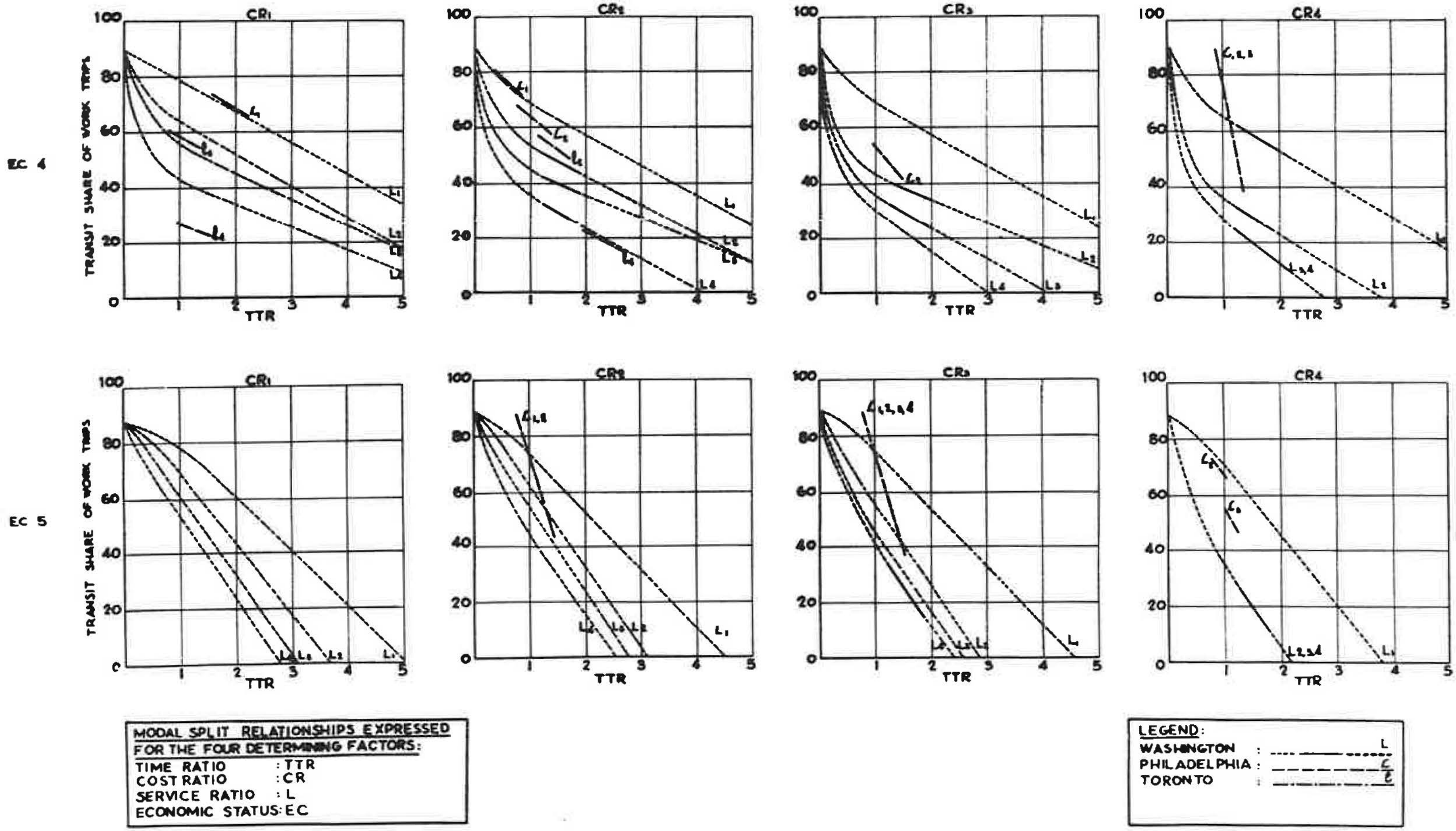


Figure 1. Work trip modal split relationships for Washington, Philadelphia and Toronto.

Figure 3. NCTA transit system.

Figure 3 also shows the assumed transit frequency of operation. In general, trains were assumed to run each 90 sec downtown with 6-min headways being common at the outer ends of the lines (these headways were applied for peak hours only). Express bus lines were assumed to operate at varying headways, in the 30- to 60-sec range, depending on passenger demand. The one commuter rail line had 10-min headways.

A local bus transit network was assumed to be in operation to serve those "close in" residents living within 5 to 6 miles of the city center and to provide feeder service to the rapid transit lines. Though the local lines are not shown in Figure 3, the lines were located in a pattern similar to the existing bus lines except for reorientation so as to intercept rapid transit stations. Local bus speeds and frequency of operation were assumed to be similar to those of existing peak-hour bus operations.

Figure 4 shows the major elements in the test highway system, consisting of 140 miles of urban freeways, and limited-access parkways, plus a connecting network of expressways, arterial streets and local streets. The most difficult element of the highway system was the determination of future assumed peak-hour operating speeds. The problem was solved by use of an iterative process as follows:

1. A judgment estimate was made of the percent of all peak-hour trips to downtown which would be by transit (62 percent) and the percent of all non-downtown destined trips by transit (20 percent).

2. The total person trip interzonal peak-hour volumes for 1980 were factored by the auto share of these trips, 38 percent for downtown and 80 percent for non-downtown trips. The resulting trips were assigned to the highway system. The assignment program used was the WMATS-BPR "all-or-nothing" process (5). Speeds assumed for this assignment were similar to the "average daily speeds" which have been used to

Figure 4. NTCA recommended highway system.

calibrate a similar highway network for the Washington Area. Volume capacity ratios were calculated for key links of the system.

3. Consideration was given to existing peak-hour speeds, to existing volume capacity ratios, to increments in capacity planned for each corridor, and to increments in the assigned volume above existing volume. A curve relating freeway volume to speed (Fig. 5) was also used as a guide. This curve was a composite of freeway operation experience in numerous urban areas. Speed estimates were prepared for each freeway link and critical arterial links. Secondary and local street speeds were assumed to be unchanged from today's speeds.

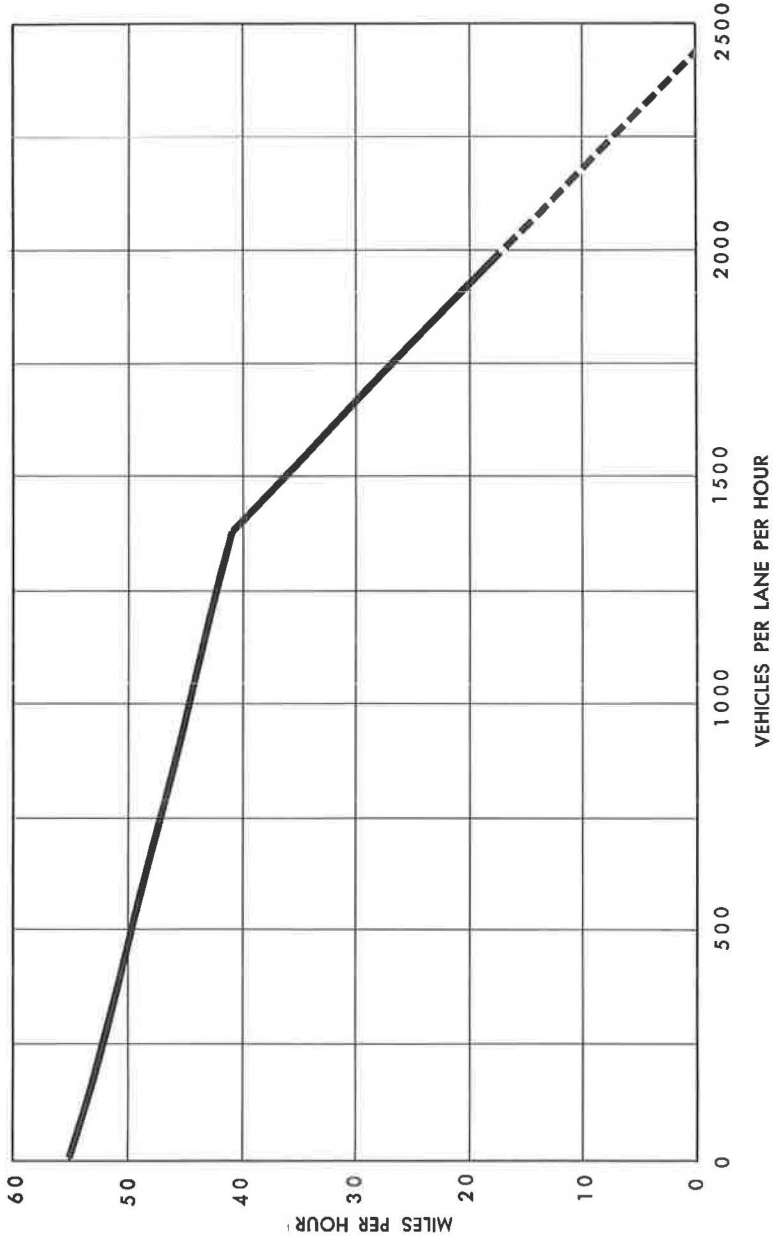


Figure 5. Relationship of speed and lane volume on urban freeways used in NCTA split analysis.

4. These speeds were introduced onto the network and new auto interzonal travel times were computed.

5. The modal split computer program was run. Resulting highway volumes were assigned and steps 3 and 4 repeated. The computer program was run again and steps 3 and 4 repeated again. This process was continued until the assumed speed on each link was consistent with its assigned volume and capacity.

The preparation of peak-hour speeds was a time-consuming and tedious operation. The time was spent because it was believed that auto speeds were critical in the final modal split calculations particularly within a 2- to 3-mi radius of downtown where highway capacity deficiencies were most likely to occur. Experience with the model has demonstrated that the travel mode split is not nearly so sensitive to fluctuations in these close-in highway speeds as was initially assumed. Sample manual calculations of typical interzonal movements confirm this.

The use of a capacity restraint program would have obviated the need for this manual process, but programming difficulties did not allow the automated procedure to be developed within time limits imposed on this project.

APPLICATION OF MODEL TO TEST SYSTEM

Figure 2 above shows the input data necessary for running the modal split program. A matrix of interzonal total person trips (without travel mode designation) is required as well as interzonal travel times by auto and transit and various parameters related to individual zones. The output includes a matrix of transit trips, a matrix of auto trips, and additional data (such as transit revenues) useful for analysis.

Figure 6 indicates the flow of data from initial assumptions to final calculation of modal split. Some of the process occurs as part of the modal split program; other steps are performed by use of intermediate programs; others are manual preparations. Modal split (Box D-21) is determined by the value of the travel time (Box D-17), cost (Box D-19) and service ratios (Box D-18) plus the income of the rider (Box D-20). (The fifth variable, trip purpose, is established by the interzonal person trips input, i.e., either work trips or non-work trips.) The travel time ratio is dependent on the time by transit (Box D-11) and time by auto (Box D-12). The auto travel time is a function of: (a) auto running time (Box C-7), and (b) auto parking delay (Box 4-5). The auto running time is a function of the speeds coded into the highway system (Box B-3) as previously described. Figure 6 can be used to relate any of the fundamental modal split determinants to the initial input.

Initial Assumptions

Some initial assumptions had to be made before the model could be used.

1. Truck traffic would be unaffected by the presence or absence of a rapid transit system.

2. Trips which have one end outside the Washington Metropolitan Area will not be diverted to transit. Actually, some 7,000 motorists (drivers and passengers) came across the boundaries of the metropolitan area during the three heaviest morning hours bound for downtown for work in 1961. It is likely that some of these will become rapid transit riders in the future by parking their cars in outlying station parking lots. Savings of downtown parking costs and avoidance of central city congestion would probably motivate them in the same way as residents living within the study area. However, to remain conservative, it was assumed that all of these travelers will continue to use their autos in the future.

3. The modal split relationships would not apply to passengers now using taxis. Taxis fill a somewhat unique transportation function in Washington. Considered on a 24-hr basis, over 10 percent of all internal trips were made by cab in 1955 (internal trips exclude trips with one or both ends outside the 1955 urbanized area). For 1980, it was estimated that 23,000 taxi trips would be made in the AM peak hour assuming no rapid transit system to be in operation. Of these, 72 percent were estimated to begin or end (or both) within "Sector 0." It would be reasonable to assume that many of

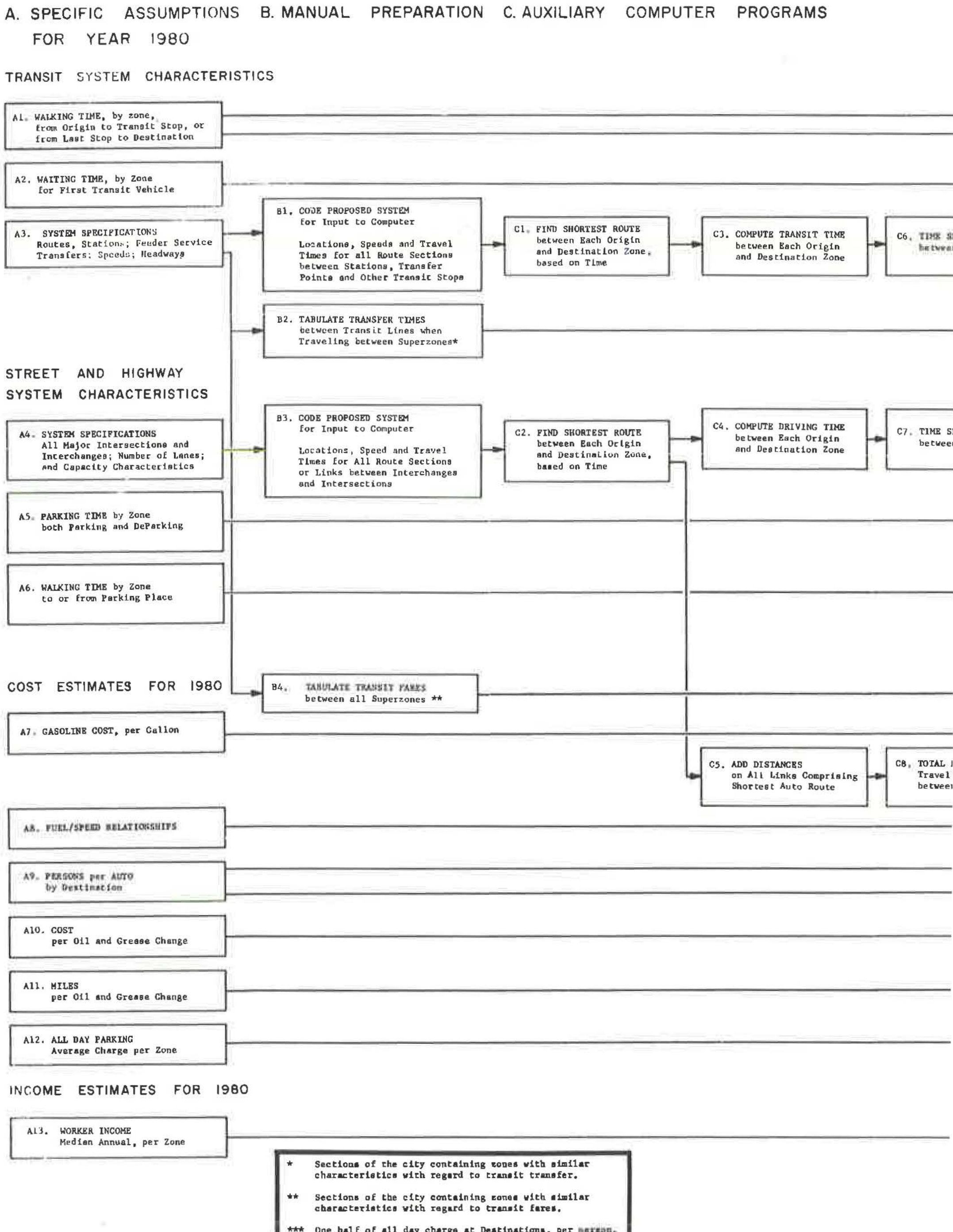
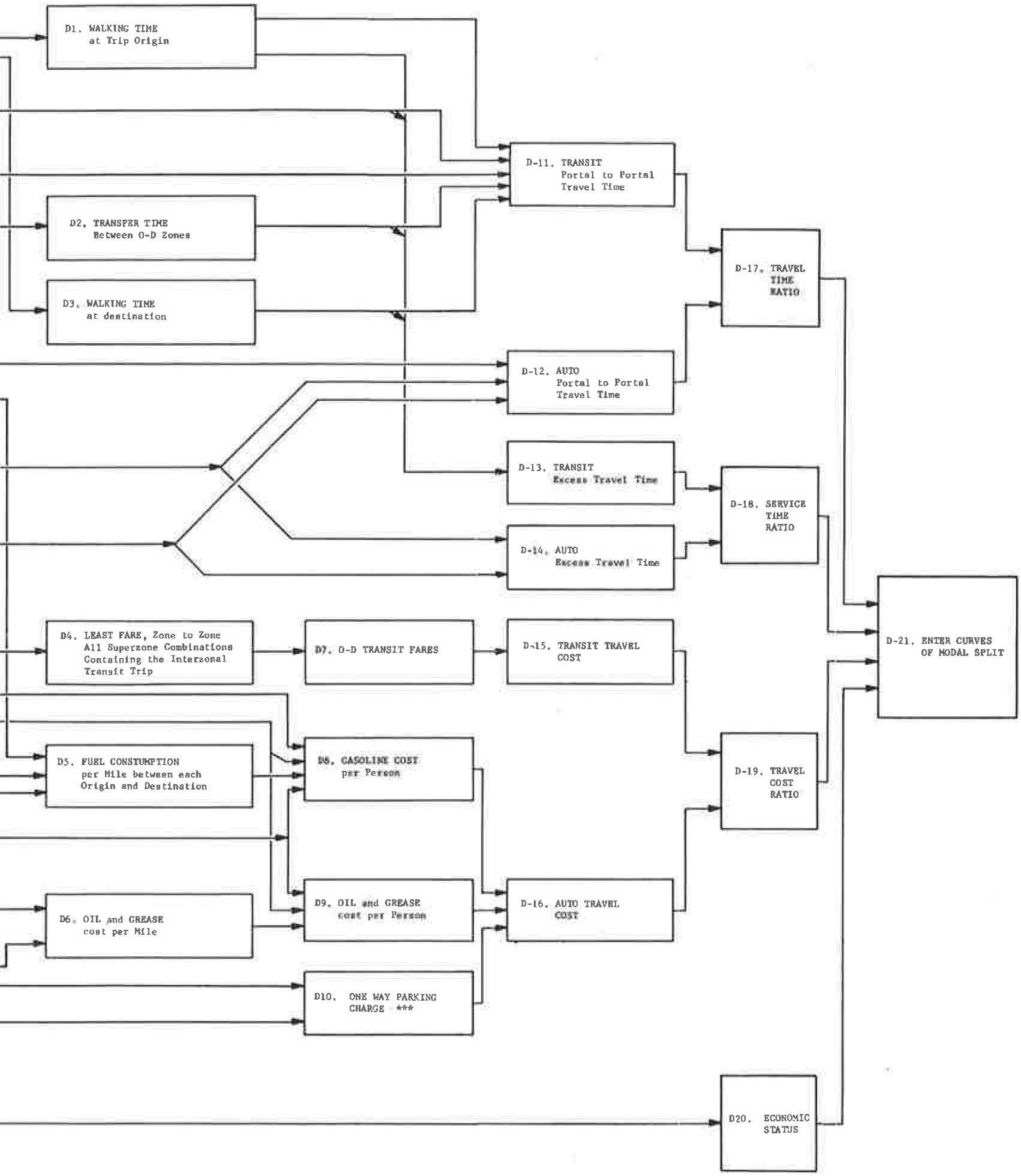


Figure 6. Process diagram for

D. MODAL SPLIT PROGRAM



analysis of modal choice.

these peak-hour trips to Sector 0 will be made by rapid transit in 1980 given the wide coverage of the proposed downtown subway system. For this reason, it was assumed that 25 percent of all peak-hour 1980 taxi trips would be diverted to rapid transit.

4. Persons making trips to school are not influenced by service and cost considerations in choosing their mode of conveyance in the same manner as persons making trips for other purposes (this was confirmed by analysis of 1955 school trips). This is probably due to the preponderance of children making these trips. Many are too young to drive and few have cars available to them. Probably the most important determinant of mode of school trips is the local school board policy on transportation. For example, Fairfax, Montgomery, Arlington and Prince Georges Counties provide school buses for public school children who live above a stated distance (usually 1 to 1⅓ miles) from their schools. On the other hand, the District of Columbia operates no school buses and Alexandria only a few. Students making school trips in the latter two areas make considerable use of public transit. For purposes of future estimates, it was assumed that all AM peak-hour trips from home to school (except those students walking to school) with destinations within the District of Columbia and Alexandria will be by public transportation. No school trips with destinations in Arlington, Fairfax, Montgomery and Prince Georges County were assumed to use transit.

5. Persons making trips to work or other purposes (except school) would, in 1980, be influenced in their choice of travel mode in accordance with modal split relationships such as shown in Figure 1. These relationships were derived from five different surveys made in three different cities over a span of seven years (1954-1961). Generally speaking, the relationships derived from each survey showed few significant differences. Inasmuch as the three cities had widely varying characteristics in terms of density, transit facilities available, street capacity, transit fares, income, etc., it is reasonable to assume that the modal split relationships represent basic and fundamental determinants of modal choice.

Procedures

Figure 7 shows the procedures used in this study for determining the modal split of trips made during the AM peak hour. These procedures incorporate the previously stated assumptions. The modal split program was run twice for each peak-hour test, once for work trips and once for non-work, non-school trips. Inputs for each run included a matrix of interzonal total person trips, interzonal travel times by transit and auto, and other inputs (Fig. 2). The matrix of interzonal auto trips output from each run was added to peak-hour taxi, truck and external auto trips. The summed trip table was then assigned to the highway system. Examination was then made (Fig. 7) of the resulting highway volumes to see if assumed link speeds were compatible with assigned volumes. The feedback loop illustrates the iterative procedure for bringing future highway speeds into line with estimated volumes.

The transit volumes resulting from each run (Fig. 7) were added together with diverted taxi trips and school trips. The summed transit volumes were assigned to the transit system.

Preparation of Inputs

Individual input items are reviewed to indicate the character of input data used in this test. Complete details of all items are not included, in the interest of brevity. Figure 6 shows the relationship of each input item to the modal split process.

1. Interzonal auto driving time (Box C7, Fig. 6): The test highway system was coded into the format required for the WMATS-BPR assignment program (6). A least time path through the network for each interzonal movement was found and its time value calculated by the computer.

2. Interzonal auto driving distance (Box C8, Fig. 6): Using the coded network, the computer calculated the distance along each minimum travel time route for each interzonal path.

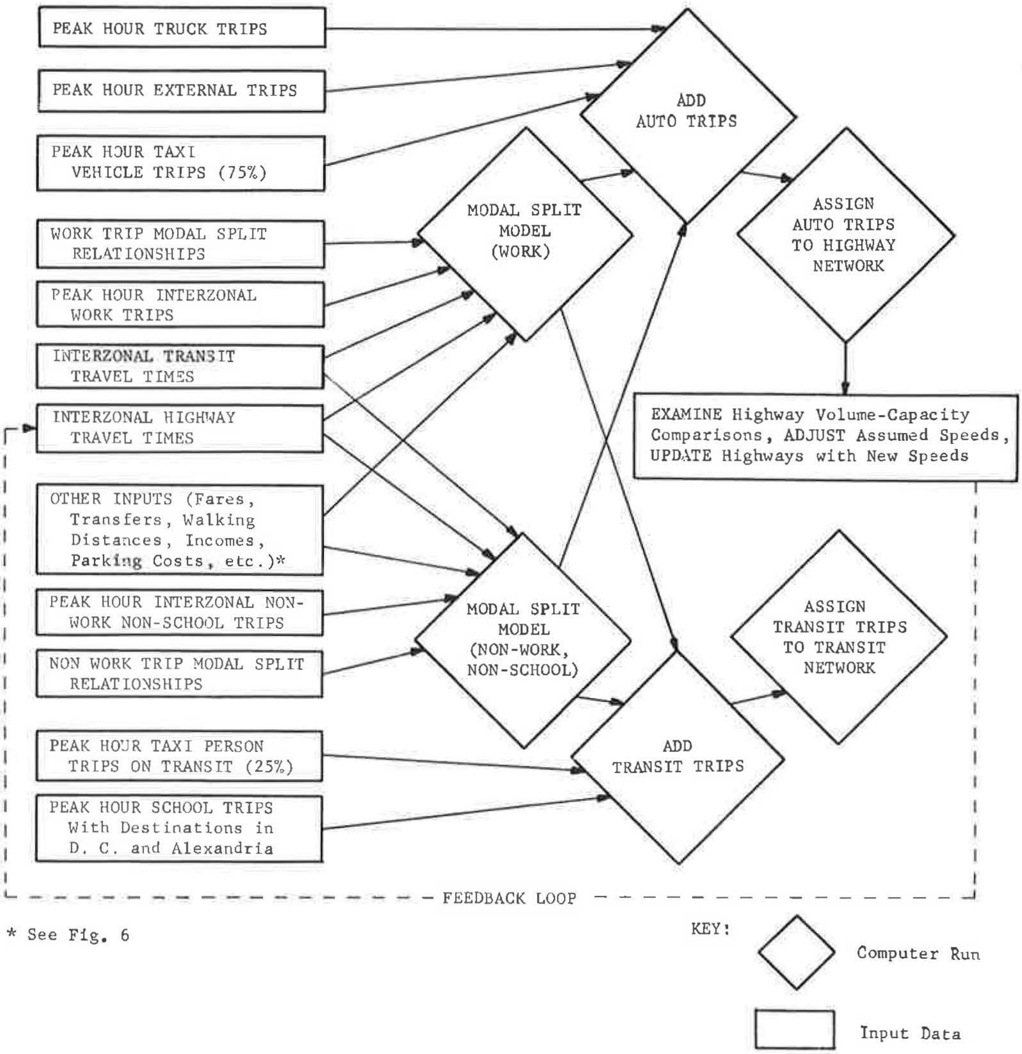


Figure 7. Procedures used in application of modal split model.

3. Interzonal transit travel time (Box C6, Fig. 6): The test transit system, both local and rapid, was coded into the format required by the WMATS-BPR assignment program. Minimum time paths between all zones on the transit system were calculated by the computer.

The problem of coding the transit system so that it would accurately represent the test system was a complex one that cannot be described in detail. One of the most perplexing problems concerns the choice of the mode of travel used to get to the rapid transit station at the home end of transit trips (submodal split). There are conceivably four modes available for some passengers: (a) walking, (b) driving an auto, (c) being driven as an auto passenger, and (d) feeder bus. Each of these has different associated travel times and costs. For such zones, there is no unique value of either cost or time for an interzonal transit trip. An acceptable solution was found by making logical estimates of the submodal split, determinating cost and time values for each submodal trip from home to station, and applying a weighted average time and cost to that link. The scope of this problem was reduced somewhat by assuming that zones more than one-half mile from transit stations would have no walkers; that zones with less than three dwelling units per acre would have no feeder bus; and that time and cost of auto passenger or auto driver trips were the same. Although these assumptions were sufficient for many zones there were others which required more detailed estimates of the submodal split. A computer program was devised to compute systematically these estimates in accordance with the method devised. While this process was approximate, the range of values of time and cost on the submode are limited such that the overall modal split calculation was not compromised by these estimates.

4. Interzonal transit transfer time (Box D2, Fig. 6): Ideally, transit transfers should be coded into the transit system. However, time deadlines required the use of a less refined transfer procedure. Transfer "superzones" were established which incorporated all traffic zones having the same transit transfer characteristics. For example, Figure 8 shows a simplified transit system consisting of two transit lines. Superzones are drawn enclosing the area served by each line. A transfer superzone matrix can then be prepared (Table 2). This matrix shows the transfer time as one-half the vehicle headway on the line to which the transfer is made. Since superzones X or Y can include any number of traffic zones, a "table of equivalents" relating the superzones to zones must be prepared. The computer can then calculate the interzonal transfer times. The superzone transfer matrix used for the test system was 20 × 20.

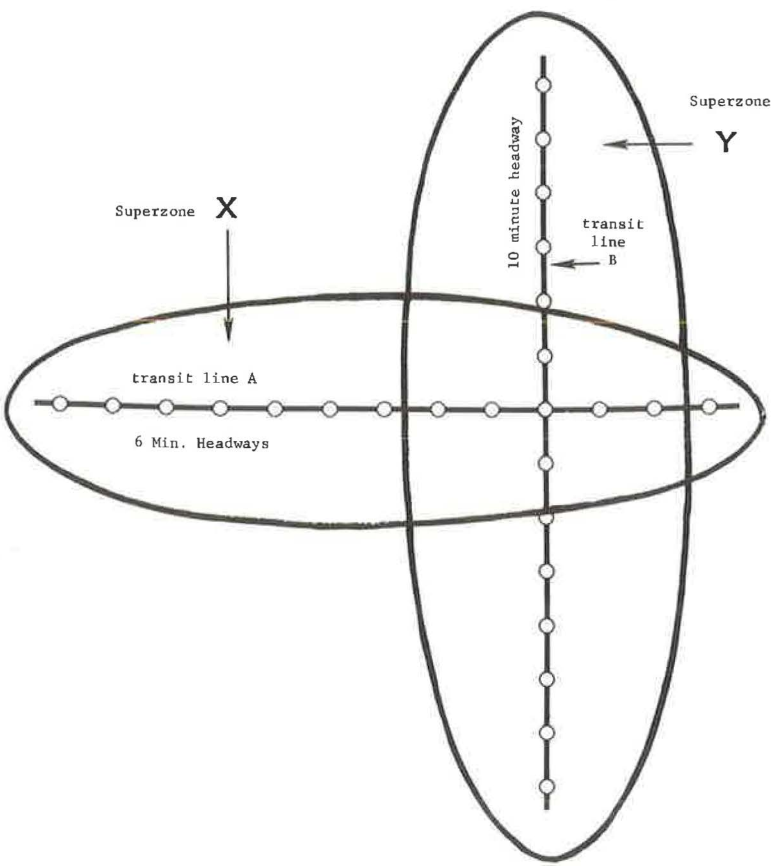


Figure 8. Transit transfer superzones.

5. Interzonal transit fare (Box D7, Fig. 6): Any transit fare scheme can be used in the model. For this test, a zone fare system was established (Fig. 9). Representation at this fare structure was accomplished by the establishment of fare superzones and a matrix of inter-superzone fares, along with a table of equivalents, similar to the method used for transit transfers. The fare matrix consisted of 625 entries (25 × 25).

TABLE 2

EXAMPLE OF TRANSIT TRANSFER TIME SUPERZONE MATRIX

Superzone	X	Y
X	0	5 min.
Y	3 min.	0

6. Zonal transit walking time (Box A1, Fig. 6): The estimated walking time to the transit stop (or station) is a component of both the service ratio and the travel time ratio. All transit riders originating or arriving at a given zone were assumed to have the same walking time. The average walking time was estimated as follows: (a) zones inside the 10-mi square: average

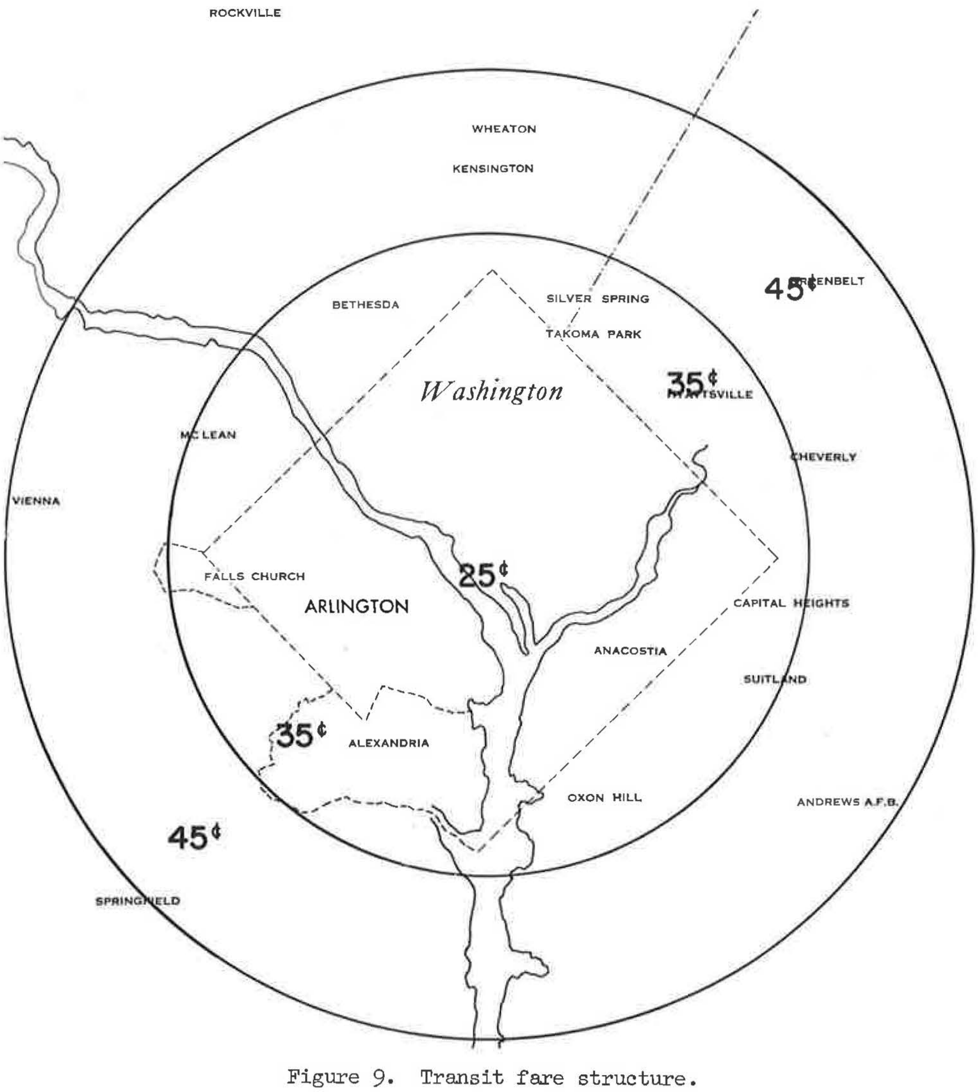


Figure 9. Transit fare structure.

walking time was estimated by examination of the transit route location and the development pattern in the zone; and (b) zones outside 10-mi square: walking time to local bus stops was assumed to be similar to average walking times in zones with similar density today.

7. Zonal transit waiting time (Box A2, Fig. 6): Transit waiting time is a component of both the service ratio and the transit time ratio. All transit riders originating in a given zone were assumed to have the same transit waiting time. It was estimated as follows: (a) zones inside the 10-mi square: average waiting time was estimated by the proposed frequency of service on transit lines serving the zone—generally, the waiting time was taken as one-half the transit headway; and (b) zones outside 10-mi square: average waiting at local bus stops was assumed to be similar to average waiting time in zones with similar density today (waiting time for rapid transit was estimated as for zones inside the 10-mi square).

8. Zonal parking delay (Box A5, Fig. 6): Time spent in parking or unparking is a component of both the service ratio and the travel time ratio. Delay was assumed to occur only at the trip destination. This delay was assumed to be 1 min except in downtown areas where delays of 1 or more minutes were used, depending on the proportion of all parking estimated to be in commercial garages.

9. Zonal walking time (from parking to destination) (Box A6, Fig. 6): Zonal walking time to and from parking facilities is a component of both the service ratio and the travel time ratio. It was assumed to occur only at trip destinations. It was generally assumed to be 1 min outside downtown except at some large employment centers with big parking lots. For downtown destinations, walking times were estimated from those reported in a recent comprehensive parking study. Times ranged from 2 to 5 min.

10. Zonal car occupancy (Box A9, Fig. 6): Car occupancy is a factor in computing the average auto passenger (or driver) trip cost, because total interzonal vehicle trip costs were assumed to be equally shared by the cars' occupants. Car occupancy was assumed to remain the same in 1980 as today. All auto trips into a zone were assumed to have the same average occupancy. Occupancy rate assumptions for the AM peak hour varied from 1.3 persons per car for trips to outlying zones to 1.8 per car for some downtown zones.

11. Zonal median worker income (Box A13, Fig. 6): Average income per worker is one of the variables in the modal split calculation. For some combinations of the other variables (travel time ratio, etc.) lower incomes show higher transit use. However, for some combinations, particularly those representing good transit service, high income riders use transit more frequently. (This may be observed on some high quality commuter rail service in operation today.) Based on median annual income per worker, each zone was classified into one of five income categories (Table 1).

The effect of income is evident in the modal split relationships. However, it is not so evident whether the median worker income is the real determinant or whether this is simply an indirect measure of another more fundamental but less measurable variable such as relative social or economic status. If the latter is true, the overall income increases between now and 1980 will not affect region-wide transit riding. In any case, the assumption of significant average regional increase in worker income must also be reflected in increases in transit fare, parking costs and vehicle operating costs. The econometric relationships between these elements are complex and obscure. For these reasons the average worker income was assumed to hold constant until 1980. At the same time no increases in transit fare, parking rates or vehicle operating costs were made to account for wage increases. However, individual zonal incomes were increased or decreased (while holding the regional average constant) to account for areas expected to decay or those where urban renewal or other influence are expected to affect income.

12. Zonal parking costs (Box A12, Fig. 6): Parking cost is the major component of out-of-pocket costs for motorists who are CBD bound. Parking costs outside the CBD were assumed to be zero. Since the model was applied only to AM peak-hour trips, only one-half of the assumed parking cost was allocated to the trip to downtown; the other half, by implication, being related to the return trip. All-day parking costs were assumed for work trips and one-half day costs for non-work trips.

Average downtown commercial parking rates were assumed to increase by about 60 percent by 1980, due to the higher intensity land use associated with higher downtown employment. The average all-dayparking cost for all vehicles was assumed to increase even more because of: (a) a reduction in the all-day street parking; (b) a significant reduction in the amount of free government space; and (c) higher land values resulting from an assumed 16 percent increase in downtown employment.

RESULTS OF TESTS

Figure 10 shows the passenger volumes assigned to the rapid transit system. These volumes were obtained by following the procedures indicated in Figure 7; they include all morning peak-hour trips. Once the matrix of transit trips was obtained, it was assigned to the transit system using the same assignment procedure used for the highway network, i.e., all or nothing to the least time path. Since local transit was coded into the transit network, those transit trips beginning close in and between the rapid transit corridors were routed to their downtown destinations without using the rapid. Volumes shown in Figure 10, then, are only for rapid transit.

Maximum 1980 load point volumes are estimated to range from about 25,000 peak-hour passengers coming in from the north (B and O Rockville line) to about 1,400 passengers on an express bus line serving a low-density area to the west (Cabin John line).

Figure 10. Transit traffic flow for NCTA recommended system.

Table 3 summarizes the shift in mode implied in these results as far as downtown oriented travel is concerned. The proportion of all peak-hour trips to the CBD by transit in 1955 was 46 percent. The model estimates that 64 percent of an increased number of trips would use transit by 1980. A 29 percent reduction in trips by auto to downtown from 68,000 to 48,000 was estimated. On the other hand, a general increase was estimated for non-downtown oriented travel by auto.

Table 4 shows modal split results for the entire metropolitan area. Twenty-five percent of all peak-hour trips are estimated to be performed via transit in 1980, compared to 33 percent on transit in the smaller urbanized area in 1955. Of 449,000 trips not going downtown in 1980, 87 percent are estimated to be by auto.

TABLE 3

COMPARISON OF AM PEAK MODAL SPLIT TO CBD: 1955 OBSERVED VS 1980 ESTIMATED

AM Peak Person Trips to CBD	1955 (Actual)	1980 (Model)
All modes	124,700	140,000
Transit (local and rapid)	57,000	90,000
Auto	67,700	50,000
% Transit	46	64

Note: Excludes trips from outside study area and taxi trips; CBD is defined as Sector 0.

Of the total estimated 153,000 peak-hour transit trips, 60,000 or about 39 percent will be to non-downtown destinations (Table 4). However, of an estimated 108,000 peak-hour work trips on transit, 80 percent will have downtown destinations. A high proportion of the non-downtown transit trips are school trips. Figure 10 shows that about 27 percent of all rapid transit trips entering the CBD will be destined beyond the CBD. Since these non-downtown volumes appear high compared with experience of some rapid transit lines, the non-downtown riding was reduced for revenue calculations by NCTA. Since making the analysis, however, it has been concluded that the model overestimated non-downtown trips owing to the manner in which the modal split curves were extrapolated for high travel time ratios. In the light of this experience, the extrapolated regions of the curves were adjusted as described in the following.

The modal split relationships (Fig. 1) were drawn so that transit riding diminished to zero at a travel time ratio of ten. Closer examination of the data for Washington and Philadelphia indicated that almost no data were available on transit riding for travel time ratios >5 in these cities. Toronto had a few cases showing some transit riding with ratios of 6 or 7, probably for short trips. Since transit use for travel time ratios >5 is almost non-existent in all three cities, new curves for work trips (Fig. 11) and for non-work, non-school trips (Fig. 12) were drawn which more nearly fit the data. Some of the non-downtown trips shown on transit in Figure 10 and Table 4 are

TABLE 4

ESTIMATED 1980 AM PEAK MODAL SPLIT FOR DOWNTOWN AND NON-DOWNTOWN DESTINATIONS

Trips	All Destinations	Downtown Destinations	Non-Downtown Destinations
All modes	606,000	157,000	449,000
Transit trips (local-rapid)	153,000	93,000	60,000
Auto person trips	453,000	64,000	389,000
% Transit	25	59	13

Note: Downtown defined as a somewhat larger area than the CBD in Table 3; all trip volumes exclude trips with one end outside the metropolitan area, taxi trips or truck trips.

oriented between adjacent or nearly adjacent radial corridors, which can be served only by very circuitous transit routing with consequent high time ratios. It is therefore believed that non-downtown trips will be estimated more accurately when new runs are made using the adjusted curves. It should be noted that downtown trips will be little, if at all, affected by use of the new curves.

MODEL SENSITIVITY

One of the greatest benefits that may accrue from the development of this model is insight into the interrelationship between modal split determinants which may be gained by its use. The great interest in the problem of modal split has included a number of experiments and studies on the subject in recent years. Some of these are theoretical, while others, particularly recent HHFA demonstration tests, produce empirical results. Interpretation of the conclusions of these various studies is difficult because they often seem to conflict. For example, reduced fares and increased service on commuter railroad lines in Philadelphia have increased riding by as much as 400 percent on some lines, whereas others have shown little increase (7). Increased service frequency on a bus line in Detroit produced 5 percent to 25 percent increases in riding during different periods of the day (8). On the other hand, Northwestern University recently conducted a theoretical study of data obtained from 5,000 Chicago commuters which indicated that it might require cash payments to commuters to get them to shift from auto to transit (9).

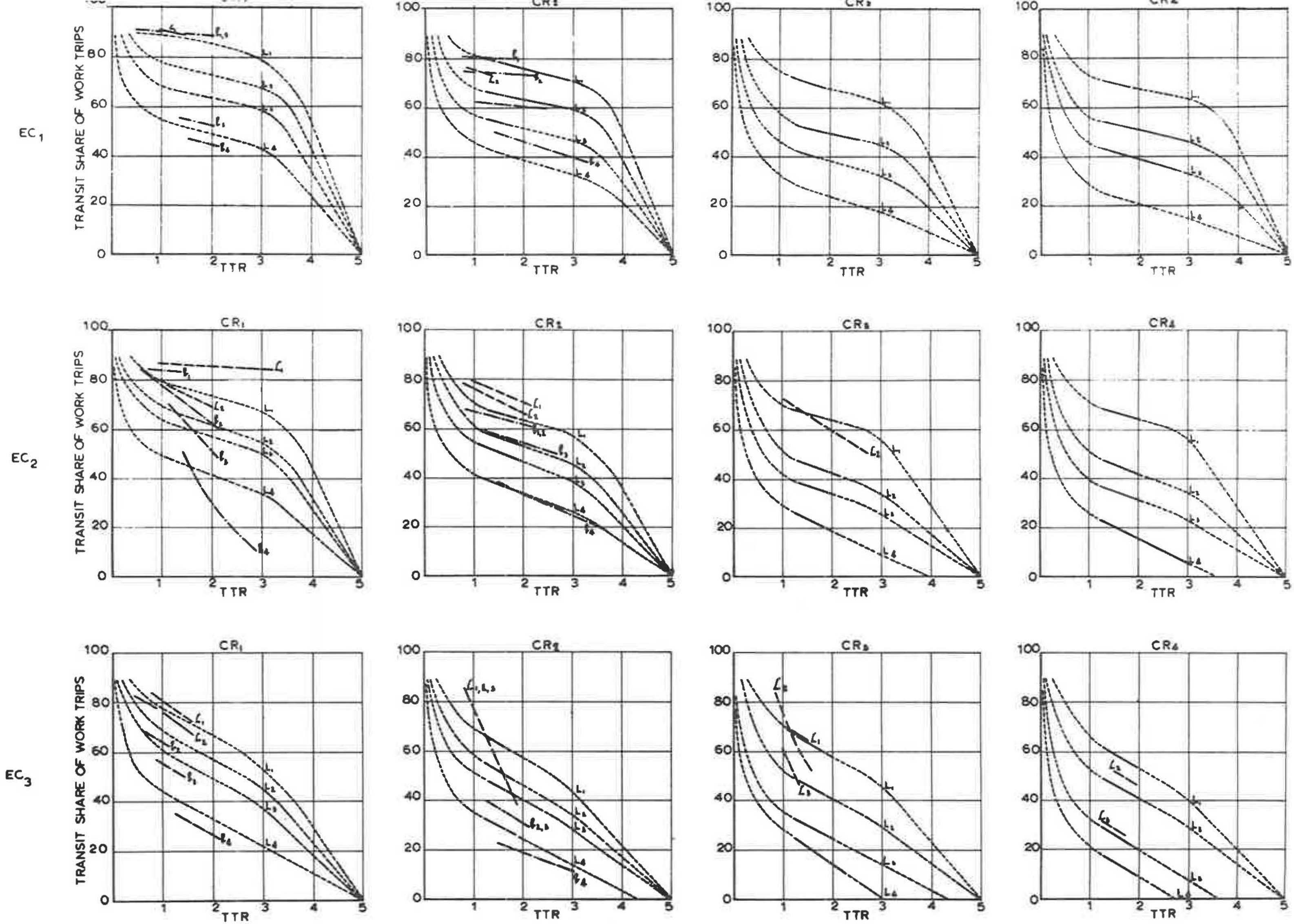
Actually all of these conclusions may be perfectly valid and also compatible. For example, analysis of the modal split relationships in Figure 1 reveals that doubling or tripling transit frequency can affect modal split significantly or not at all depending on the combination of other modal split determinants which are extant in a particular case. A 50 percent decrease in transit fares will produce dramatic changes in patronage in one instance but little or no change in others. Some understanding of the interrelationships between the modal split variants must be achieved before adequate interpretation of modal split tests can be made.

It is not proposed that all the many variables are accounted for in this model. It was noted for example that the model shows little sensitivity to the effect of extending a rapid transit line farther out into low-density suburbs. With adequate parking facilities assumed at most or all suburban stations, the downtown oriented suburban commuter who drives his car to the station may park at the station nearest his home, or, if there is a good highway in the corridor, park at a station several miles closer to town. In either case his costs or travel time or convenience is not substantially different. The net result is that the rapid transit line attracts the same number of riders whether it ends 10 miles from downtown or 12 miles. (Further shortening of the line would eventually affect riding as indicated by the model, because higher density areas, closer in, with substantial walking or feeder bus access to the stations would get poorer travel time ratios.) The unanswered question here concerns whether transit patronage in such cases is really unaffected by length of line or whether the model is simply insensitive. Perhaps another variable need be introduced and examined, namely, the "usage ratio": the proportion of the total O-D transit trip distance that is actually performed on transit.

Several sensitivity checks have been performed using the model. The data for the sensitivity checks are taken from some preliminary results of a more thorough test of the model now under way by the Bureau of Public Roads. These tests are based on the NCTA transit and highway system and other inputs as presented in this paper. The conclusions presented here are those of the authors alone. Although not enough checks have been run to provide comprehensive conclusions, several of the more interesting ones follow.

Increase in Transit Fare

For the proposed NCTA zone fare structure (Fig. 9), the basic fare is $0.25 with additional increments of $0.10 for traversing each of three fare zone boundaries. To check the results of an across-the-board fare increase of $0.15, i.e., $0.15 added



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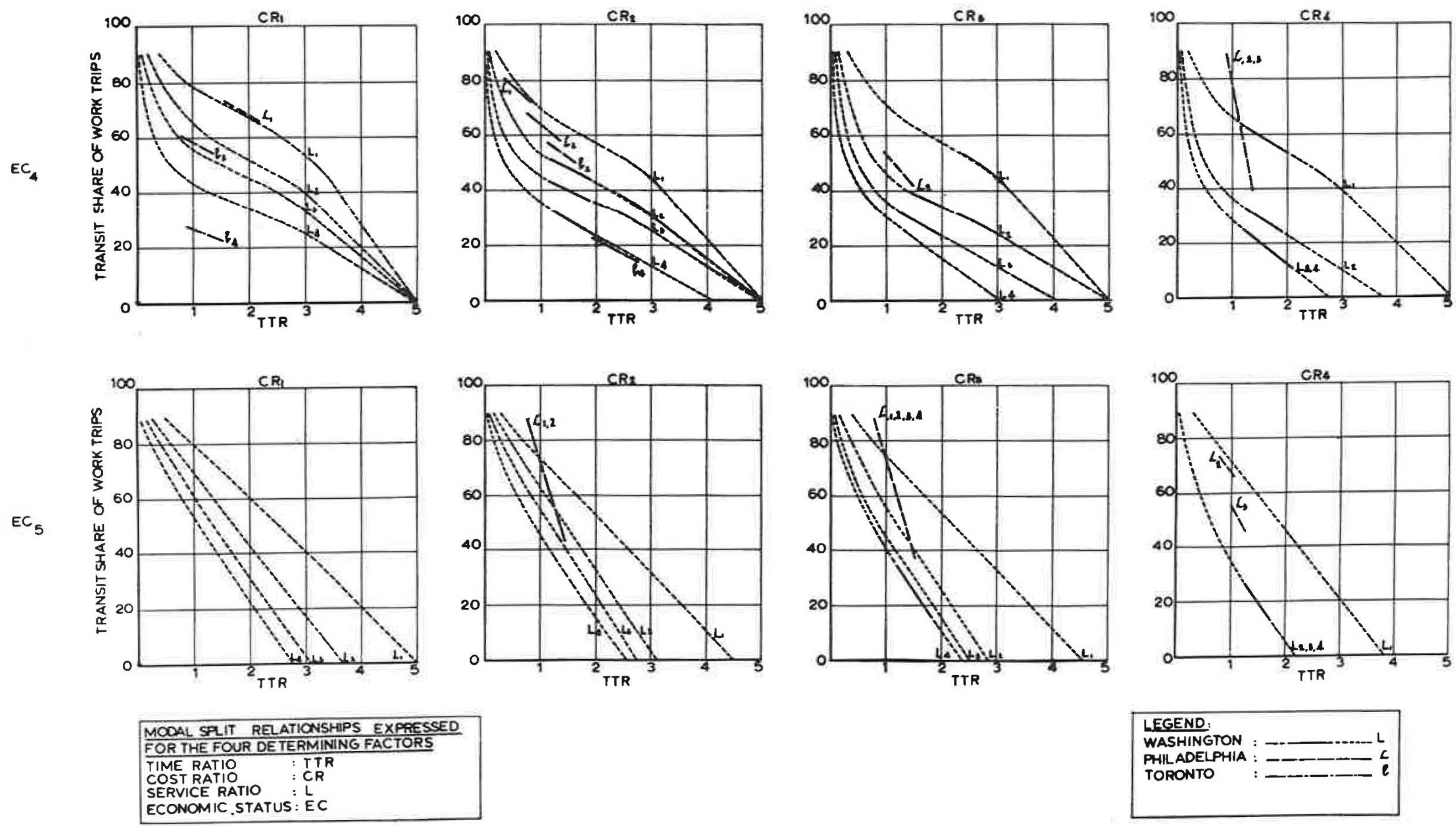
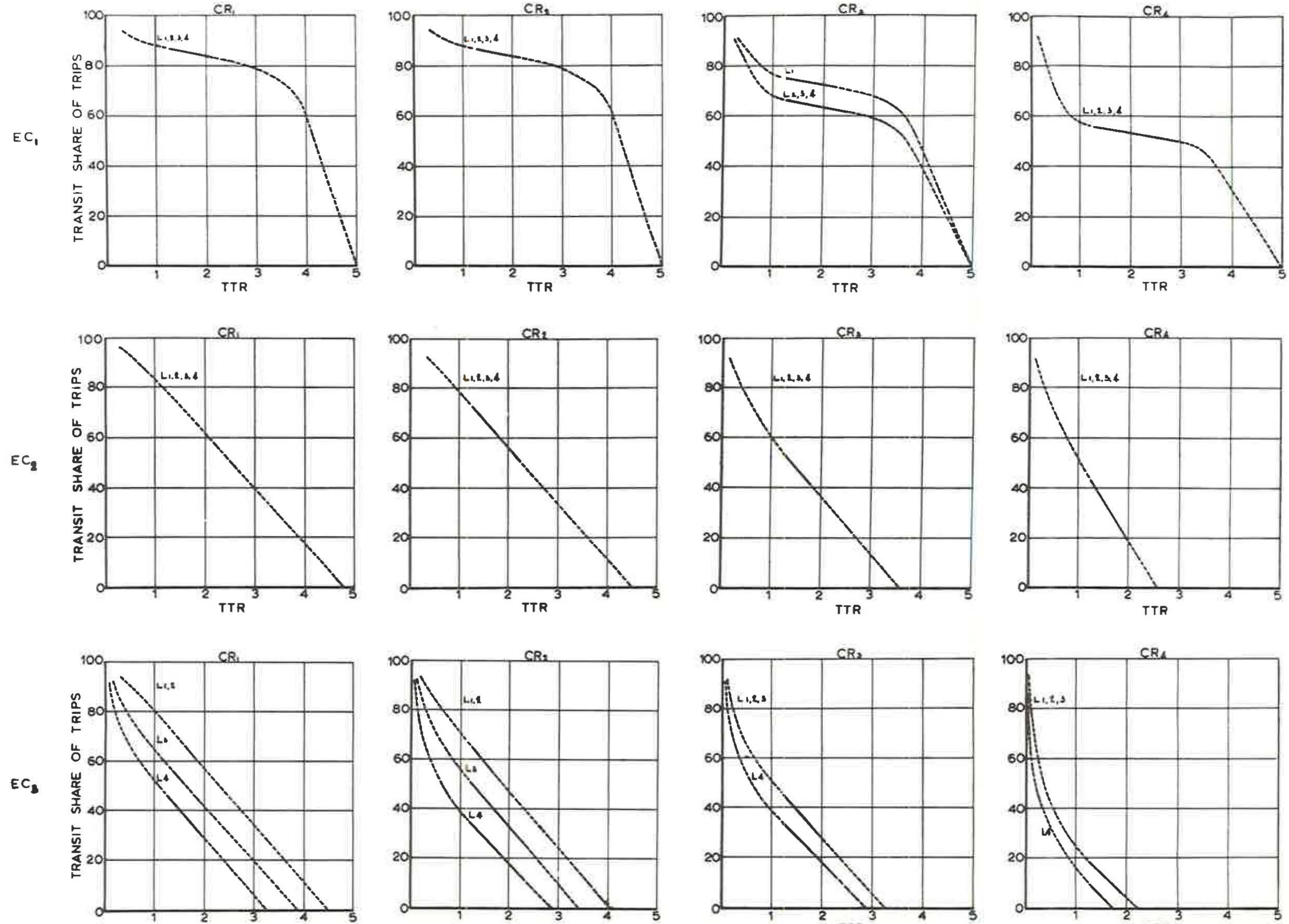


Figure 11. Work trip modal split relationships with adjusted extrapolations.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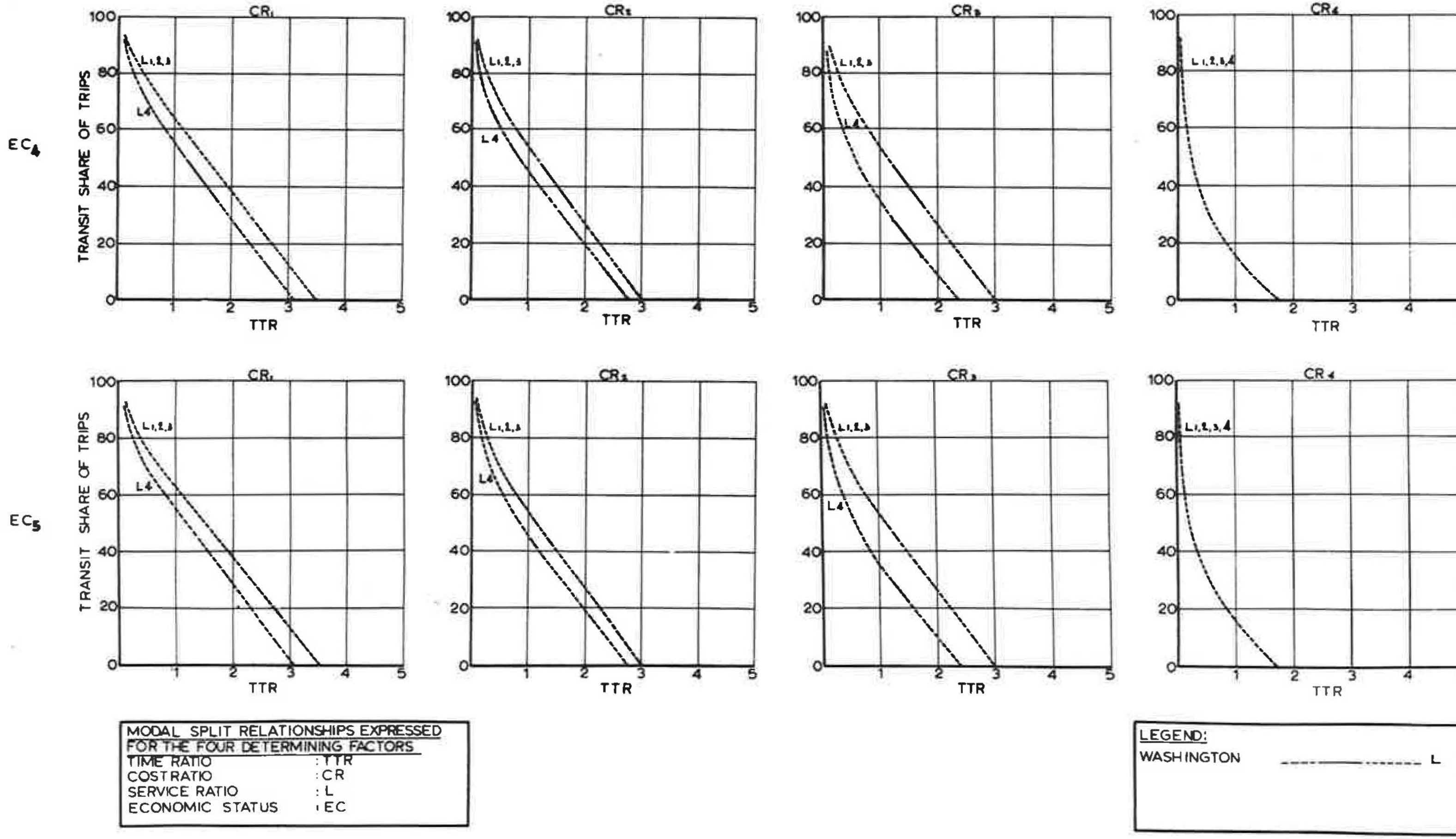

Figure 12. Non-work, non-school trip modal split relationships with adjusted extrapolations.

to the fare in each zone, making the basic fare $0.40, the program was run only for work trips. Total transit trips dropped from 108,200 to 102,700 or about a 5 percent drop in passengers. Non-downtown travelers experienced the greatest drop, about 8 percent.

Increase in Parking Costs

Holding transit fares and other inputs to those previously described, the parking costs were increased by a factor of 2. Since zones outside downtown had no parking cost assumed initially, this factor influenced only downtown riding. Transit riding for work trips increased from 108,200 to 114,900 for a 6.2 percent increase. It is likely that this test resulted in cost ratios of 0.1 or less for trips to some downtown zones. Since cost ratios of 0.15 or less were only rarely observed in any of the cities from which the curves were developed, the model is probably not sensitive to the full effects of such an auto trip cost increase. Cost ratios of 0.001 are treated the same as cost ratio 0.01 or 0.1, simply because these values lie outside the range of observed data. A general conclusion is warranted here: any output from the model which results from inputs outside the range of observed data should be treated with caution.

Increase in Worker Income

NCTA assumed that the median worker income for the metropolitan area as a whole would not change by 1980. This led to speculation of the effects on total transit riding if incomes were assumed to increase substantially. Such an increase would of course have a variable effect on other fiscally related items that are input into the model, such as parking costs, transit fares and gasoline costs. However, to gain some insight into the problem, median worker income was assumed to increase by 50 percent, without corresponding increases in the other variables.

This dropped transit work trips from 108,200 to 103,300, a 5.4 percent decrease. Figure 1 shows that income level has very little effect on transit riding where service is good (e.g., travel time ratios 1.25 or less and service levels L_1 or L_2) and in some instances where travel time ratios are less than 1.0, higher income travelers show a higher propensity for transit riding. However, where service is poor (e.g., travel time ratios 1.25 or more and service levels L_3 and L_4), dramatic differences are revealed depending on income. This is confirmed in this test. Whereas overall riding dropped 5.4 percent, downtown riding (where transit service is best) dropped only 1,600 transit work passengers or 1.9 percent. Non-downtown riding (where transit service is not as good) dropped 15 percent.

Increase in Parking Delay and Walking Time

The great attractiveness of the automobile is its convenience. Nevertheless, in crowded downtown centers inconveniences are associated with auto travel. One of these inconveniences is delay in parking a car, particularly the wait for a car in an attended parking facility. The scarcity or high cost of downtown parking also often requires parking some distance from the real trip origin or destination.

All NCTA tests held auto walk-wait time the same as had been assumed when the curves were developed, from 4 to 8 min for downtown zones and two minutes for non-downtown zones. (This time was applied to the destination end of trip only; thus trips from residential areas into downtown did not have any auto walk-wait time assessed at the trip origin.)

The sensitivity test for this variable consisted of adding 2 min to the auto walk-wait time or an increase ranging from 25 to 100 percent. This rather drastic reduction in auto convenience increased transit riding by 33 percent. Downtown trips (where the auto walk-wait time increase was 25 percent for most trips) increased by only 10.4 percent. For non-downtown trips, where the increase in auto walk-wait time was 100 percent, the increase in transit riding was 122 percent. Several conclusions might be drawn from this:

1. Auto convenience is its most attractive feature in attracting use.
2. No conceivable condition is likely to cause a 100 percent increase in auto parking delay outside downtown.
3. The whole test is subject to question since it contains inputs of auto delays which are outside the range of observed values.

Increased Transit Walk, Wait and Transfer Time

Time spent walking to the transit stop (or station), waiting for the transit vehicle, and, in some instances, transferring is one of the inherent characteristics of transit service. NCTA assumed frequent rapid transit service ranging from 1½- to 6-min headways. Local and feeder bus service was assumed somewhat similar to today's service. Walking and waiting times for each zone were estimated on this basis.

This check, then, was to test the effect of increasing the walking, transferring, and waiting time for transit by 50 percent. This resulted in a 15 percent decrease in transit riding, 13 percent for downtown riders, 29 percent for non-downtown riders.

CONCLUSION

It is believed that the modal split model is an operational tool which produces results with accuracy similar to other techniques and procedures used in urban travel forecasting. Although the model requires many assumptions and estimates of future conditions, it is believed that the problems of estimating the input parameters are not significantly more difficult than those associated with other travel forecasting requirements.

Possibly the greatest gain from the model in the long run will be the insights and knowledge gained concerning the interrelationships between the various modal choice determinants. In this regard, a great deal can be learned by further research, specifically: (a) developing modal choice relationships in other cities to see how consistent the relationships are in a wider range of population density, service levels, etc.; (b) comparing this approach to modal split determination with other approaches being developed, such as the multiple regression model now under way at the Penn-Jersey Transportation Study; (c) development of additional factors for representing transit service in a model, automated feedback procedures for restraining highway speeds, and more research generally into the effect of the development of highway and transit systems on total travel demand.

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A Systems Engineering Model for Trip Generation and Distribution

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This paper discusses the applicability of a systems engineering technique (linear graph theory) to urban traffic forecasting. The primary concern of the research is the analysis of the components. Synthesis of the system and its solutions were of secondary importance, but did serve to reinforce the original hypotheses. Traditionally, urban traffic forecasting models have been separated into three distinct parts—trip generation, trip distribution, and trip assignment. The research concentrates primarily on trip distribution with some work on trip generation. The problem of trip assignment is not yet included.

The techniques of systems engineering are applied to work-trip and shopping-trip distribution systems in two theoretical examples. The research confirmed two hypotheses: first, that these trip distribution systems could meet the requirements of a system solution by linear graph theory, and second, that the results of the system solution would provide acceptable trip interchanges which would compare well with other models. The results of the work indicate further that these rigorous models have the advantages of more precise definition of the parameters and their interaction.

SYSTEMS THEORY

A SYSTEM is defined as an orderly arrangement of interrelated elements acting together to achieve a specific purpose. Thus, a system must have an avowed purpose, must be free of extraneous or mathematically redundant parts, and must have the elements or components joined in an orderly fashion. System engineering problems require the use of some type of mathematical technique to achieve solutions. In this study, linear graph theory is used to solve the problem of urban traffic forecasting.

The principles of linear graph theory are stated only very briefly here. A fuller discussion of the subject is given in a previous article (1) and two of the prominent texts in the field (2, 3).

Linear graph theory is an orderly technique for formulating the mathematical characteristics of a physical system. The steps in the solution of a physical system by linear graph are shown in Figure 1.

For computation of the system characteristics, two steps are necessary; namely,

1. To establish a mathematical description of the relevant physical characteristics of the system components expressed in terms of measurements.
2. To establish in mathematical form and in terms of measurements from a knowledge of the component characteristics and their mode of interconnection, the characteristics of the system; i.e., a mathematical model of the system.

Thus the analysis of any physical system requires a mathematical description of each component part, as well as a mathematical description of how the components

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are joined to form the system. Collectively, these mathematical equations provide what is referred to as system equations. In the mathematical analysis of any given type of physical system (electrical, mechanical, thermal, hydraulic, etc.) the tie between the mathematics and the system is generally accomplished through the use of two basic measurements; the "across" or x and the "through" or y measurements.

The terminal characteristics of the component are completely described by

$$x = R\,y \qquad (1)$$

which relates the x and y measurements and is referred to as the terminal equation, which with the addition of the terminal graph of the component forms the terminal representation of the component. Components are described mathematically by relating the two measurements x and y on the component in isolation from other components. This infers that the terminal equations of the components must be independent of the system in which they are used. These measurements must be such that one is a "through" (or series) measurement called y, which when summed at the vertices must equal zero, and the other is an "across" (or parallel) measurement called x, which when summed around the circuits must equal zero. These requirements are referred to as vertex and circuit postulates and are used for the solution of the system with the aid of a systems graph constructed from component terminal graphs and a knowledge of their mode of interconnection.

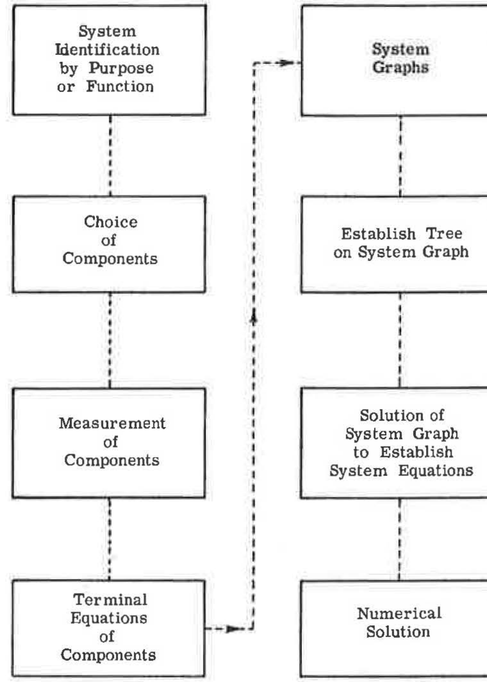

Figure 1. Steps in solution of a physical system by linear graph theory.

APPLICATION POSSIBILITIES

The work presented here is one of the earliest attempts to apply the techniques of systems theory to traffic problems, specifically to forecasting future work and shopping trips and their distribution. Two illustrative problems are presented in the Appendix.

Components

The system components which evolved are residential zones, employment zones, and shopping zones, similar to those generally established in O-D studies. Route components include the various types of streets and intersections used in traveling from an origin to a destination. These components must meet the following requirements if the techniques of linear graph theory are to be used in the systems solution:

1. The basic component must be describable mathematically by relating two valid measurements on the components.
2. When the components are arranged in a systems graph, one of the measurements taken on the component, which is noted as x, must sum to zero when the summation is made around a circuit; the other measurement, y, must sum to zero at the vertices of the systems graph.
3. The x measurement must be related to the y measurement through a linear or nonlinear function.

Measurements on Components

As a result of the analyses made to date, it was concluded that the best measurement for the through variable, y, is the flow of work or shopping trips from, to, or through the component. The measurement for the across variable, x, is a pressure-type measurement related either to some measure of desire, propensity, or trip motivation or to some measure of income and consumption assigned to trip making. The dimensions of the x and y measurements must be consistent for all components.

The y Measurement

The most logical y measurement for a traffic system of this type appears to be flow. This flow would represent the movement of persons, vehicles, or both. In the systems approach to electrical, thermal, and hydraulic systems, the y measurement represents flow of current, heat, or fluids, respectively. It seemed reasonable to assume that the y measurement for the traffic system also represents flow, inasmuch as the flow of vehicles will satisfy the criterion that the algebraic sum of y's at a vertex must equal zero.

The x Measurement

In the fields of electrical, thermal and hydraulic systems, where y is a measure of flow, the x measurement is a type of pressure differential which causes flow. The establishment of the units for the x measurement in the traffic system is not so obvious. There are no physical components on which one might measure readily a pressure differential. Because the y measurement flow is a function of the pressure differential, x, the x measurement can be evaluated in terms of its effect on the flow of trips. The development of the x measurement follows this reasoning process:

1. There is some reason for the variation in the flow of trips from several residential zones.
2. For the sake of a title, this reason is here called pressure.
3. The "pressure" term can best be described as a function of certain factors which explain the variations in the y values.
4. Two factors are used here separately to approximate the pressure term. One factor might be labeled "desire" and the other "money."
5. These can be related to more specific parameters which are subject to actual physical measurement.

The procedures and extent of the research into the x measurement can be shown more clearly by Figure 2. Eventual acceptance of a method will depend on how well it can

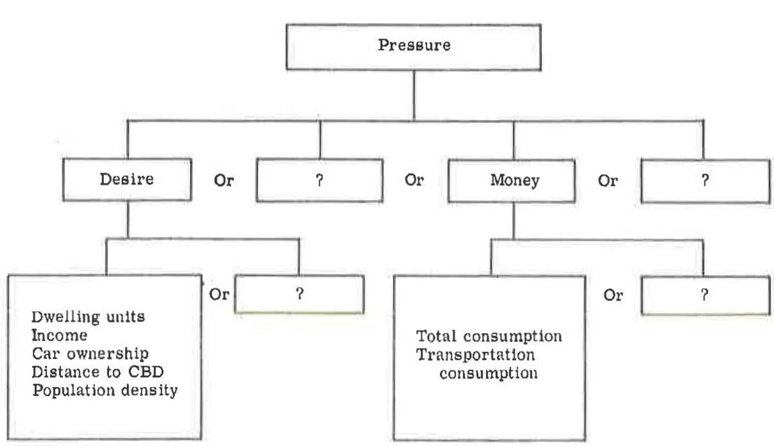

Figure 2. Organization of research on the x measurement.

predict changes in the flow of trips and on how easily the final parameters can be measured.

Desire. —A measure of desire or motivation can be related to the pressure which induces flow. The logic of this assumption can be checked by referring to Figure 3, which is a schematic representation of a simple circuit from a residential zone component, through a route component away from the zone, on through an employment component, and the return route component, for a fixed period of time, say 24 hours.

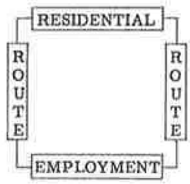

Figure 3. Simple work-trip circuit.

Considering only the single-purpose work trips made along the circuit, the desire or pressure produced in the residential zone must precisely be enough to overcome the pressure loss at each of the route components and through the employment zone. The sum of the pressure measurements will vanish around the circuit and, in so doing, will produce y trips. Some routes and employment zones will require larger pressure differentials than others. If a residential zone has a specific x value available, the circuit with the least R or resistance value will produce the greatest flow of trips to utilize the available x value. The pressure value, like that used in hydraulic systems, is equal in all directions from the residential zone. A discussion of the quantitatively descriptive parameters used to evaluate the term of desire is presented later.

Money. —From the fact that travel costs money, it can be assumed that the number of trips made is a function of the total amount of money available for transportation and the expenditure required per trip. The use of money to estimate the flow of trips has been suggested by others (4). The amount of money consumed yearly for transportation purposes has steadily increased. The approach used here assumes that the cost of travel will be minimized in terms of time and money. The measurement on x, although not necessarily equal to the money value, is related to it. A detailed explanation of the relationship between transportation consumption and the pressure, x, is presented in the next section.

Terminal Equations of Components

The terminal equations for all components have been assumed to be of the form of Eq. 1, but each term of this equation is generally a more complex expression. The following postulates concerning these terms have been established:

1. The y value shall be the flow of work or shopping trips. The y value is specified for the destination zones.
2. The x value shall be a measure of pressure which can be related to a function of desire in one case and of money spent in another. The x value is specified for the residential components.
3. The R value shall be a measure of resistance to flow, or reciprocal of attraction, which can be specified for the route, shopping, and employment components. For the employment component, R is a function of the jobs available. For the shopping area, R is an inverse function of the relative attraction of the area. The alternates presented for the establishment of R on the route component are (a) R is a function of the ratio of probable trips to actual trips, and (b) R is a function of the cost of travel through the route component.

The discussion of these postulates is presented under each of the components for which it was developed.

Residential Zone Component

Of the three possible measurements noted, only x is utilized for the residential zones.

The x Measurement--Desire. —The x measurement which represents the pressure for work trips from the residential zone will be established as a function of desire according to Eq. 1 on the following basis:

1. From existing O-D data, an equation is established for Y resident trips per dwelling unit based on income index, α; car ownership, β; distance to CBD, γ; and population density, δ;

$$Y = -A + B\alpha + E\beta + D\log\gamma - C\log\delta \quad (2)$$

2. This equation is maximized with limiting values of all parameters as forecast in the whole area for the future year. This maximum value is related to a measure of the theoretical pressure or desire by

$$X_T = Y_{max} \quad (3)$$

assuming, of course, that the equation is dimensionally adjusted.

3. If Y is developed for all trips, then the pressure or desire for work trips per dwelling units will be found by using the relation of work trips to total trips, K_W, or

$$X_W = K_W X_T \quad (4)$$

4. Using maximizing input values for all parameters except income, one can establish ΔX, the change in X due to a particular value of income, or

$$\Delta X = X_W - Y_{\alpha:\beta,\gamma,\delta} \quad (5)$$

The maximum change is found for some limiting value α; then R_α, the resistance value, can be found by equating

$$R_\alpha = \Delta X_\alpha / \Delta X_\alpha (\max) \quad (6)$$

A relationship for R_α versus the income, α, is shown in Figure 4, which isolates the effect of income alone on the pressure to make trips.

Similar techniques are used to establish values for R_β, R_γ, and R_δ, as shown in Figures 5, 6, and 7.

5. A subsystem of the zone parameters will be solved in order to establish each value of x_i. Schematically, this can be shown as in Figure 8, or as a system graph as in Figure 9, from which

$$x_1 = N(X_W) \quad (7)$$

in which N is the number of dwelling units in the zone; and R_α, R_β, R_γ, and R_δ are found from previous curves. The subsystem can then be solved for x_6 in terms of values x_1, R_α, R_β, R_γ, and R_δ. The unknown, y_6, will be solved for in the final system solution. The element number 6 can now be used in lieu of the subgraph; that is,

$$x_i = x_6 = x_1 + 1/\Sigma R^{-1} y_6 \quad (8)$$

The x Measurement—Money.—The x measurement, which represents the pressure for shopping trips from the residential zone, is established as a function of money or consumption allotted to the making of shopping trips, not including the money spent for purchases made. The consumption for shopping trips is found by first determining income and the percentage of income consumed. A portion of the total consumption per family is spent for transportation costs. Because this amount is distributed over the trips for many purposes, it is necessary to establish the actual amount allotted for shopping trips.

The x measurement is established on the basis of the following:

The average amount of money allotted yearly to the cost of shopping trips made from a residential zone i is C_i. Then

$$x_i = K\,C_i/300 \quad (9)$$

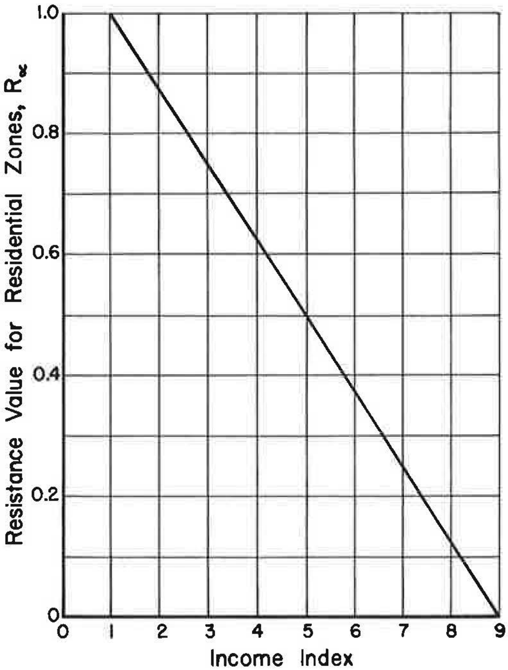

Figure 4. Relationship between resistance on residential zones and income index.

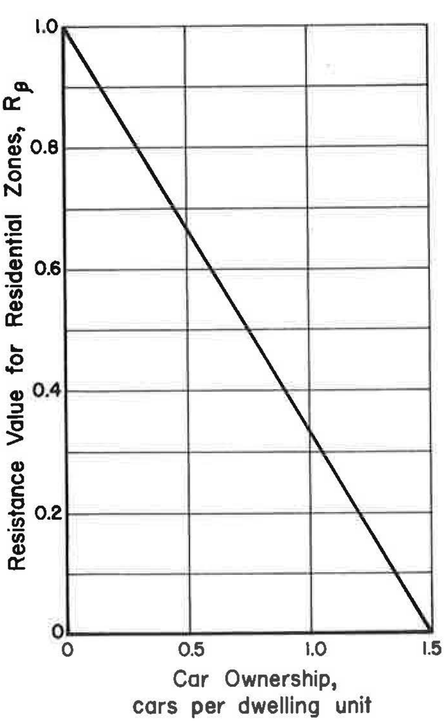

Figure 5. Relationship between resistance on residential zones and car ownership.

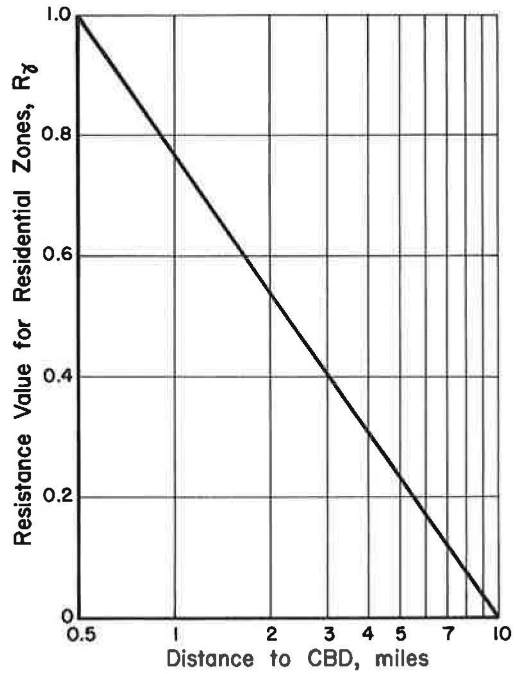

Figure 6. Relationship between resistance on residential zones and distance to CBD.

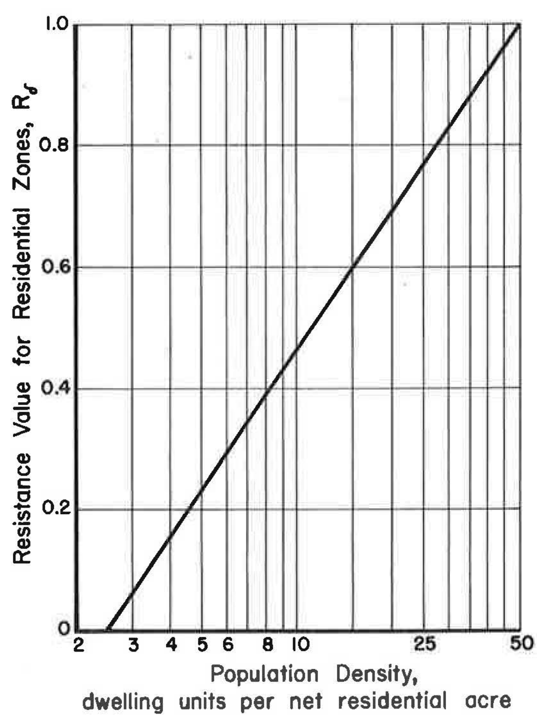

Figure 7. Relationship between resistance on residential zones and population density.

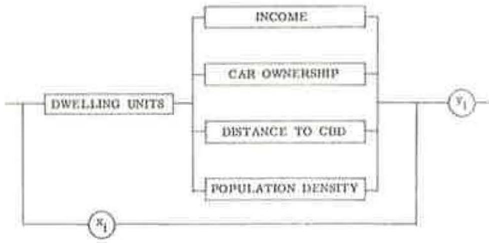

Figure 8. Schematic of zone parameter subsystem.

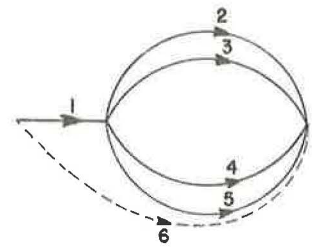

Figure 9. Typical simple system graph.

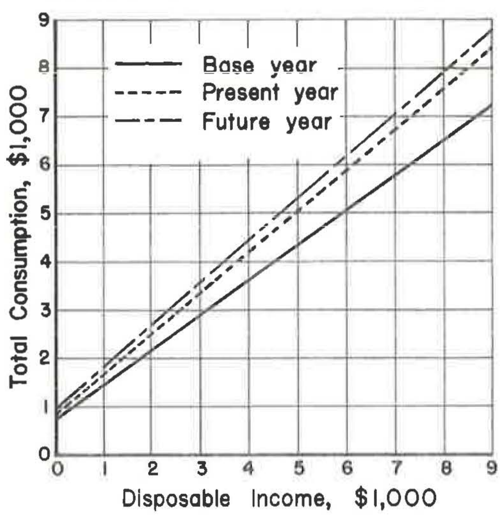

Figure 10. Relationship of consumption to disposable income (4).

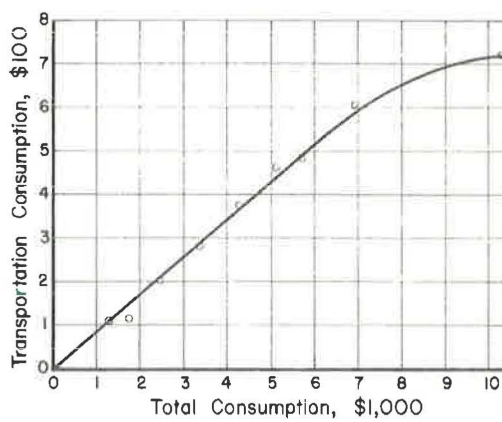

Figure 11. Relationship of transportation consumption to total consumption (5).

in which K is a constant determined to adjust for the differences in dimensions, and 300 is the number of available shopping days per year.

The value C_i can be estimated in the following manner:

1. Determine from a previously established plot of income versus consumption an estimate of the future year consumption, Z_i, based on an estimate of the future year mean income, I_i, for the zone (Fig. 10); that is,

$$Z_i = f(I_i) \tag{10}$$

2. Establish from previous data a relationship, E, between transportation consumption, z_i^t, and total consumption, Z_i, (see Fig. 11). Based on observations of trends, the yearly change in this ratio can be established; that is,

$$E_f = E_b + n \Delta E \tag{11}$$

in which E_f is the ratio of future amount spent on transportation per total consumption for the future year, E_b is the same for the base year, ΔE is the yearly change, and n is the number of years from base year to future year.

The amount of expenditure spent on transportation for the future year can be found from

$$z_i^t = E_f Z_i \tag{12}$$

3. The $z_i{}^t$ represents the total amount spent for transportation per family in zone i. The amount spent for transportation per zone for the future year will be this factor times the number of families in zone i, or

$$Z^t = N_f \; z_i{}^t \tag{13}$$

4. Inasmuch as the primary concern is home-based shopping trips, it is necessary to determine the amount spent for these, using K_h as the weighted percentage by trip length of all trips that are home-based. Therefore,

$$Z_i{}^t = K_h \; Z^t \tag{14}$$

5. The amount of money spent for trips to shopping can be found by first establishing the ratio of the total mileage for shopping trips to the total mileage traveled for all trip purposes. This ratio is

$$K_s = \frac{k_s \; m_s}{M_{tot} \text{ (All purposes)}} \tag{15}$$

in which

$$M_{total} = (k_w \; m_w) + (k_s \; m_s) + (k_{sc} \; m_{sc}) + (k_{sr} \; m_{sr}) + (k_{em} \; m_{em}) + (k_b \; m_b) \tag{16}$$

k_w = percentage of trips to work;
m_w = average trip length to work;
k_s = percentage of trips to shopping;
m_s = average trip length to shopping;
k_{sc} = percentage of trips to school;
m_{sc} = average trip length to school;
k_{sr} = percentage of trips to social-recreation;
m_{sr} = average trip length to social-recreation;
k_{em} = percentage of trips to eat meals;
m_{em} = average trip length to eat meals;
k_b = percentage of trips to business; and
m_b = average trip length to business.

The input values for Eqs. 15 and 16 can be determined from Tables 1 and 2. Then

$$Z_i{}^{st} = K_s \; Z_i{}^t \tag{17}$$

but, by definition,

$$C_i = Z_i{}^{st} \tag{18}$$

Employment Zone Component

The y measurement, which represents the flow of work trips destined to the zone, will be specified. The number of existing work trips destined to an employment zone j can be found from the data of the O and D study. A relationship of work trips to some

TABLE 1

HOME-BASED TRIPS BY URBAN RESIDENTS IN STUDY AREAS ACCORDING TO PURPOSE[a]

Urban Area	Home-Based as % of All Linked Trips	Trips by Purpose (%)							Total Home-Based Trips per Dwelling Unit (no.)
		Work	Business	Shopping	Social-Recreational	School	Other	All Purpose	
Chicago	86.8	37.5	9.7	18.9	22.8	4.0	7.1	100.0	5.17
Detroit	87.0	41.6	8.6	13.9	20.1	6.3	9.5	100.0	4.67
Washington	91.6	43.1	9.6	14.2	12.5	9.4	11.2	100.0	4.23
Pittsburgh	87.0	37.7	21.6	14.9	13.8	12.0	—	100.0	4.21
St. Louis	91.3	37.5	8.1	17.3	21.5	6.4	9.2	100.0	4.90
Houston	91.0	33.1	8.9	17.3	18.6	10.8	11.3	100.0	5.51
Kansas City	88.2	33.4	8.8	17.2	22.7	6.0	11.9	100.0	5.14
Phoenix	85.3	25.2	10.2	19.7	20.0	11.6	13.3	100.0	4.76
Nashville	85.5	30.3	8.5	16.9	23.9	7.4	13.0	100.0	5.48
Ft. Lauderdale	86.5	27.9	15.3	24.0	22.9	0.9	9.0	100.0	2.82
Charlotte	83.9	32.2	8.0	15.6	23.8	6.6	13.8	100.0	5.56
Reno	86.5	29.2	12.7	18.1	26.3	0.5	13.2	100.0	4.88
Average	87.6	34.0	10.8	17.4	20.8	6.8	10.2	100.0	4.78

[a]After Smith (6).

TABLE 2

AVERAGE TRIP LENGTH FOR HOME-BASED TRIPS, BY PURPOSE[a]

Purpose for Home-Based Trips	Average Trip Length (mi)
Work	5.56
Shopping	3.15
School	2.97
Social-recreation	4.27
Eat meals	3.44
Business	3.71

[a]After Bevis (7).

other parameter can be determined, such as trips per acre, per job, per labor force, or other standard. It might be necessary to establish a predicting equation on the basis of multiple correlating parameters. The parameters which provide the highest correlation would then be estimated for the future year, so that a growth factor is established for each zone. The number of work trips to zone j at some future year would be solved by

$$Y_j' = G_j \, Y_j \tag{19}$$

Shopping Zone Component

The flow of shopping trips to each destination zone will be specified in a manner similar to the employment zones except for the use of different predicting parameters.

Route Components

The only one of the three possible measurements that can be used for the route component is the parameter R. The route component, analogous to a piece of hydraulic pipe, has no facility for generating pressure or flow. It seems logical if a long period of time is chosen; furthermore, if the arterial routes chosen as components provide no overnight parking there will not be any storage in the component. If a 24-hr period is chosen from 4 a.m. to 4 a.m., during this period the flow into the component equals the flow out of the component.

The flow of trips through a route component can be determined from a knowledge of either the pressure drop through the component or the friction encountered throughout the component. If pressure measurements for the components are in terms of either desire or money, it is difficult to vary the amount of this pressure in order to note the effect on the flow of trips. Friction can be related to such measurements as travel time or distance and these can be easily varied and measured while the relationship to flow of trips is recorded.

Several methods are proposed to establish the measure of friction through the route component which relates the pressure x to the flow y.

In several of the procedures that follow, it was assumed that the best single measurement that could quantitatively assign a value to the resistance term would be travel time. Contemporary writers on this subject have used, besides travel times, travel distances and straight-line distances from origin to destination. Of the three parameters, the straight-line distance is most easily measured, but gives the poorest indication of the friction or resistance encountered. Travel distances are a little more difficult to measure, but give a better estimate of the resistance. Travel distances can be the same for alternate routes, one having most of the travel on minor routes and the other on arterials and expressways, yet the friction established by distance alone would not show that the friction on the minor routes is much larger than on the other.

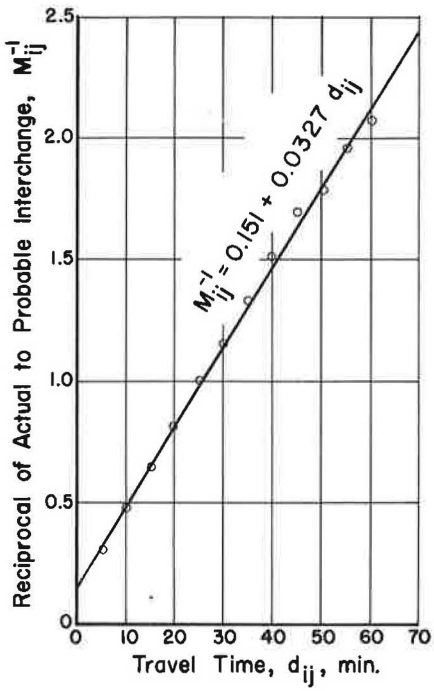

Figure 12. Relationship of travel time to actual trips per unit of probability interchange.

Probable vs Actual. —The curve used here is established using the data from an O and D study. The actual number of trips from each of the residential zones to each of the employment zones, Y_{ij}, is determined. The probable number of interchanges, P_{ij}, is calculated by assuming equal travel times from each residential zone to all the employment zones (8). A ratio, M_{ij}^{-1}, is determined; that is

$$M_{ij}^{-1} = \frac{P_{ij}}{Y_{ij}} \tag{20}$$

The value of M_{ij}^{-1} can then be plotted against travel time, d_{ij}, in minutes, as shown in Figure 12. The plot of these values can be fitted by a straight line represented by

$$M_{ij}^{-1} = 0.151 + 0.0327\, d_{ij} \tag{21}$$

It seems reasonable to find the differences between the actual interchanges and the probable values related to travel time (9).

Money Value. —The following approach to R does not use travel time alone as the controlling factor. This technique follows from an early attempt to establish an x_{ij}, or pressure value, on the route component. The subscripts ij are used to designate the route component from a zone of residence i to a zone of shopping j. The pressure drop along route ij was called x_{ij} and was related to the total cost of making the trip per vehicle, C_{ij}. The factor K was used to adjust the equation dimensionally and y_{ij} represents the actual flow.

$$x_{ij} = K\, C_{ij}\, y_{ij} \tag{22}$$

The value of C_{ij} would be the sum of the products of vehicle costs per mile times the number of miles and travel time costs per minute times the number of minutes for the route from i to j, or

$$C_{ij} = c_v m_{ij} + c_t d_{ij} \quad (23)$$

in which c_v is the total operating cost per vehicle mile; m_{ij} is the length of the route, in miles; c_t is the time cost per vehicle mile per minute of travel, assuming an occupancy of one person per vehicle; and d_{ij} is the travel time per vehicle per route, excluding terminal time. Inasmuch as the y_{ij} of actual flow in the component is the same y_{ij} required in the system solution, the equation can be further reduced and

$$R_{ij} = \frac{x_{ij}}{y_{ij}} \quad (24)$$

$$x_{ij} = K C_{ij} y_{ij} \quad (25)$$

$$R_{ij} = K C_{ij} \quad (26)$$

This last equation makes it evident that for route components the parameters which establish x are confounded in y and that specified x's are not possible. Specified R values of the route components can be determined on the basis of money.

SUMMARY

The findings can be summarized with regard to the components and the system solution. The postulates previously established are utilized in the solution of two illustrative problems (see Appendix). The most pertinent findings from this research pertain to the selection, measurement and terminal equations of the components.

Component Selection

A work trip distribution system contains workers, jobs, and some facility to bring the workers to the jobs. It was determined in this study that the best components would be the residential zone component, the route component, and the employment component. For the shopping trip distribution system, a shopping area zone component was used in lieu of the employment zone. In actuality, these two zones could be the same one.

Measurements

Two measurements are necessary on each component: one, y, must sum to zero at vertices of the system graph; the other, x, must sum to zero around the circuits of the system graph. Analogous to the other fields of system analysis, it can be established that the proper y measurement should be the flow of work trips or shopping trips. The x measurement was assumed to be a pressure-type measurement which is a causative influence on the flow and diminishes around the circuit.

The fact that the amount of travel varies from person to person is generally accepted. It might be reasoned that the variation can be tied to a set of circumstances which influence travel. In an effort to be more specific, two possible measurements were proposed which could be related to trip making. It was hypothesized that the trip interchange is a function of demand, as expressed in a need or willingness to travel. This x measurement was designated as desire. As the amount of desire increases, the number of trips also increases. This relationship between desire and trips is also influenced by the relative attraction of the trip and the friction or deterrent factors encountered. The number of trips made is based on the amount of desire available for trip making modified by the attraction of the destination and friction incurred on the route of travel.

The second expression for the pressure-type x measurement is money. The amount of money available for travel can be determined for each residential zone. The flow of trips must then be large enough to use up the money available.

Terminal Equations

A basic equation which utilizes the foregoing postulates can be stated: the flow of trips equals the pressure measurement divided by the resistance encountered, or $y = x/R$. This can also be related to a relative attraction term, G, or $y = Gx$.

For expediency in the formulation process, the basic equation is retained, even though values for x and R or G cannot be directly measured. The x measurement in terms of desire is related to parameters such as income, car ownership, distance to the CBD, and population density. The x measurement in terms of money is related to disposable income, transportation consumption, and specifically the consumption utilized for the making of shopping trips.

For the employment and shopping zones, the flow or y measurement is used throughout the research. This serves as a control volume that will properly adjust the magnitudes of the trip interchange.

The route components are related to the friction term, R. The best single predictor of R for the route components seems to be travel time. When the pressure measurement, x, is related to money, it seems advisable to express R as a function of travel costs in terms of time and vehicle costs.

System Solution

The illustrative problems in the Appendix are presented to test on a theoretical basis the application of the postulates in a system solution. In summary, the results of these illustrative solutions show that:

1. The most basic solution of future zonal interchanges occurs when the estimated trips from each residential zone, y_i, and the estimated trips to each employment zone, y_j, are specified. The R value on the route components is established as a function of an empirically established ratio of probable to actual trip interchanges.
2. The use of the pressure measurement in terms of desire provides reasonable interchanges and the trip origins at each residential zone closely approximate those found in a multiple regression equation.
3. The use of money as a function of the x measurement for residential zones and the R measurement on the route component provide results which are balanced and reasonable.

CONCLUSIONS

The justification for further research into the application of systems engineering techniques to urban traffic forecasting can be evaluated on the basis of the following conclusions:

1. Models of this type have many advantages. The parameters which influence travel patterns can be better understood through testing and evaluation in a mathematical model. A procedure for keeping the model up to date can be devised which will make periodic tests and adjustments.
2. The complex interaction of persons, vehicles, facilities and jobs in the work trip distribution system cannot be simply stated in equation form without the use of a formulation technique such as linear graph theory. This is just as true for a shopping trip distribution system.
3. Through the use of systems theory, it is possible to establish a mathematical model of the relevant physical characteristics of the system components in terms of measurements.
4. A mathematical model of each system can be formulated in terms of the characteristics of the components and their mode of interconnection.
5. The systems approach provides for a balanced flow between inputs and outputs of the system. Other models in use generally require an iterative process to produce this balance. The iteration procedures used are aimed primarily at achieving a balance of flows. The true system's effect or the interaction of the component parts is placed second in importance to the balance of flow.

6. The system engineering model is much more flexible than iteration-type models for establishing parameter values from empirical data.

7. The eventual goal of the traffic forecaster is a theoretical model that can be used in any urban area, independent of a previous O and D study. The models proposed by others have not had much success in their application to other areas. Although it has yet to be substantiated, it is proposed that a general model, which predicts the pressure for the flow of trips from any residential zone, can be established by the techniques of systems engineering.

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Appendix

SAMPLE PROBLEMS

PROBLEM 1

<u>Problem Statement</u>

Given Information—

For the hypothetical city "Red Cedar," the following information is established from a current O and D survey and a special sampling survey:

1. The present interzonal work trips, t_{ij}.
2. The present travel times between zones, d_{ij}.
3. Present and future evaluation of employment zones to establish relative attraction values on the basis of number of jobs and/or other parameters.
4. Probability interchange established on the basis of the relative attraction of employment zones assuming equal travel times, P_{ij}.
5. The actual trips per unit of probability interchange, $M_{ij} = Y_{ij}/P_{ij}$.
6. Curve plot or equation for $1/M_{ij}$ versus d_{ij} (Fig. 12).
7. Present estimates of income, car ownership, distance to CBD, and population density.
8. Forecast of these parameters for each zone, i, for the future year.
9. Forecast of area-wide limits or ceilings on these parameters for the future year.
10. Distribution of trips by purpose, where K_W is the work trip factor.
11. Existing land-use data.
12. Future land-use forecasts.

To Find—

The problem is to forecast future interzonal work trip movements when specified x's or "pressure drivers" are given for the residential zones, specified y's or "through drivers" are given for the employment zones, and resistance values are given for the route components.

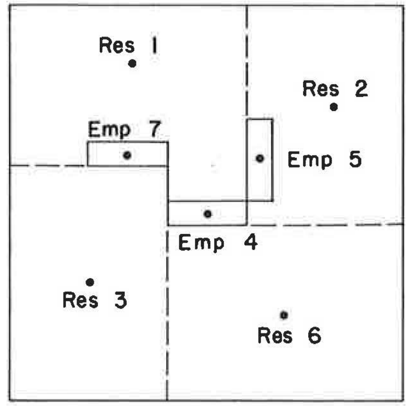


Figure 13.

Schematic of Physical System

The schematic of the physical system involved is given in Figure 13.

Input Values and How Established

The following input values are necessary for solution of this sample problem by linear graph theory:

1. The value of trip desire or pressure, x_i, for each residential zone, i, is required. The values will be established in the following manner:

(a) From existing O and D data for income index α, car ownership β, distance to the CBD γ, and population density δ, an equation will be established for Y, resident trips per dwelling unit. For this example,

$$Y = -0.1958 + 0.0008\,\alpha + 4.6480\,\beta + 1.7288 \log \gamma - 0.5464 \log \delta \quad (27)$$

Eq. 27 is then maximized with limiting values of all parameters as forecast in the whole area for the future year. The limiting values used to maximize Eq. 27 are income index, 9; car ownership, 1.5 cars per dwelling unit; distance to CBD, 100 (tenths of miles); population density, 2.5 (dwelling units, in tenths, per net acre). This maximum value of Y is defined as the theoretical pressure or desire,

$$X_T = Y_{max} \quad (28)$$

The pressure or desire for work trips per dwelling unit is found by using the previously defined factor, K_W, in

$$X_W = X_T\, K_W \quad (29)$$

(b) Using maximizing inputs for Eq. 27 on all parameters except income, α, will develop a relationship between discrete values of income and $Y_{\alpha:\beta,\gamma,\delta}$. A curve plot or equation is then established for r_α. The decrease in X from the maximum value is related to the coefficient r_α by

$$\left[X - Y_{\alpha:\beta,\gamma,\delta}\right] = \left[r_\alpha X\right] \quad (30a)$$

or

$$r_\alpha = \frac{\left[X - Y_{\alpha:\beta,\gamma,\delta}\right]}{X} \quad (30b)$$

The value of R_α is found by normalizing r_α (see Fig. 4) and should serve to isolate the effect of income on pressure and trips made.

(c) Similar techniques are used to establish curves or equations for R_β, R_γ, and R_δ (see Figs. 5, 6, and 7).

(d) A subsystem of the zone parameters is solved in order to find each x_i value. This can be shown either schematically (Fig. 8) or as a system graph (Fig. 9), and Eqs. 7 and 8 apply. The summary of solution of input x values and $(\Sigma G_i)^{-1}$ is given in Table 3.

2. Y_j values for each employment zone are determined by methods previously defined.

3. The input values for the route components are R_{ij}^{-1} or G_{ij} values as given in Table 4.

TABLE 3

COMPONENT INFORMATION NECESSARY TO SOLVE THE LINEAR GRAPH

Element No.	Component	Travel Time (min)	R_{ij}^{-1} or G_{ij}	Work Trips, y
1	Employment (I-7)	—	—	2,000
8	Street	10	2.092	
9	Street	17	1.414	
10	Street	20	1.242	
11	Street	10	2.092	
12	Street	14	1.642	
13	Street	10	2.092	
18	Street	10	2.092	
19	Street	14	1.642	
20	Street	17	2.092	
21	Street	14	1.642	
22	Street	10	2.092	
23	Street	14	1.642	
26	Residential (R-1)	—	—	—
27	Residential (R-2)	—	—	—
28	Employment (I-4)	—	—	2,000
29	Employment (I-5)	—	—	4,000
30	Residential (R-3)	—	—	—
31	Residential (R-6)	—	—	—

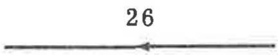
TABLE 4

SUMMARY OF SOLUTION OF INPUT x VALUES AND $(\Sigma G_i)^{-1}$ FOR SUBGRAPH OF RESIDENTIAL ZONES

Item or Factor	Res. 1 (26)	Res. 2 (27)	Res. 3 (30)	Res. 4 (31)
No. dwelling units	1,050	1,010	818	715
Income index	8	7	5	6
R_α	0.118	0.250	0.500	0.368
Car ownership	1.3	1.1	0.8	0.9
R_β	0.133	0.266	0.466	0.400
Distance to CBD	8.0	3.0	2.0	4.0
R_γ	0.075	0.401	0.538	0.306
Population density	10	20	30	20
R_δ	0.462	0.694	0.828	0.694
Factor K_x	0.22	0.22	0.22	0.22
Factor K_w	0.348	0.348	0.348	0.348
x_i (total)	-773	-742	-600	-525
$(\Sigma G_i)^{-1}$ or R_e	0.0317	0.0855	0.1387	0.1007

Terminal Representation of the Component

1. Residential zones i will have a computed x value



2. Employment zones j will have specified y's or "through drivers"

3. Route components are given in equation form where

$$R = \frac{x}{y} \tag{31}$$

System Graph and Tree

The system graph and tree is shown in Figure 14. The specified flows or y's at the employment zones are placed in the chord set; the residential zones are placed in the branches. Figures 8 and 9 have been replaced by the equivalent element (element 1) in the system graph (Fig. 14).

Formulation in Cut-Set Equations

Symbolically the cut-set equation can be shown without the Y_{b-1} term because there are no specified x variables.

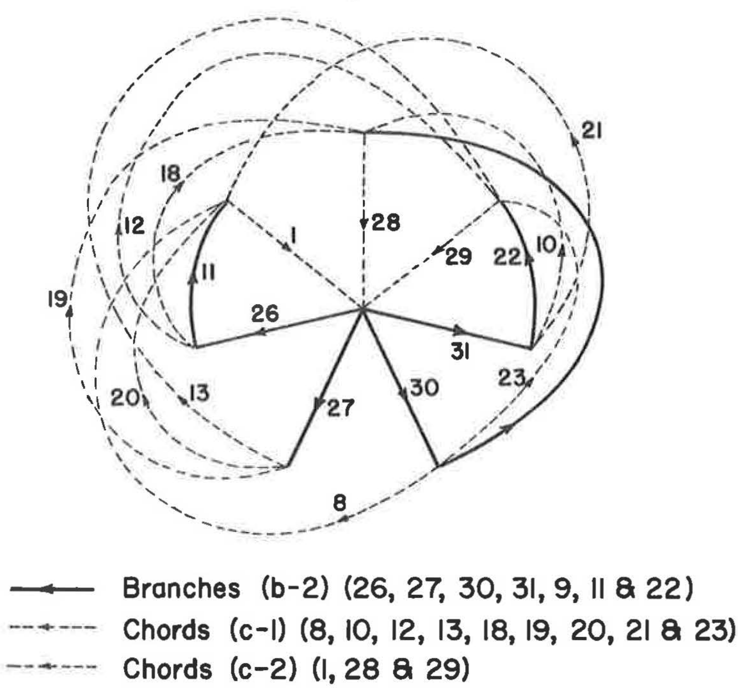


Figure 14. System graph and tree, problem 1.

$$\begin{bmatrix} U & A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} Y_{b-2} \\ Y_{c-1} \\ Y_{c-2} \end{bmatrix} = 0 \tag{32}$$

By multiplying the matrix through,

$$\begin{bmatrix} U & A_{21} \end{bmatrix} \begin{bmatrix} Y_{b-2} \\ Y_{c-1} \end{bmatrix} + A_{22}\, Y_{c-2} = 0 \tag{33}$$

The Y values can be established as an explicit function of the X values and the x term is the specified x value from the previously noted subgraph:

$$\begin{bmatrix} Y_{b-2} \\ Y_{c-1} \end{bmatrix} = \begin{bmatrix} G_{b-2} \\ G_{c-1} \end{bmatrix} \begin{bmatrix} X_{b-2} \\ X_{c-1} \end{bmatrix} - \begin{bmatrix} G_{b-2} \\ 0 \end{bmatrix} \begin{bmatrix} x_1 \\ 0 \end{bmatrix} \tag{34}$$

This value can be substituted in Eq. 33, or

$$\begin{bmatrix} U & A_{21} \end{bmatrix} \begin{bmatrix} G_{b-2} \\ G_{c-1} \end{bmatrix} \begin{bmatrix} X_{b-2} \\ X_{c-1} \end{bmatrix} - \begin{bmatrix} U & A_{21} \end{bmatrix} \begin{bmatrix} G_{b-2} \\ 0 \end{bmatrix} \begin{bmatrix} x_1 \\ 0 \end{bmatrix} + A_{22}\, Y_{c-2} = 0 \tag{35}$$

The X_{c-1} term can then be expressed in terms of X_{b-2}, or

$$X_{c-1} = A_{21}{}^{T}\, X_{b-2} \tag{36}$$

and the final form becomes

$$\begin{bmatrix} G_{b-2} + A_{21}\, G_{c-1}\, A_{21}{}^{T} \end{bmatrix} \begin{bmatrix} X_{b-2} \end{bmatrix} - \begin{bmatrix} A_{21}\, G_{b-2}\, x_1 \end{bmatrix} + A_{22}\, Y_{c-2} = 0$$

Final Solution

The work trip interchanges found from this computation are given in Table 5. The details of the final solution have been omitted from this example, because the procedure is a straightforward matrix multiplication.

Discussion of Results

The value of desire, as a measurement of the pressure x, was found by maximizing the multiple regression equation for Y, given in the section on input values. The primary specified x_1 value for work trips for all residential zones was found to be 0.734 per dwelling unit. The final x values for each residential zone varied according to the number of dwelling units and the resistance factors.

The theoretical pressure for each zone is reduced because the parameters of income, car ownership, and so forth are different from those which would optimize the pressure for trip making.

TABLE 5

RESULTS OF ILLUSTRATIVE PROBLEM 1

Origin	Destination	Work Trips (no.)				
		Systems Engineering		Multiple Regression		Adjusted Total
Zone 26	Zone 1	873		—		
	Zone 28	965		—		
	Zone 29	1,165		—		
	Total		3,003		2,940	3,014
Zone 27	Zone 1	590		—		
	Zone 28	536		—		
	Zone 29	1,207		—		
	Total		2,333		2,180	2,235
Zone 30	Zone 1	322		—		
	Zone 28	281		—		
	Zone 29	737		—		
	Total		1,340		1,310	1,343
Zone 31	Zone 1	215		—		
	Zone 28	218		—		
	Zone 29	891		—		
	Total		1,324		1,373	1,408
Total			8,000		7,803	8,000

The trips from each residential zone computed in this problem are compared with the trips generated by each zone, using the multiple regression equation for Y with specific parameter values. The comparison (Table 5) shows that the total trips by the Y equation are only 7,803, whereas the stated input trips to the employment zones total 8,000.

Trips generated by the multiple regression equation are then adjusted proportionately to agree with the total destinations estimated at the employment zone.

PROBLEM 2

Problem Statement

Given Information—

For a given hypothetical city "Grand River," the following information is established from a current O and D survey and a special sampling survey:

1. The present interzonal trips, t_{ij}.
2. The present travel times between zones, d_{ij}.
3. Present and future evaluation of the shopping zones to establish relative attraction values on the basis of number of employees, retail square feet, and/or other parameters.
4. Probability interchange established on the basis of the relative attraction of shopping zones assuming equal travel times, P_{ij}.
5. The actual trips per unit of probability interchange, $M_{ij} = Y_{ij} / P_{ij}$.
6. Curve plot or equation for $1/M_{ij}$ versus d_{ij}.
7. Present and future estimates of income, consumption and their relationship (Fig. 10).
8. Relationship for transportation consumption, present and future, by yearly change.
9. Families per zone, present and future.
10. Percentage of trips for each purpose and their mean length (Tables 1 and 2).
11. Existing land-use data.
12. Future land-use forecasts.
13. Additional requirements on the route components, such as (a) length of each route, in miles; (b) average speed over each route component; (c) average vehicle costs per mile (Table 6); and (d) average time costs per hour.

TABLE 6

ESTIMATED COST OF OPERATING A MOTOR VEHICLE[a]

Item	Cost (¢/mi)	Percent of Total
Costs, excluding taxes:		
Depreciation	2.54	26.0
Repairs, maintenance	1.72	17.6
Replacement tires and tubes	0.18	1.8
Accessories	0.14	1.4
Gasoline, except tax	1.45	14.9
Oil	0.19	2.0
Insurance	1.29	13.2
Garaging, parking, tolls, etc.	1.08	11.1
Sub-total	8.59	88.0
Taxes and fees:		
Gasoline	0.70	7.2
Registration	0.10	1.0
Titling and property	0.10	1.0
Oil	0.01	0.1
Auto, tires, parts, etc.	0.26	2.7
Sub-total	1.17	12.0
Total operating cost	9.76	100.0

[a]After Smith (6).

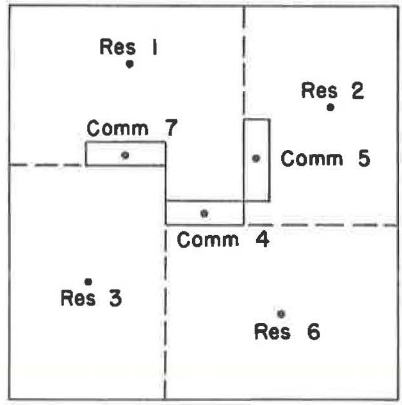


Figure 15.

To Find—

The problem is to forecast future interzonal shopping trip movements when x values for the residential zones are specified on the basis of money available for shopping trips, y values are specified for the destination zones as shopping trips, and the route components have specified resistance value, R, established on the basis of the money spent on traveling the route.

Schematic of the Physical System

The schematic of the physical system involved is given in Figure 15.

Input Values and How Established

The necessary input values for the solution of this sample problem by linear graph theory are:

1. The x_i on the basis of amount of money, in dollars, to be spent for the total shopping trips made from the residential zone i. The following equation is the condensation of all factors discussed in detail in the text:

$$x_i = \frac{K}{300} \frac{k_s m_s}{\Sigma(km)} K_h N_f (E_b + n \Delta E) Z_i \tag{37}$$

in which

K = constant to adjust differences in dimensions;
300 = number of shopping days per year;
Σ (km) includes:
k_w = percentage of trips to work;
m_w = average trip length to work;
k_s = percentage of trips to shopping;
m_s = average trip length to shopping;
k_{sc} = percentage of trips to school;
m_{sc} = average trip length to school;
k_{sr} = percentage of trips to social-recreation;
m_{sr} = average trip length to social-recreation;
k_{em} = percentage of trips to eat meals;
m_{em} = average trip length to eat meals;
k_b = percentage of trips to business;
m_b = average trip length to business;

K_h = weighted percentage, by trip length, of all trips that are home-based;
N_f = number of families in the zone;
E_b = ratio of amount spent on transportation per total consumption for base year;
ΔE = yearly change;
n = number of years from base to future year; and
Z_i = total consumption per base year.

A summary of the solution leading to values of x by the foregoing procedures is given in Table 7.

2. The input y_i values for each shopping zone are determined by methods previously defined in the text.

3. The resistance value on the route components is also established on the basis of cost of travel on the route, as explained in the text. The combined equation is

$$R_{ij} = K(c_v m_{ij} + c_t d_{ij}) \quad (38)$$

TABLE 7

SUMMARY OF SOLUTION TO x INPUT VALUES FOR RESIDENTIAL ZONES

Item	Res. Zone 1 (26)	Res. Zone 2 (27)	Res. Zone 3 (30)	Res. Zone 6 (31)
(a) Present Year				
Average disposable income per dwelling unit ($)	5,300	6,300	4,300	4,300
Total consumption, Z ($)[a]	5,300	6,150	4,400	4,400
Transp. consumption, Z^t ($)[b]	455	530	375	375
Ratio, $Z^t/Z = E_b$	0.0859	0.0862	0.0852	0.0852
(b) Future Year Estimate				
Average disposable income per dwelling unit ($)	5,700	6,500	4,800	4,600
Total consumption, Z ($)[a]	5,900	6,600	5,100	4,900
Ratio, Z^t/Z ($E_f = E_b + n E$)	0.1002	0.1005	0.0995	0.0995
Transp. consumption, Z^t ($)[b]	591	663	507	488
Percent for shopping trip, K_s	0.107	0.107	0.107	0.107
Shopping trip consumption, Z^{st} ($)	63.2	70.9	54.3	52.2
Number of dwelling units	750	510	442	464
Total shopping trip consumption ($1,000)	47.5	36.2	24.0	24.2
$x_i = K(C_i/300)$[c]	39.6	30.2	20.0	20.2

[a]From Figure 7. [b]From Figure 8. [c]Assume K = 0.25.

TABLE 8

SUMMARY OF SOLUTION OF R_{ij} BY SUM OF VEHICLE AND TIME COSTS

Route No. (element)	Length, m_{ij} (mi)	Vehicle Cost, $c_v m_{ij}$[a] ($)	Travel Time, d_{ij} (min)	Time Cost, $d_{ij} c_t$[b] ($)	Total Cost, C_{ij} ($)	Resistance, R_{ij}, = $K C_{ij}$[c]
8	3.3	0.325	10	0.225	0.550	0.3850
9	6.8	0.664	17	0.382	1.046	0.7322
10	8.0	0.781	20	0.450	1.231	0.8617
11	3.3	0.325	10	0.225	0.550	0.3850
12	4.7	0.458	14	0.315	0.773	0.5411
13	3.3	0.325	10	0.225	0.550	0.3850
18	3.3	0.325	10	0.225	0.550	0.3850
19	4.7	0.458	14	0.315	0.773	0.5411
20	3.3	0.325	10	0.225	0.550	0.3850
21	4.7	0.458	14	0.315	0.776	0.5411
22	3.3	0.325	10	0.225	0.550	0.3850
23	5.6	0.546	14	0.315	0.861	0.6027

[a]Vehicle cost per mile assumed at $0.0976 (6).
[b]Time cost per hour assumed at $1.35 (6).
[c]K assumed to be 7×10^{-3}.

in which

K = constant for all route components to adjust for differences in dimensions;

c_v = total operating cost per vehicle mile;

m_{ij} = length of the route, in miles;

c_t = time cost per vehicle per minute, assuming an occupancy of one person per vehicle; and

d_{ij} = travel time per vehicle per route, excluding terminal time.

A summary of the solution leading to values of R_{ij} for the route components on the basis of vehicle and time costs is given in Table 8.

System Graph and Tree

Figure 16 shows the system graph and tree used for the solution. The specified x values on the residential components were placed in the branches (b - 1) and the specified y's from the shopping zones were placed in the chord set (c - 2).

Inasmuch as the solutions require only mechanical substitution in equations, they are omitted and only the results are presented (Table 9).

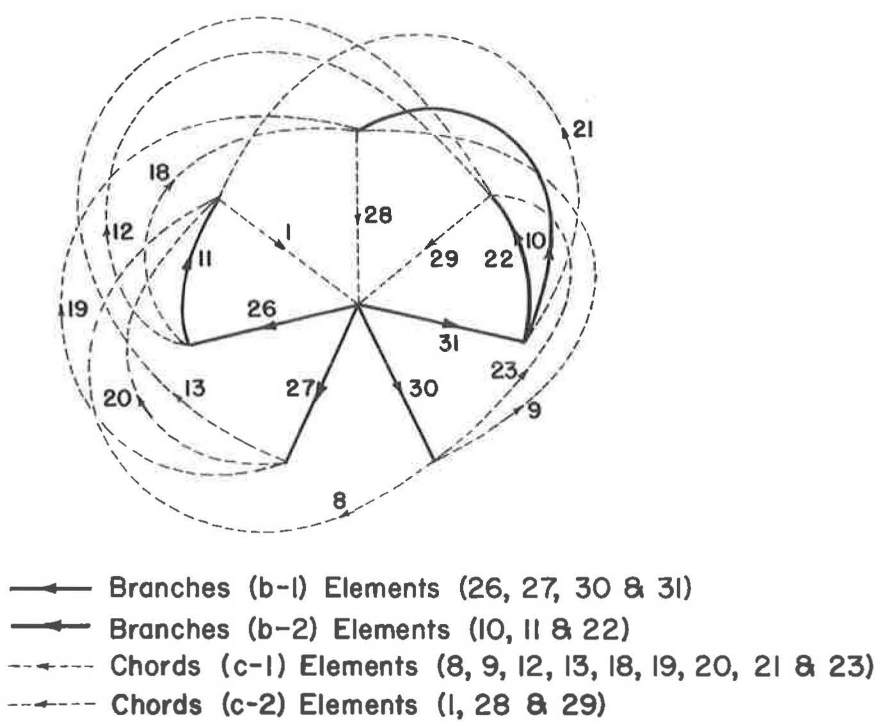


Figure 16. System graph and tree, problem 2.

Discussion of Results

The two sample problems are for systems having different trip purposes, and no effort was made to compare the two methods on like systems. The pressure-type x measurement of problem 2 is dependent only on income and consumption. In contrast to this, problem 1 uses income as well as other parameters such as car ownership, population density, and distance from the CBD. It is anticipated that these parameters are related to income, but the extent of the correlation has not yet been established.

The establishment of R_{ij} for the route components in problem 2 should provide a better estimate of the resistance offered. Whether the increased data collection is warranted by an improved estimate is subject to further evaluation.

TABLE 9

RESULTS OF ILLUSTRATIVE PROBLEM 2

Origin	Destination	Shopping Trips (no.)	
Zone 26	Zone 1	111	
	Zone 28	137	
	Zone 29	129	
	Total		377
Zone 27	Zone 1	86	
	Zone 28	80	
	Zone 29	157	
	Total		323
Zone 30	Zone 1	60	
	Zone 28	45	
	Zone 29	83	
	Total		188
Zone 31	Zone 1	43	
	Zone 28	38	
	Zone 29	131	
	Total		212
Total			1,100

What Is Needed for a Fact Finding Study of Intercity Transportation In the United States

A Panel Discussion*

Introduction

On July 27, 1961, D. Grant Mickle, then Chairman of the Committee on Origin and Destination Surveys, suggested that a panel discussion on the intercity origins and destinations of traffic be included on the agenda for the 1962 meeting of the Committee. Such a panel discussion was organized by Harold W. Hansen. Subsequently, Harmer E. Davis, E. H. Holmes and J. Douglas Carroll, Jr., agreed to lead the discussion in each of three areas within the general subject.

At the suggestion of Dr. Carroll, background material was mailed to Committee members and nearly 100 guests who were in attendance at the January 1961 sessions of the Committee. This material was intended to stimulate thinking in advance of the proposed panel discussion so that basic considerations could be undertaken more rapidly.

Background

Harold W. Hansen
Senior Planning Engineer
Portland Cement Association, Chicago, Illinois

A factual study of the intercity movements of people and goods in the United States is one of the pressing research needs today. The problems which generate this need are neither small nor uncomplicated. The great number of transportation vehicles, the considerable extent of their use, and the extent of facilities needed for their operation are unprecedented in the history of man. Reasonably current information (Tables 1 and 2) shows something of the shear size and range of transportation in the United States.

There are other problems, too. Sociological changes now taking place, accompanied by accelerating population growth and redistribution, have an important effect on the whole complex of interrelationships in the transportation field. Technological advances and other factors are sharpening competition between carriers; casualties of this warfare have an effect on the general economy. Understanding of the controlling factors is imperative to prevent needless waste, inefficiency and possible chaos.

SOME PROBLEMS

Described as a "loose grouping of individual industries and individual efforts," transportation in the United States is afflicted with several ailments. Some of these are no doubt due in part to the piecemeal uncoordinated development of the several transportation modes over many years.

---

*Conducted under the auspices of the Committee on Origin and Destination at its meeting during the 41st Annual Meeting of the Highway Research Board (January 1962).

TABLE 1

TRANSPORTATION IN THE UNITED STATES BY MODE OF TRAVEL

Mode of Travel	Vehicles in Use (no.)	Extent of Use (millions)
Highway:		
Passenger automobiles	59,892,000	571,090 veh-mi
Trucks and combinations	11,622,000	122,746
Commerical buses	76,000	2,876
School and non-revenue buses	188,000	1,459
Total	71,778,000	698,171 veh-mi
Rail:		
Freight cars	1,723,200	575,439 ton-mi
Passenger cars	30,000	17,533 pass.-mi
Locomotives	29,256	—
Total	1,782,456	
Air:		
Commerical	1,841	28,127 pass.-mi 3,167 ton-mi
Business and private	70,627	10, hr
Total	72,468	
Water:		
Towing vessel and barges	28,227	109,131 ton-mi
Pipeline:		
Oil transmission	—	1,022 bbl/year
Gas trans. and distrib.	—	11,500,000 cu ft/year

TABLE 2

EXTENT OF TRANSPORTATION NETWORKS IN THE UNITED STATES

Network Type	Extent (mi)
Highway:	
Interstate	40,521
Primary	402,284
Local	2,960,481
Federal	107,374
Total	3,510,660
Rail:	
Line haul	384,500
Switching	7,600
Total	392,100
Air:	
Controlled airways	182,500
Airports	6,400[b]
Water:	
Improved routes[a]	28,600
Pipeline:	
Oil transmission	182,982
Gas trans. and distr.	595,000
Total	784,982

[a]Excludes Great Lakes.
[b]Number of airports.

Technological and sociological changes underlie some of these problems. For example, population shifts to cities, together with a higher standard of living, have brought about a massing of motor vehicles in the cities. Failure to plan and to provide street improvements that keep pace with this development is resulting in urban traffic congestion. Less evident, perhaps, but just as real, are the deficiencies known to exist on highways, roads and streets across the country.

All these deficiencies keep the standard of highway service inexcusably low and contribute needlessly to killing and injuring thousands each year. At the same time they add unnecessarily to transportation cost.

ILLINOIS AND MICHIGAN STUDIES

A pioneer research effort to come to grips with the factors controlling highway transportation was a pair of studies conducted during the period 1948-51, when the Michigan and Illinois state highway organizations reviewed their existing legal classifications of road and street systems. Although they worked independently, essentially the same techniques were employed.

Highway use was assumed to relate directly to economic forces operating in the state. These forces were known to fall generally into trade areas, which were identified. The focal points of traffic generation within trade areas were believed to be the market centers—cities, towns, etc. Indicators of economic strength were used, including population and bank resources of the immediate trade area, and newspaper circulation and assessed valuation of the trade center. It was found that the proportion of traffic passing from one trade center to another increased with the size of the centers and as the distance between them decreased.

Although these studies related to highway transportation alone, they were significant for at least two reasons: First, they represent an attempt to determine a scientific relationship describing the nature and cause of at least a portion of total travel. Second, although output from the mathematical processes were used to describe highway travel, the formulas tended to measure all movements regardless of mode.

COMPETITION

Although these studies partially opened the door to greater knowledge, they represent but a very small fragment of the total transportation picture. There are other serious problems.

In the freight-hauling field, regulated truckers are facing increasing competition from private truckers, rail carriers and air carriers. The passenger and freight business of railroads has been declining. Although passenger and freight transport by commerical air carriers has increased steadily, future growth involves winning customers from other modes of transport who offer lower-cost service. As with private air travel, the relatively higher unit costs of commercial air travel have yet to be overcome. An inland water transport, despite some gain in volume, has not materially increased or decreased its share of the total cargo business. Competition from other modes—particularly pipelines—is a factor.

Competition and a variety of transportation modes are desirable, if not necessary. However, blind adherence to past practices without any attempt to fit resources to present and future transportation needs can result in needless waste and less-than-adequate service. The quality of transportation service must continue to improve. Costs must gradually be reduced.

NEED FOR INFORMATION

Such a future is not inevitable. It demands realistic planning based on understanding and guiding controlling factors in this vast enterprise called transportation. This is the heart of the problem.

Adequate facts on the transportation situation are not available, and those which are on hand relate principally to regulated carriers. However, even these are generally not comparable between modes of transportation; therefore, they are not of use for the type of study to be undertaken.

With what is now known, one cannot accurately analyze intercity movements of people and goods on a nationwide basis when all modes are taken into consideration.

These intercity flows are believed to be the very backbone of the nation's transportation system. They are the major transportation corridors. Lack of factual data about these movements is a serious and fundamental research deficiency that is impeding improvements in the quality of transportation service and delaying reduction in cost.

PREVIOUS RELATED WORK

An early effort to single out major travel corridors was that undertaken by the U. S. Bureau of Public Roads at the direction of the Congress. Published in 1944, much of the work for the report was done in the late 1930's. The report suggested a 39, 000-mile network of interregional highways to connect most larger cities (of more than 10, 000 population). These routes were to be as direct as possible and not deviate to serve cities of substantially less than 10, 000 population. The system included appropriate links in and through the cities served, as well as circumferential and distribution routes.

WASHINGTON STUDY

On the heels of the Michigan and Illinois road system classification studies referred to previously, came an exhaustive analysis by the Washington State Council for Highway Research. Using a similar approach, economic indices were developed to describe centers of population. Equations were then tested until it was possible to simulate, within reasonable limits, the low point in traffic volume between pairs of population centers. The study argued that this low point represented an approximate measure of the "through" traffic using the road. The study also recognized that a corrective factor might be needed when computing intercity travel desire between places 250 mi or more apart to allow for travel using other modes of transportation.

NORTH CAROLINA SURVEY

During 1959 and 1960 the North Carolina State Highway Department further refined the Washington concept of through traffic by undertaking a special, area-wide origin-and-destination traffic survey in a five-city area. From the total of all trips, those trips having their origins and destinations in the five cities were selected. Having thus excluded trips with either a rural origin or destination, a gravity formula or model was developed to simulate observed intercity trips. Although the model was similar to the one developed in Washington, the basic concept differed somewhat. Instead of using economic data pertaining to a trade area, the North Carolina process used estimated population counts of the cities involved. Here, for the first time, was developed a formula which could be said to relate to highway transportation specifically.

Inherent in all the foregoing premises is an assumption that the major corridors were being defined, measured and sorted in accordance with their importance, function and relative use.

Subsequently, the North Carolina State Highway Commission applied its formula on a statewide basis. The quantitative measure of motor vehicle traffic interactance was used to classify all rural roads into functional systems.

ASF STUDY IN IOWA

Concurrently but independently, the Automotive Safety Foundation was conducting a statewide study of road and street needs in Iowa. Using concepts similar to those adopted in North Carolina, the Iowa study applied a conceptual model developed by Alan Voorhees for simulating interzonal traffic flow in cities. The gravity model was used to produce an index of travel desire rather than the actual number of trips. It was assumed that the index was proportional to the actual number of trips having origins and destinations in the centers of population selected for analysis. The intercity travel study used 50 larger centers of population in Iowa and the surrounding region. Inherent in the Iowa study were the following concepts:

> Population outside cities or city-like places is thinly distributed. When considered apart from city population there appear to be no factors which would cause rural trips to consolidate into major, statewide travel corridors. Accordingly, travel by rural persons was omitted from consideration.
>
> Trips into and between smaller cities and towns, together with their relative location and economic strength, are not of such a nature as to cause these smaller centers of population to serve as control points for major, statewide travel corridors. They were therefore, disregarded as of controlling importance.
>
> Trips out of larger population centers do not radiate equally in all directions but are attracted more strongly to other centers of population. The strength of the pull to other centers is directly proportional to the size of centers and inversely proportional to the distance between them.
>
> Travel corridors lying between centers of population—particularly between larger centers—are the major travel corridors of the area or region studied.
>
> Mathematical expressions for conceptual models do not of themselves indicate mode of travel unless fitted to data for a particular mode.
>
> Only those trips having origins and destinations in cities are produced by the above process. Therefore, it is necessary to add city-to-rural, rural-to-city and rural-to-rural trips to each route to obtain a measure of total vehicular trips.

CONCLUSION

The foregoing examples of what has been done relate to one mode of transportation; except for the Interregional Highway Study each was limited to a single state. A nationwide study of the scope here contemplated would be much more comprehensive. Because of the scale and extensiveness of such a study it is essential that controls be clearly set forth to guide the proposed study to a useful conclusion. This raises questions. What, actually, is needed to undertake a factual study of the intercity movement of people and goods in the United States?

What should be the scope of such a study?

Why should such a research endeavor be undertaken?

Is the know-how available to execute such a study?

Comments on a Proposed National Study

Harmer E. Davis, Director
Institute of Transportation and Traffic Engineering
University of California, Richmond, Calif.

Interest in a national transportation study, or census, or survey, is not of recent origin. Any attempt to institute a large-scale nationwide study should take into account the lessons learned from past efforts. Public Law 671, 80th Congress (1948), and its subsequent history, and the NAS-NRC Study and Conference at Woods Hole in 1960, are examples of expressions of general interest and need. Proposals for a national transportation census have run into some opposition, however.

In connection with highway transportation, the studies by the Bureau of Public Roads leading to the report "Toll Roads and Free Roads," House Doc. 272, 76th Congress, 1st Sess., in 1939, and the report "Interregional Highways," House Doc. 379, 78th Congress, 2nd Sess., in 1944, represented substantial contributions toward defining a system of truck highways on a nationwide scale. However, active progress in planning for and constructing the National System of Interstate and Defense Highways during the past decade, together with mounting problems of urban congestion, have focused a large share of attention and effort, on the part of those concerned with highway transportation, upon developing information relating to intra-urban aspects of the highway systems. It appears timely and important again to give attention to the problems of intercity and interregional transportation, but this time on a new scale and with a broad perspective.

WHAT IS A NATIONAL TRANSPORTATION STUDY?

The idea of a national transportation study means different things to different people or groups. To some it means merely a program of collecting more, or supposedly lacking, data or information about transportation on a nationwide basis. To others, at the opposite end of a spectrum, it means a report giving the views of the study group on what should constitute national or Federal transportation policy. It should be obvious that the mere collection of extensive statistics can be a sterile exercise, often resulting in wasted effort. And there are a number of examples of policy-study reports, prepared without adequate facts or understanding of the working of phenomena, that, after a short period of emitting heat but little light, gather dust in the archives.

I think what is really sought is better understanding of that technico-socio-economic activity (or phenomenon) that is called "transportation." What is needed is improved insight into the workings of this activity or process under changing technological, social and economic conditions. Insight is needed to aid in sharpening predictions of demand, usage and performance of existing and proposed transportation systems. What is desired is an improved base for rational and defensible planning and design of transport facilities and operations.

Obviously, a basic step in attaining better insight into any process or activity—natural, social or economic—is the acquisition of some minimum amount of factual information about the process. A concomitant step is the formulation of concepts or models of how the process works, which are successively refined to some degree of concordance with the real-life process. A parallel requirement is the capability of analyzing the process, using the data and models. The ultimate objective is (a) to be able to explain why things perform the way they do, and (b) to predict the performance and cost of the system under various possible conditions (inputs or demands, levels of internal capability, and ambient conditions).

Unless there is some preliminary understanding, however crude, of how the process or system works, it is difficult to know what data should be sought. Because of the enormous mass of data involved in describing the workings of a transportation process on a national scale, it is impractical and probably not feasible to blindly set in motion a vast data-collection system which would just accumulate statistics. Likewise, without the capability of analyzing, summarizing and synthesizing the information so as to ultimately produce or test workable concepts, the data and the models do not contribute to the ultimate objective of rational understanding.

It should be apparent that the three steps—data collection, model formulation and analysis—are intimately interrelated, and for the successful pursuit of a national transportation study all three must be worked together. This will take much thoughtful preparation and, ultimately, substantial resources for the support of a worthwhile effort. Such an effort is important and timely, and capabilities of accomplishing it are available or can be developed.

AVAILABLE INFORMATION

If it is decided to begin working toward a national transportation study, it is not necessary to start from the beginning in designing such a study or preparing for its pursuit.

The highway field has a background of three decades of experience in planning interstate highway networks, and in recent years in several of the states (for example, California, Iowa, Michigan, Illinois) planning studies for trunkline state highways have contributed to an evolving methodology for analyzing and projecting intercity travel. Studies in the State of Washington, and recently in some of the large metropolitan areas, are contributing to the evolution of models of intercity traffic flows.

In the air transport field, studies in connection with a national airport plan, and for the national airway system, have contributed concepts and information on intercity movement of persons, in particular.

There have been other such study efforts. The point is that some backlog of information, some concepts of system behavior, and some analytical methodology, are available.

In addition, there are large masses of data, now more or less routinely collected, some of which certainly would be useful in contributing to the objectives of a national study as I have defined them. For example, with respect to freight transportation by rail, the continuous waybill sampling work of the Interstate Commerce Commission contributes some useful data on commodity movements. The main deficiency in the present over-all data-collecting activity is that it does not produce all of the kinds of, nor some of the key information necessary to really understand the workings of the national transportation systems; that is, there appear to be critical gaps in national transportation data.

Some of the appraisals of the status of the current data-collecting process are abstracted in the following paragraphs.

In the report of the Data Panel of the 1960 Woods Hole Study (NAS-NRC Publication 840) pp. 51-52, the following statement is made:

> The following primary questions guided our evaluation of the adequacy of data pertaining to the transportation system of the United States:
>
> Are available data sufficient to describe the performance of the various transportation activities?
>
> Are they sufficient to enable one to understand the interrelationships of the various transport modes with each other, with the economy as a whole, including its international component, and with various regional and industrial sectors of the economy?
>
> Are they adequate to allow understanding of the effects of transportation upon individual welfare, and the character of rural, urban, and metropolitan life?

Are they adequate to allow an informed assessment of the future developments in the transport field and of their effects on each of the above-mentioned areas?

Are they adequate to permit the formulation and validation of hypotheses which seek to explain the transport operations as a system phenomenon within a socio-economic framework?

Are they adequate to allow for timely and effective planning for defense needs?

In addition to these several questions addressed to the adequacy of type of data is this question:

Is the data collection system capable of providing information responsive to current and anticipated needs in a timely and efficient manner?

It was concluded that in important respects the data now available are inadequate to answer any of the above questions affirmatively. This conclusion does not minimize the usefulness of the data now available, nor the resources of the agencies which collect these data.

The panel report then examines the principal aspects of national data-collecting activities, and draws the following conclusions (pp. 59-60):

From a composite of the questions raised and our examination of the data problem, we concluded as follows:

Information is not adequate for scientific examination of the transportation system as a whole, nor its relationships to vital economic, social, political, and defense questions. Without such information it is difficult to identify important problems and promising methods for solution.

As research, experimentation, and understanding of the transportation system grow, there inevitably will be a need for data which are not now foreseen. It is likely that at least some of the required data will be outside the scope of interest and authority of present data-collection bodies.

The present aggregation of organizations collecting transport data does not now provide the information required for the satisfactory understanding of the transportation system as a whole and its ramifying effects. This deficiency should be remedied.

In the Doyle Report of 1961 (transportation study for U. S. Senate Committee on Interstate and Foreign Commerce), the following appraisal in made (p. 275):

B. TRAFFIC AND SERVICE TRENDS OF INTERCITY TRAVEL

To properly understand the trends of intercity travel, we should have facts that would relate travel volume to cities and would in addition show the origin and destination of the important passenger flows. Such data would give us a clear picture of the relative importance of regions and cities, the important city pairs in numbers of passengers exchanged, and an accurate picture of the geographic flow of traffic in varying seasons and such characteristics as average length of trip and vehicle used. Unfortunately, such information is not available for any mode of passenger transportation except the regulated air carriers. There are random survey materials on highway passengers, principally by private auto, in Bureau of Public Roads surveys but these are the responsibility of the States and are not carried out systematically nor repeated from time to time. There are no geographic passenger data for rail and bus since 1940 except for what may be implied from the operations of individual companies reporting to the ICC. Thus we are unable to make a comprehensive geographic or traffic flow analysis of intercity passenger movement in order to identify the most important flows and the means by which the passengers move in these flows. The Government is indeed remiss for not having taken the necessary steps to secure adequate passenger movement surveys on a continuing basis through the years.

In the absence of market oriented travel data we must use total reported passenger miles by the various carrier groups to review the present trends. While rail and bus data are available for geographic regions, the boundaries differ for each mode, making the data incomparable.

Some of the conclusions drawn in the report by the Undersecretary of Commerce for Transportation to the Secretary of Commerce in 1956, on a "Program for a Census of Transportation" are (p. 1):

1. Comprehensive transportation statistics are required for many public purposes. They are essential to the conduct of the Nation's commerce, and the administrative and legislative processes of Government.
2. There are serious gaps in presently available transportation data.
3. Comprehensive transportation statistics can be obtained most efficiently through a program which utilizes existing data to the maximum feasible extent, and bridges the gaps by a series of interrelated basic surveys, with provisions for necessary supplemental research and developmental activity.

VIEWPOINTS OF SOME WHO HAVE STUDIED THE PROBLEM

There have been numerous considered judgments made concerning the importance of a nationwide study of some kind.

In the Department of Commerce report of March 1960, summarizing the study made under the direction of Williams and Bluestone, there appears the following statement (p. 9):

i. Census of transportation. This is essential to give shippers, carriers, and Government the same factual basis for policy and practice. It should cover sources of traffic in the manufacturing, agricultural, and extractive industries, as well as common, contract, private and exempt carriers in all modes of transportation. It should show both geographically and by commodity the weights, sizes, volumes, distances, rates, and types of carrier moving the traffic, as well as the reasons for carrier selection. It should be repeated at regular intervals to inform us of trends as they are developing, and to measure the effects of actions taken. Without such a regular census, rational price action by carriers is difficult, as is regulation upon the standards here proposed. Although obtaining facts about their transportation market is primarily a responsibility of the transportation industry, the Government should take action to correct this lack of adequate information.

j. Cost finding. A critical element in rate freedom is the concept of prices based on costs. At present, too little is known about the relative costs of transporting traffic via the several modes and routes typically available to shippers. A comprehensive study should be made to explore the cost-finding methods most likely to afford proper comparisons between the several forms of transport.

The effect of such a study cannot be overemphasized. Improved methods of cost analysis, when applied within a framework of agreed economic standards, will enable the transport industries to set prices and establish services more rationally. Regulatory agencies can then set maximum and minimum criteria rather than specified detailed rates, and the carriers will have the normal managerial initiative of other American enterprises. And the regulated carriers can be equipped to meet the competition of private and exempt transportation where their cost and service capacities permit.

It should be noted that in this report a need for an improved approach to costing is emphasized.

In the report "Program for a Census of Transportation" to the Secretary of Commerce in 1956, appears the following statement (p. 11):

B. NEED FOR CENSUS BUREAU ACTIVITY

Transportation is the blood stream that nourishes and keeps alive and growing the very tissues of our economic welfare and our national security. The significance of adequate transportation statistics is strikingly indicated by the fact that transportation costs represent probably the third highest expense item in production, following only labor and materials. Accurate information about the flow of raw materials and finished products, as well as the transportation media available, enables private enterprise to solve many of its production and distribution problems. In Government, adequate transportation statistics are necessary for responsible agencies to carry out fully their regulatory and promotional functions, and for the planning and programming of national defense requirements.

SOME CONSIDERATIONS IN DEVELOPMENT OF A NATIONAL TRANSPORTATION STUDY

In the concept and planning of a national study of transportation such as is under discussion here, general scope might be somewhat as follows:

(a) The study would be concerned with developing deeper understanding of the nature and factors influencing the movements of persons and goods, which movements underlie the functioning of the national economy.

(b) This means, in turn, that the magnitudes and patterns of travel of persons and movements of goods should be determined and their characteristics studied for all modes of transport, and regardless of whether or not the persons and goods are moved by private or for-hire carriage.

(c) The study would be primarily concerned with the intercity and interregional flows. Among other things, it would enable a delineation of the main flows and corridors of movement, and an understanding of the patterns of intraregional and interregional circulation, as distinguished from local, or intra-urban, or localized rural circulation.

(d) The study should provide not only for obtaining information sufficient to develop a picture of national patterns of movement of persons and goods, per se, but should develop information concerning concomitant economic and social activity which creates the potential or the needs for movement. This would be an important and essential component of a study which is ultimately to provide a basis for predicting transport needs under conditions of changing economy and technology. Knowledge of such factors will be important in order to take into account the effects of shifts in industrial activity, employment patterns, and patterns of commodity utilization by our society together with other information.

Another basic question about which understanding is needed is the relation of the level of economic activity to transport requirements. There are indications that as an industrial society becomes larger and more complex, the volumes of communications and physical transport increase, not linearly, but with some power function. Another question to be considered is whether there is a trend toward regional economies which operate at some level of self-sufficiency, and how this will influence patterns and requirements of transport.

(e) The study should be so designed as to permit some estimation of transport requirements in the future resulting from changes in technology of transport and in communication. For example, what part of physical travel can or may or will be replaced by further use of communication (information and data transmission)? Or, with changing types of fuel utilization, or energy transmission, how will transport requirements and patterns be affected?

(f) An important factor that influences transport decisions are costs, or supposed costs. A comprehensive study should include determination and analysis of cost factors.

Various statements have been made concerning the possible scope of a comprehensive national transportation study.

The 1956 Department of Commerce report on a "Program for a Census of Transportation" proposed for 1958 (although it was never carried out) (p. 2):

> The 1958 program should consist of the following interrelated surveys:
>
> a. Commodity Distribution by Land, Air, and Water Transportation.
> b. Passenger Travel by Land, Air, and Water Transportation.
> c. Truck Transportation Inventory and Utilization.
> d. Bus Transportation Inventory and Utilization.
> e. Air Cargo Commodity Movements.
> f. Experimental Surveys.

A supplemental report by Williams and Bluestone, in connection with the Department of Commerce study, "Rationale of Federal Transportation Policy," goes into a number of aspects of the cost finding problem (pp. 33-39).

The Data Panel of the 1960 NAS-NRC Woods Hole Study reported (p. 60):

> Because of the interdependence between information and understanding, it is necessary that information functions be an intergral part of the assignment of a group whose basic purpose is to understand transport as a whole. Such a group should include physical and social scientists, and representatives of government, industry, universities, labor, and others with interest in transportation and its effects.
>
> For the purpose of understanding the transportation system as a whole, the information functions should include:
>
> (a) the specification of necessary data;
> (b) the formulation of concepts and measurement techniques;
> (c) the establishment of procedures designed to ensure comparability of data where necessary;
> (d) improvement in the accessibility of data;
> (e) provision for coordination of collection and measurement efforts;
> (f) provision of advisory services to other groups engaged in similar activity.
>
> It is important, in discharging these functions, that undue burdens be avoided. The group should not assume statistical and informational functions in the transport field now being performed by other agencies. Where feasible, this group should use existing data-collection resources.
>
> We are aware that accomplishment of the data objectives listed herein would be expensive. Though we are not now in position to estimate such expense, we have little doubt that the improvement in the efficiency of operation of the transport system would vastly exceed the cost of such an effort. Moreover, it is felt that the creation of a data system as indicated would result in the elimination of much obsolete and unnecessary data.

DESIGN AND CONDUCT OF A STUDY

It should be obvious that the design and conduct of a study thoughtfully aimed at the objectives herein set up, could be no offhand enterprise. A period of deliberate ingestion would be a requisite. And the marshalling of support would probably be difficult.

Although some of the features of data collection are obvious, such as origin-and-destination surveys of persons and goods, even the sampling design would require much preliminary thought as well as new techniques.

New ways of summarizing so great a mass of factual information would undoubtedly have to be devised, although expansion of the notion of desire lines could provide a means of illustrating the great major flows on main national corridors. But to develop sufficiently fine-grained summaries of diverse patterns of movement may require considerable ingenuity.

Research would undoubtedly be required in developing the socio-economic side of the picture, although some current types of regional economic analysis may give some sense of direction.

The final step, that of developing an adequate model, or models, of transport activity and its determinants to the point where they can be usable practically for reasonable forecasts, would undoubtedly be a process of iteration and successive adjustment or refinement.

CONCLUSION

A national transportation study, of a type and scope implied in these comments, sounds complicated and difficult. It would be very complex and extremely arduous. But at least it is essential to think and plan in these terms.

Why a Fact Finding Study Should Be Undertaken

E. H. Holmes
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The need for these studies has already been touched upon. Furthermore, it would be most difficult to separate the need for data and the manner in which they are collected; the two are pretty much interrelated.

The previous speaker has mentioned the early study made by the Bureau of Public Roads at the time it prepared a report on toll roads and free roads, and then the later report on the Interstate Highways, which were then called Interregional Highways. It is true that some effort was made at that time to determine a system of highways based on the best economic data that could be found, including a review of all that had been produced by the Census Bureau and any other locatable source. The data studied pertained to such things as agricultural production, industrial production, population, and all of the factors that it was thought might influence highway transportation. These data were then spotted on maps, not with the techniques projected on the screen earlier (reference to the cartographatron), but laboriously and by hand. From this a system was laid out by eye that went through most of the dots.

This method was not as crude as may have been implied. After all, the routes of travel and transportation in the United States have been historically developed from the time somebody started walking from one place to another. There were many topographical, geographical and other features which determined the location of cities as they developed and at the same time developed the lines of communication between them. Sometimes route location was based on the possibility of communication between one city and another.

As transportation developed, the arteries of transportation developed and they in turn induced other population developments. In delineating a system of air travel, which is unfettered and completely free from any topographical or other limitation, a map of the airways of the country showed that these followed just about the same lines as have always been followed.

This interaction is found to persist; which means, to take one of the previous speaker's points, that there is no great advantage in collecting very large volumes of information unless there is some specific use for it, and unless there is fairly certain to be use of it. The method used twenty years ago in laying out what is now the Interstate System in perhaps the most rudimentary manner was dictated by the necessity of furnishing such a system. We were called upon to develop a system of 40, 000 miles, and that is what was done.

The best economic data that could be found were applied in the way that was thought best. The highway system was laid out because the people of the country wanted such a system, and because the President urged it and the Congress voted it. It is now being built.

Many things have happened since then. No longer can the Congress and others be satisfied, especially in other transportation areas outside the highway field, by saying that this is good because this is the way the people want it. It has to be proved that what is being built for the people is needed and is economically sound.

This is found to be true in the cities every day. But certainly it is even truer when one is talking about a national transportation system of the type previously referred to. It must be recognized that the present position requires planning of a system not only for highway transportation, but also for a highway system in relation to other forms of transportation.

Much greater amounts of social, economic and other data are available now than were available 25 years ago. The Bureau of the Census has been collecting data and filing them away. These can be made available. Yet even that is not enough. We have been steadily advocating a census of transportation for many years. One has been authorized time and again, but funds have never been appropriated for that study even though it is broadly recognized that a census of transportation is needed.

So, first of all, there is the job of finding what is needed for wise planning of highways. Also, there will be no relief from all planning once the Interstate System is built. That is when planning will be needed more than ever. It took twenty years (from 1937 to 1956) to get the Interstate System approved and the first real money appropriated. It is not too early to think of what is to be done in 1972 after this present system has been built.

So there is the job of planning ahead in the field of highway transportation, knowing that the planning must be done in full recognition of all other transportation media in the country and the changing uses that will be made of them.

In highway transportation the primary concern is with people moving themselves and their goods around in their own vehicles. Most other governmental agencies that have responsibility for collection and use of transportation data are concerned with organizations that, for a price, are moving other people and other people's goods around in vehicles owned by these organizations. They have the job of regulation, which is an important one. However, the data they need are quite different from that needed in the highway planning field.

No one knows why some people move themselves or their goods as they do; neither does Walter Rainville when he is planning his transit system know just why some people ride on his train systems and some do not. But, that is what he needs to know, not only about people but also primarily about goods. That is where there is a very great lack of information and one which is most important to the future of highway planning.

One last thing should be said about planning a national system of major transportation corridors. One reason the Bureau of Public Roads set up an Office of Planning is that it recognized the importance of this function in the future, to the extent that it was deemed important enough to concentrate the activity of an entire office on that subject without interference from anything else.

A newly established Division of National Highway Planning has as its function exactly what is under discussion. We recognize it, and don't know how to do it; but we are going to call on everyone we can to help us. As highway officials and others interested in highway transportation, we must place ourselves in this broad picture. Also, the Highway Research Board must be placed in this broad picture, with all future work being fitted in with that of many other people. The facilities for which we are responsible must be planned in an analytical manner, and not on an emotional or crude rule-of-thumb manner as has been done in the past.

Fundamentals and Techniques Essential To a Fact Finding Study

J. Douglas Carroll, Jr., Director
Chicago Area Transportation Study

If this study is needed, the problem is one of determining the actual dimensions. Can it be done? What is the state of the art today?

Let it be assumed that an effective study of national, interregional transportation can be measured in the ability of the study to simulate traffic interchanges sufficiently accurately so as to aid and assist in decision-making. This may be arguable, but is postulated as a condition of the study. Now, skipping over the really monumental problems of traffic by ground, by air, by pipeline, by rail and by automobile, and all of the communication exchanges and all of the traffic that pass through the telephone and telegraph lines, and all the potentials of these, concentration is focused simply on the quality of the predictive tools as they are today.

The crucial prediction is one of intercity traffic. However, a strong note of caution should be inserted here. Although there is a feeling that understanding and more accurate description of this factor are coming, there can be overoptimism with respect to this in the matter of national transportation.

There are at least four formulas to describe intercity travel or intracity travel. The first, traditionally called the gravity model, is

$$T_{ij} = k \frac{V_i V_j}{d_{ij}^n} \qquad (1)$$

in which T_{ij} is the travel between points i and j, k is a constant of proportionality, V_i represents the size of some place i, V_j the size of j, d_{ij} is some measure of the distance (cost, time, etc.) separating the places i and j, and n is an exponent that must be determined empirically.

The second is the description of the system developed in Seattle, which is

$$T_{ij} = k \frac{\left(V_i V_j\right)^{1/n}}{d_{ij}} \qquad (2)$$

The third, developed by Morton Schneider, Chief of Systems Research for the Chicago Area Transportation Study, and known as a probability model, is

$$T_{ij} = V_i \left[e^{-\ell V} - e^{-\ell(V + V_j)}\right] \qquad (3)$$

in which e is the base of the natural logarithms, ℓ is a determining parameter used to identify the probability density, V is the total number of trips lying closer to the zone of origin than does the zone of destination, and the other symbols are as previously defined.

The fourth, proposed by John Wardrop of the British Road Research Laboratory and similar to the one used in Toronto, is

$$T_{ij} = \frac{k V_i V_j e^{-\lambda d_{ij}}}{d_{ij}} \qquad (4)$$

in which λ represents a constant of the system, a determining parameter.

Several other models were mentioned by previous speakers. The magnetic field theory is one of these, but the writer is not altogether familiar with all of them.

The four equations are given here to illustrate that many different kinds of functions are being used to describe the rate at which traffic interchange falls off with distance or time or cost. It should be noted that several things of consequence are involved.

In each of the equations the notations V_i and V_j appear. These represent the size of terminal places—cities, regions, nodes, zones, whatever they might be. Therefore, one of the first ingredients is to know what this measurement truly is.

What is the weight of V_i and V_j? Is it population? Is it economic activity? Is it the volume of car ownership? Each investigator has his own special way of describing the volume, or potential, or background pressure at any one point that measures the propensity to generate trips or traffic.

It is also necessary to know what T_{ij} is. In short, what is a trip? This factor also is subject to individual interpretation. If a motorist stops at a service station to get gas, is that the end of one trip? If a person takes a trip from Chicago to Washington by air, is the trip from airport to airport or from home to destination? Is it a series of trips? The point will not be dwelt on except to indicate that the item in which there is interest must have a firm and measurable definition.

Finally, what is the appropriate rate of fall-off or decay? The gravity models and the theoretical problems have been mentioned, but none of these formulas fits a perfect description or leads to things not previously known. These formulas are useful and effective in their description, but none has yet been demonstrated to be a superior model in describing the form of growth or decay. Therefore, we are not yet ready to step up to this next scale—a national transportation study—with confidence.

There is one other point to be made about scale, supplementing what has been said here. As previously mentioned, the Federal Aviation Administration collects all kinds of travel information. Lately, Gene Letendre of the Penn-Jersey Transportation Study, Philadelphia, Pa., has been converting the nation's air flights to map form. Using the special purpose electronic display device called the cartographatron (see pp. 86-108, HRB Bull. 253), he has been drawing pictures of one day's aircraft traffic for the Federal Aviation Agency.

For example, it is known that the jet pattern is the long-distance pattern, but the minute that many data are brought to bear, a much clearer picture emerges. So, too, it is seen that the piston flights are short flights and the turbo-prop flights are of intermediate length. From the "all flights" map the massive pattern of commercial air traffic over the country is seen.

Obviously, at the national scale the interest is in a different set of parameters and different set of problems. The formulas we have been finely "tuning" to describe traffic flows between zones in a city may prove to be quite inadequate for a nationwide study of the intercity movement of people and goods. This is to say that a great deal of work is still needed to reach the required scale.

But I end on a positive note because our "hardware"—our equipment, our muscle power—is substantially greater than it was 20 years ago. We have the capabilities of computers, of automatic devices, of a substantial range of data-collecting and data-amassing systems, and a great deal in the way of new techniques, new strategy, operations research, systems analysis, etc.

So the time is ripe. It would be wrong to promise that we know how to do this job, but it should be done. We should go forward to break into this new scale of traffic analysis.

General Discussion

ALAN M. VOORHEES, Alan M. Voorhees and Associates, Washington, D. C.—I thought that when Dr. Carroll was describing all the various models now being used in urban transportation planning he was going to indicate that the main thing they had in common was that they only used two variables. Maybe this is the trouble. Messrs. Davis and Holmes both seemed to indicate that socio-economic factors are important. However, these are not presently included in the traffic models. Several papers scheduled for presentation at the 41st Annual Meeting of the Highway Research Board indicate the importance of these factors, and it appears that these factors are even more important when involved in intercity travel. Therefore, shouldn't efforts be concentrated on these socio-economic factors in developing national transportation models, as well as on the other factors that are now being used in the traffic models in urban areas?

DR. CARROLL.—That is a tough question to answer. We must first know what causes this massive exchange of people and goods. Then it can be splintered off into air traffic, pipelines, etc., if that is desirable. The additional ingredients which are part of the more refined picture can then be used to better define the massive picture. But the massive picture comes first.

MR. VOORHEES.—There has been a great deal of difficulty in simulating traffic between major cities with the various models that have been described. For example, the travel patterns between New York, Los Angeles, San Francisco and Miami are quite different in nature. Some of this difference is related to seasonal characteristics and some is related to socio-economic characteristics. Therefore, these factors cannot be ignored in intercity travel.

CHAIRMAN HANSEN.—Although that is a different approach, it is aimed at getting a better way of simulating observed events.

ANTHONY R. TOMAZINIS, Assistant Research Professor of City Planning, University of Pennsylvania, Philadelphia, Pa.—I would like to approach this problem from a different point of view. The problem for me is not the kind of data or the amount of data which will be required, but what will be the objective of such a study?

If the objective is simply to predict the magnitude of travel without consideration of human behavior, much trouble will ensue. That is, transportation needs must be projected as a function of human behavior and as a result of the interactions among economic activities. No transportation engineer should come up with a projection of transportation trips 20 to 25 years hence without considering human behavior and economic factors.

We should consider a much larger framework upon which to build before establishing the number and the mode of trips which will be generated in this country, or the length of these trips, or their destinations. There is a tremendous problem here of predicting human behavior and establishing transportation demand in relation to the income and price elasticity of the commodity and the tendencies toward a level of "optimum" transport inputs by type of household, type of activity, areal location, and income level.

Then there is the problem of projecting non-person trips (commodity movements). This implies projection of industrial or regional specialization. Transportation engineers cannot achieve a factual understanding of this subject, hence cannot propose acceptable solutions unless they include in their study group people with other skills or unless a different approach to the subject is established than a strictly engineering study can express. Besides, the problem and the degree and type of industrial specialization which might be favored or penalized by such a transportation study is obviously much broader and more complex than a mechanical projection of trips could denote.

A third problem is measuring the amount or the size of industrial activity in the United States. Even this job is much smaller than the tremendous job of projecting modern industry into the future. The means are not currently available to satisfactorily simulate modern industrial activity. A nationwide study of transportation should, however, be concerned with this problem and make every projection with the implication of this problem incorporated with regard to both the amount and the pattern of commodity movement, as well as the most appropriate or economical future mode of travel.

I am not much concerned with the amount of data and the problems of developing the particular mathematical relationships required to simulate present traffic patterns and, later on, projected traffic patterns. Substantial improvements in existing mathematical models are possible. Inasmuch as rapid improvement of these models has occurred during the past few years, we should be optimistic on the subject. We may even find that there have already been important improvements in some cities. But I would express my utmost concern about the framework on which such a study should be built.

ROBERT T. HOWE, Associate Professor of Civil Engineering, University of Cincinnati, Cincinnati, Ohio. —A possible solution or way of gathering these data was suggested at the 1960 meeting when a representative of the Pennsylvania State Highway Department spoke on their statewide, screenline origin-and-destination survey. Does a possibility exist of throwing substantially simultaneous screenlines in a north-south and east-west direction across each state to intercept all transportation?

MR. HOLMES. —There is at present a Mississippi Valley origin-and-destination survey that has been carried out by a dozen states. I believe it was the brain-child of T. F. Morf of the Illinois Division of Highways.

That seems to be a thoroughly practical way to do it. Good information can be obtained as to what movements are actually taking place. It does seem, however, that in looking into the future, that is only a partial answer to the question. Attempts have been made at various times, without much success, to see if we could infer from that not only what is happening, but why.

We must know why people move their goods as they do, or move themselves as they do, if we are to be able to predict the future. That is why we have had the view recently that it is difficult to get complete information from the field. To know why people move themselves or their goods as they do, one must go to the people who actually buy the transportation. In respect to commodities, that would be the shippers. Person movements by motor vehicles are somewhat different. A person traveling in his own automobile is driving it himself and buying the service himself. One can therefore talk to the purchaser at any place and time.

But with "for hire" transportation one has to go to the shipper to find out why the goods are being moved. That is the thing that concerns us more than anything else.

EDWARD M. HALL, Street Improvement Administrator, City of Phoenix, Ariz. —We are spending vast sums of money in urban areas; money for studies which point to even vaster sums to be spent in cities and elsewhere. There is some discussion as to whether all modes of transportation require the expenditure of these vast sums of money.

The question is: Wouldn't the same effort directed at urban area transportation problems and relationships produce a more urgently needed answer to serve 70 to 80 percent of the people—the urban traveler? Stated another way, would it not be better to tackle first things first?

CHAIRMAN HANSEN. —It is true that urban population includes the majority of the people in the country. Depending on the definition of "rural" and "urban," it can be as high as 76 percent urban.

But the people living in cities do not live on islands apart from everybody else. In the United States they create about three-fourths of the travel on main rural roads. This is a part of the answer to Mr. Hall's question. That is, it is necessary to the whole posture regarding urban transportation that consideration be given to the relationship of each city to the whole.

This is not an endeavor to put the city dweller at a disadvantage and the rural man at an advantage. This is not what will happen. It is the intent to gather information on what is actually going on in the total transportation system comprising a group of subsystems, one for each mode, without discrediting the necessity to study individual components—that is, individual cities and metropolitan areas.

WILLIAM S. POLLARD, JR., Partner, Harland Bartholomew and Associates, Memphis, Tenn. —It has been established that this type of information is needed. I would like to suggest as a possible beginning the listing of the many variables affecting a projection of this type and the definition of their parameters to isolate the problem areas and their interactions. This obvious first step would re-emphasize the need for caution.

Surely it is recognized by all that any such effort would lead to a set of projections of the " if. . . . . , then. . . . . " type. Huge families of considerations would thus be described. Depending on trends or policy, it would be possible to choose from many concepts rather then any one optimal concept. This would avoid the danger of concluding that in the year "X" this Nation is going to be "like so," with reference to these things.

CHAIRMAN HANSEN. —There is no intent to "straightjacket" the uses for results from such a study. In a letter from James S. Burch, Planning Engineer of the North Carolina State Highway Commission, to be presented later, he points out that it would be dangerous to think that a study of this character should eventually lead to greater Federal controls over transportation.

Greater controls, or for that matter any change in control, is certainly not an objective of such a study. The real objective is to obtain new knowledge so that one can, for example, speculate with more certainty as to what alternative situations might produce, if tried. A study of this character provides an inexpensive way to look more closely, more realistically, and more factually into the future. This is the intent behind much of the discussion here.

PAUL W. SHULDINER, Assistant Professor of Civil Engineering, Technological Institute, Northwestern University, Evanston, Illinois. —A brief comment is suggested by these remarks in the matter of feedback of the results of the study, whether it be in terms of policy, pricing, or otherwise, or physical construction on the basis from which projections have been made. This is something we have not been able to do yet in the urban areas. However, it cannot be ignored as an important item in the study proposed here.

THOMAS FRATAR, Partner, Tippetts-Abbett-McCarthy-Stratton, New York, N.Y. — How will the information be used after it is obtained, and to what extent may some of it be simply in the form of wish fulfillments? Take jet transports, for example. A study is made and it is decided on the basis of the best hypothesis that there is a potential for increased travel from one place to another. The airline puts on more flights, and as a result there is more travel.

MR. DAVIS. —The fact that Mr. Fratar has raised this kind of comment is a confession of our national ignorance. If reasonable or rational decisions are to be made under conditions of change in the future, there must be some basis for making a judgment other than political pressures.

One of the fine things about our democratic system is that, having reduced certain kinds of phenomena to a scientific explanation, we can get together and arrive at some compromise in which we decide that this is the way we will do it until something better comes along. We are approaching a condition where such rapid changes are being made in technology, in location of our economies, and the shaping up of regional economies which transcend the single shapes, that these can be expected to have a very large impact on transportation requirements in the next generation.

Preparation should be made for it. The objective is not to tell somebody what to do, but to try to get "one up on" a better understanding of how this phenomenon works, together with the variables that influence it. In a group such as this, concerned with better transportation, there can be no better justification than that it really has a responsibility to society for offering the best kind of judgment, information, and analysis that is possible, because these people derive their living from working in transportation.

The potentials are at hand to improve that understanding. If we simply toss it off, we are negating our responsibility.

JOSEPH KATES, President, Traffic Research Corp., Toronto, Ont.—This is building up toward the proposal of a huge, very lengthy study, a lot of which probably is necessary.

Such a study probably will be used for two quite distinct things. The first is to help make policy decisions on the relative allocations of efforts to different transportation systems and different transportation modes, such as between highways, pipelines, railroads, airlines. That is really the number one transportation problem today in the United States and other countries as well.

To help the government do this, as massive a study as is seemingly emerging here is not necessary. It is not a requisite to picture every highway between every city, and everything in detail. What must be determined is the effect of putting different amounts of emphasis upon these different transportation needs.

That brings us to Mr. Fratar's question. In jet transportation enough data have been collected to tell what the influence would be on travel by jet as a function of just two things—cost and time. As fares are being lowered or raised, on the one hand, or as the supersonic jets are accelerated or slowed, one can determine what amount of travel can be expected.

Rough volume of demand is the first thing that can be determined from such a study. The second is the cost to provide service at different volumes and different speeds. What would be the cost to the aircraft industry? Or what would be the national cost for a reasonable standard of service?

When these two things are known the airline industry might know the optimum volume at which to operate. To go much farther may put the industry in trouble, as it has been in the past few years. If it doesn't go as far, then it might not make as much money and the service might not be as good.

The same thing also holds true for highways and railroads. The first objective of such a study should not be to get a detailed pattern geographically across the country, but just a simple economic study to help decision makers and law makers decide what should be the relative effort between different alternatives. Having determined this for each transportation system (the railways, the highways, the airlines, etc.), subsequent work would then have a target to shoot at.

Then there is the second problem—the design problem—which has been very much in mind during the discussion. How can we now design a U. S. highway network or an international airway network that will fit the demand, the laws, and so forth? How much do we intend to allocate to highways, to railroads, to airlines, etc.

Can the study be broken up into two distinct parts? One, not nearly as large as imagined here, would be a general economic study to help the government get a better insight into the effect of decision-making relative to allocation of effort to various means of transportation. The other, for various organizations interested in their specific transportation methods, would lead to developing data on which to base their design.

MR. CARROLL.—That is a very persuasive statement, Mr. Kates, but it is based on the premise that traffic can be described accurately, which is quite the contrary to what has just been said. If it could be described accurately, there would be the second problem, which is that of assisting someone in making decisions.

This is a question of values, and involves a fairly deep study of those regions in which decisions and values are specified by decision makers. At this stage we are short of this armament and this concentration, because the whole transportation system in the United States is affected by divers regulatory agencies, without clear-cut over-all government policy. There are a number of reasons of this kind. The bulk of all the congressional and other studies has been directed toward this policy arena without effect. Until such time as there is common understanding and a policy-making group which can apply factual estimates, there may be some difficulty in finding a market for the strategy proposed by Mr. Kates.

MR. KATES.—A study might show the government to what extent different transportation systems affect one another and therefore to what extent such a central agency might be necessary. To that extent such a study is needed.

The argument about accuracy is of interest. I gather from Dr. Carroll's remarks about the inaccuracy of various models that he is concluding that we are in trouble.

However, for many economic methods a great deal of accuracy is really not necessary. One must simply show, roughly, directional movements and the relative order of magnitude of what to expect—the movement in one direction or another. For instance, in a number of studies made on pipelines, railways, etc., extremely little accuracy was required to show what effect on railway rates would have in dividing the traffic between the railways and other carriers and what the railway industry and the oil industry should do to avoid increasing transportation costs. We do not have to worry about 20 or 30 or even 40 percent precision.

As a matter of fact, with these large-scale economic studies, which deal with the economy as a whole rather than with fine details, one is much less subject to statistical error.

CHAIRMAN HANSEN.—In support of that point, the graphic material presented earlier in this discussion showed a rough cut at what has been discussed here, and would certainly be of interest to this group, however crude.

MR. DAVIS.—We are not in a position at present to design a national transportation study having the dimensions that have been alluded to here. Many of us sense that in the future this will be possible, but to start thinking about it is imperative, and that is what this meeting is about.

Perhaps a more limited objective, maybe within the Highway Research Board, through cooperative effort of some of the committees, would make possible the development of a prospectus in somewhat finer detail than has been possible here today. We could then argue the justification of whether this part is good or this part is useless.

There might be a period of a couple of years in which the question of what constitutes the useful dimensions of such a study might be discussed.

MR. TOMAZINIS.—There is one good objection to the approach suggested by Mr. Kates. We might be in a better position if we do not approach the problem having in mind only cost and time, a very limited objective.

This might turn out results which could be unrealistic and would be rejected outright as erroneous by many groups in the country. But if the problem is approached with a much larger objective first, and if we outline the areas in which we can go further (if we explicitly outline the means of accomplishing it, if we project what is possible to be projected), then we might be more honest with ourselves and others and would be able to persuade more people, including decision makers.

It has possibly been the tendency of some people to take the easiest way out and, after forming a set of all-inclusive and over-simplified assumptions, to derive conclusions rapidly. In a couple of years most people forget what the original assumptions were and only remember the conclusions. I am afraid that the strategy proposed by Mr. Kates might lead to such a segmentation of the analysis and over-simplification of the problem. It seems the reverse of what was suggested by Mr. Kates might be the best approach to such a study.

MR. KATES.—Mr. Tomazinis apparently has misunderstood: the example I mentioned was cost and time. But what I was shooting for was separate studies in two parts, one providing a basis for national policy without going into detail, and a second providing the basis for design policies for railways, highways, etc. The example given had only two variables, but this was only to make a point.

I agree with him that other variables which have a significant effect on results should be taken into consideration.

L. M. CLAUSON, Chief Engineer, Iowa State Highway Commission, Ames, Iowa (written comment). —Presently, Iowa, together with ten other midwestern states, is awaiting the results of a rural regional origin-and-destination study. The data collected by the eleven-state group is being analyzed by the Bureau of Public Roads for the regional movements. Each state will analyze its own intrastate movements. A similar study should be undertaken in other regions of the United States and later these data from each of the several regions should be correlated with the others.

A study of this nature can provide data for development of transportation facilities which would augment the Interstate Highway System. Private industry should at the same time undertake a similar study that could be correlated with a study of highway needs to provide a complete solution to the over-all problem of transportation.

The know-how of the collection and analysis of the necessary data is available; however, implementation of results of such a study is not available, both as to finance and desire. The recommended solutions should be practical and within an attainable period of time.

WILLIAM R. McGRATH, Director, New Haven Department of Traffic and Parking, New Haven, Conn. (written comment). —The intercity transportation study described in the advance material would undoubtedly be of great value, particularly in formulating over-all national transportation policy. The study will need to be broad enough to make it possible to finish the job, yet with enough detail to provide knowledge of the major travel desires by modes and the means of projection. We probably have sufficient knowledge in the field now to select the correct data collection method and carry it through, but additional research in advance and throughout the study might be needed to determine the best analyses.

Any attempt to patch together results of the many studies of all sorts that have been made all over the country would not be worthwhile other than for the familiarity gained by review. A committee could not undertake a study of this magnitude; it would have to be put forth by some major organization of national scope, such as the Highway Research Board itself, or a special project of the U. S. Bureau of Public Roads, or a Congressional committee. There is no doubt that a large expenditure would be required in the long run.

I foresee a data collection effort similar in magnitude to parts of the census. In fact, the U. S. Census Bureau could perhaps help develop procedures. A direct interview sample spread throughout the entire country might well be the best source of information. Probably it could be handled through the state highway departments. Possibly the HHFA could cooperate with transit study funds, which might be available.

Arbitrary zoning or exclusion of trip areas or persons on the basis of low land use, density, or whatever, would tend to discard in advance much valuable information that might be gained in such a study. Perhaps, instead, it would be possible to develop computer techniques to be operated directly on sample data against control statistics such as land use, density, and so on, and that such computer work might produce guidance for proper zoning and grouping of information.

JAMES S. BURCH, Planning Engineer, North Carolina State Highway Commission, Raleigh, N. C. (written comments). —The justification for such an enormous study is one which cannot be perfunctorily assumed by this committee. Its magnitude and importance is one justifying careful consideration by the Board itself. It should be stressed that all forms of transportation—highway, rail, water, air, pipeline, etc. —are encompassed.

It is apparent that the highway organizations should not be expected to conduct such a voluminous study alone. Although available data do not permit a comparable common denominator of "transportation," it is likely that the motor vehicle accounts for a major portion of passenger vehicle-miles, but a minor portion of ton-miles of movement of goods (even though the vast majority of products use trucks at one or more stages in the industrial production line from raw materials to the ultimate consumer).

It would appear that such an herculean and all-encompassing effort could only be approached by the formation of a national committee, made up of a score of competent, experienced, full-time directors, each drawn from an organization having long experience and voluminous data related to his own phase of transportation (rail, street, highway, air, pipeline, truck, river, canal, maritime, coastal, etc.)

Such men—carefully selected and on perhaps a five-year leave of absence from their present organization—working full time with adequate staff, space, and budget, could assemble, analyze, assimilate and develop the necessary guides in the problem, each calling on branches of his organization to assist in obtaining and supplying basic data.

Although Federal financial support would be appropriate and necessary, other sources of support could and should be solicited and received. The Highway Research Board, under the National Research Council, would be an appropriate parent organization, acting in somewhat the same capacity as in the Illinois Road Test project.

The study itself should not be Federally controlled or directed, to avoid the inevitable accusations of lobbying, party politics, concealment of facts, favoritism toward vested interests, and the like. This, however, would not preclude the service of competent leave-of-absence Civil Service technicians or directors on the research project.

The conduct of the study should avoid the philosophy of complete Federal control of transportation, being limited to that now necessary to avoid monopolies, protect the public interest, etc., as now covered by law. The study should be factual and should be directed toward recommendations to improve services and efficiency, and to lower costs, without excessive new Federal controls, or loss of competition based on private initiative and the profit motive. That this will be difficult is readily admitted. That the basic philosophy be predetermined is, however, of paramount importance.

The magnitude of the undertaking is surely much too vast for active sponsorship by this Committee, or even by the Department of Traffic and Operations. It will have to be a separate, large, and full-time group made up of a large number of competent, experienced directors, operating directly under the Board itself.