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.

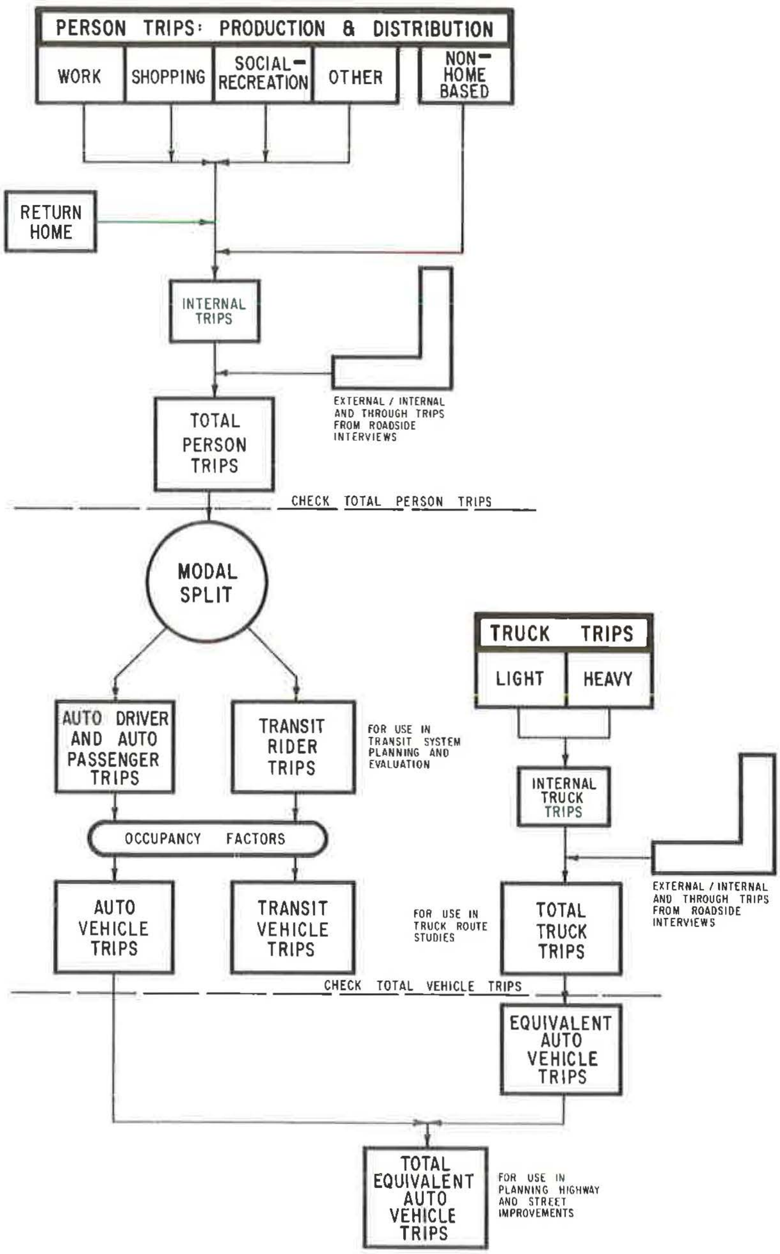


Figure 1. Interrelationships of the Hamilton model components.

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.

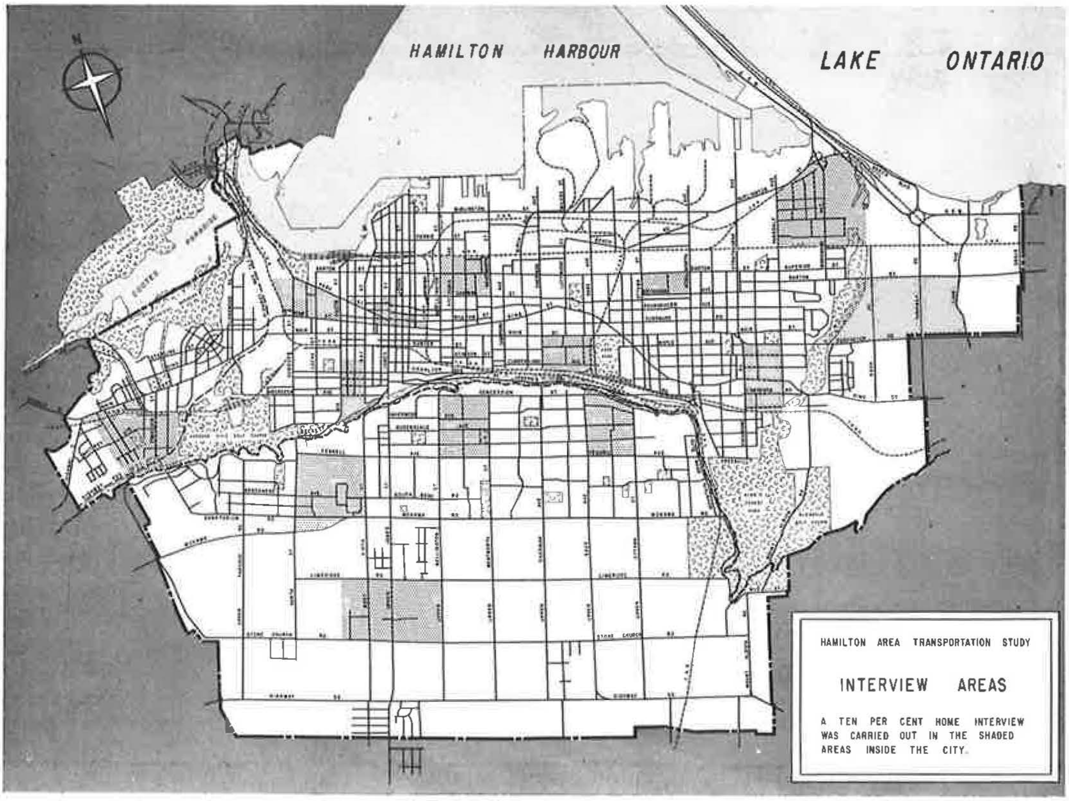


Figure 2.

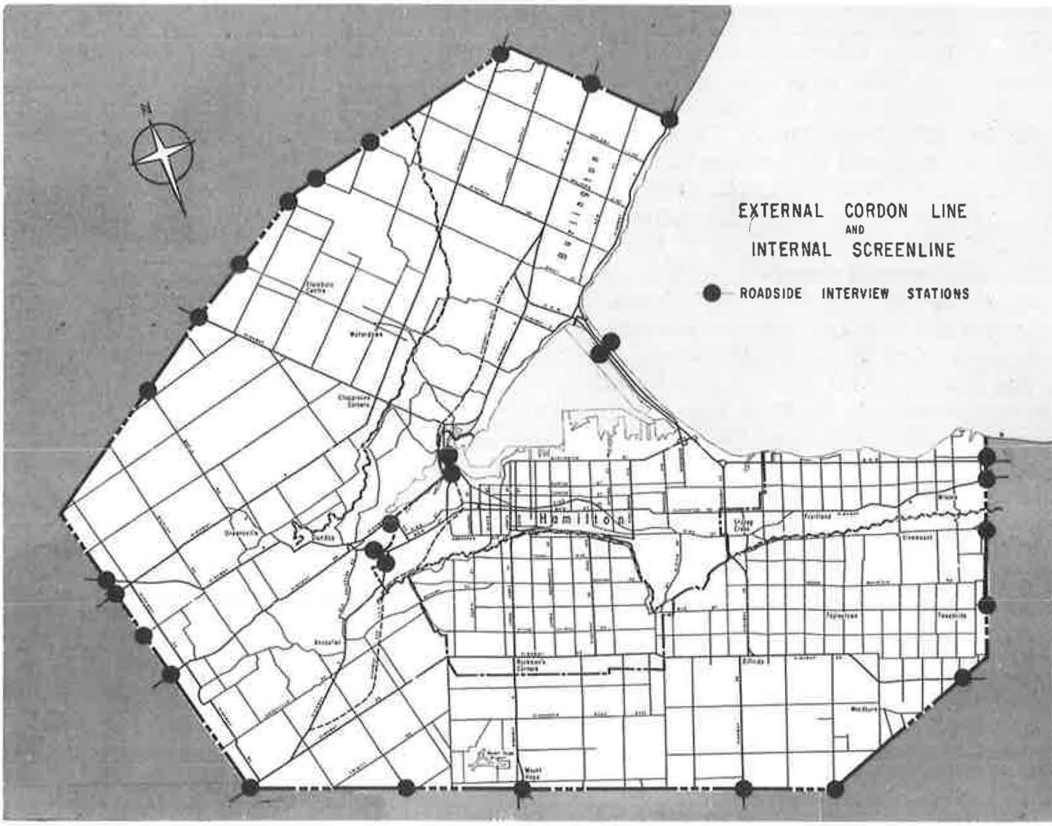


Figure 3.

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

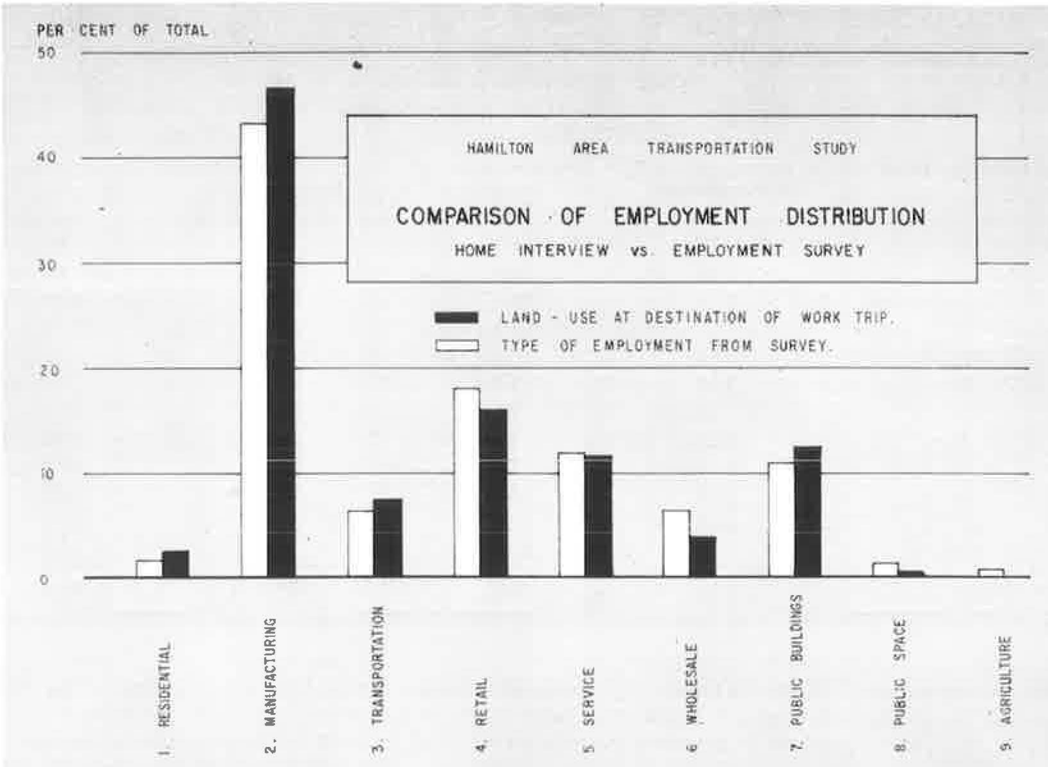
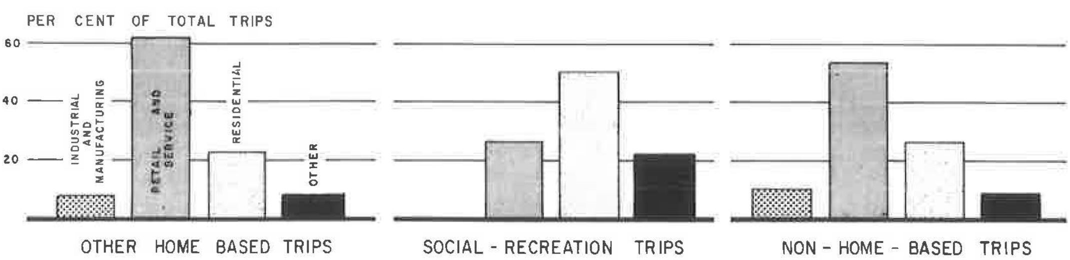


Figure 4.

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

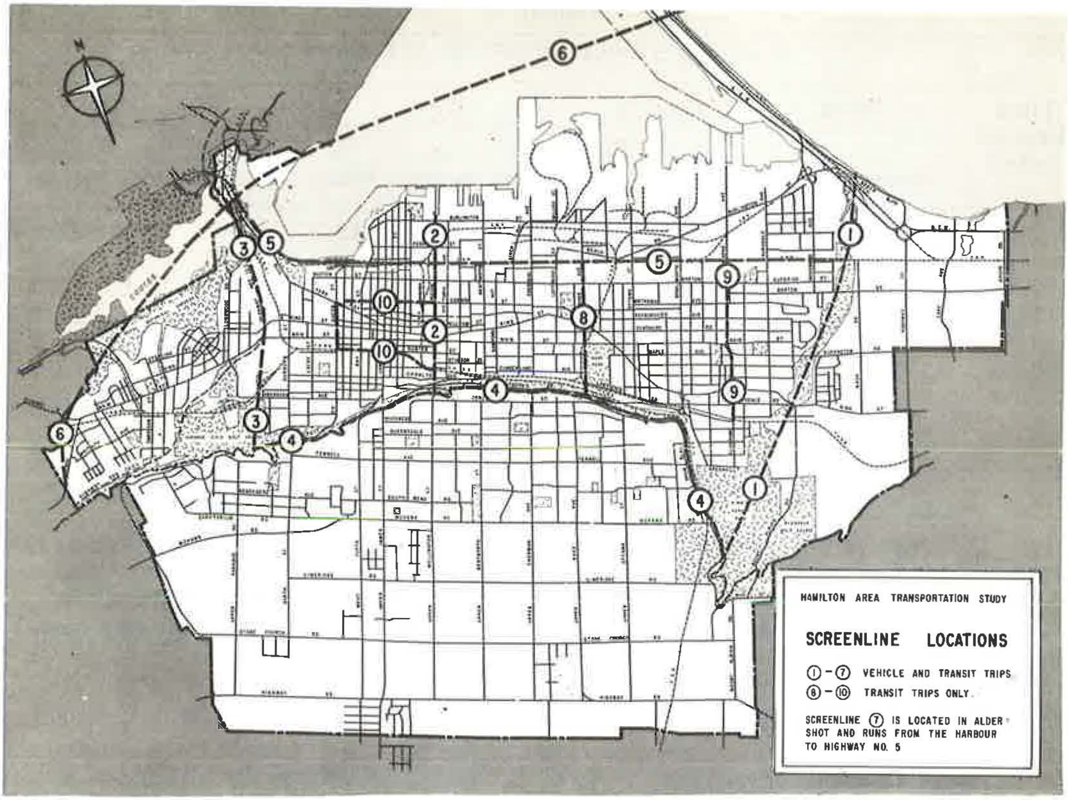


Figure 6.

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.

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

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.

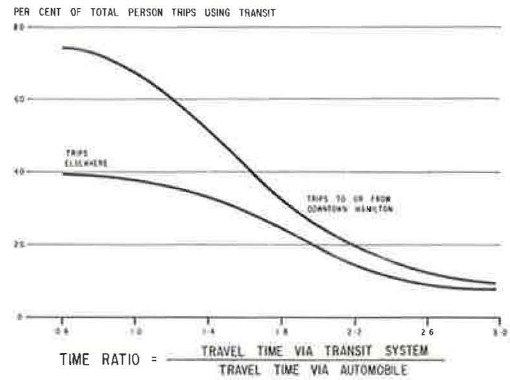


Figure 7. Transit usage inside the city.

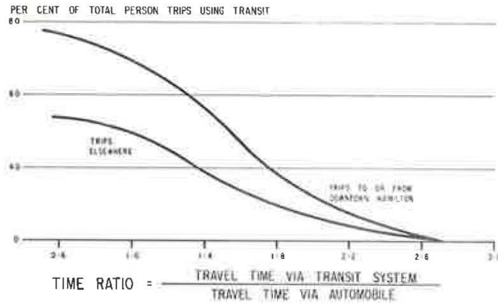


Figure 8. Transit usage suburban area.

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

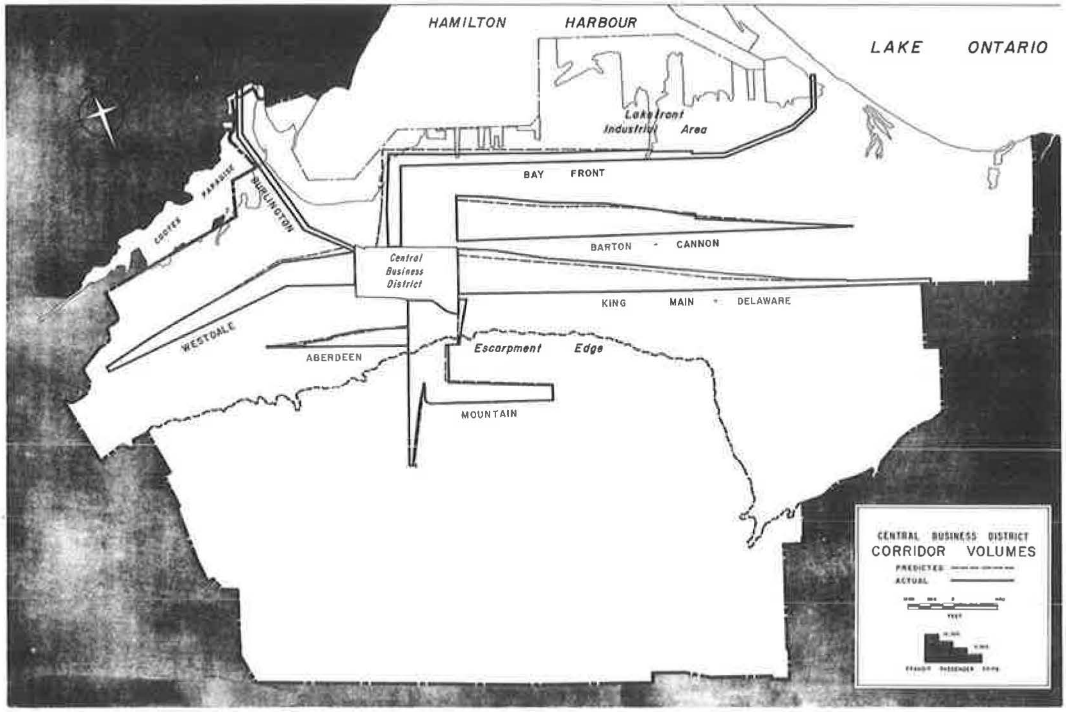


Figure 9.

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

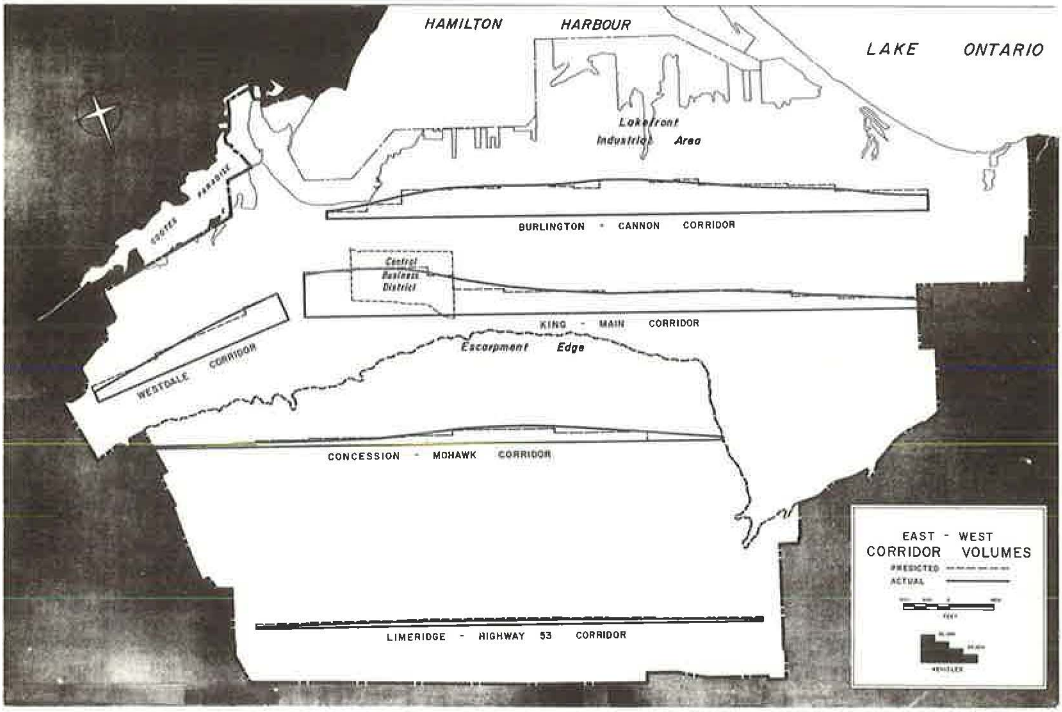


Figure 10.

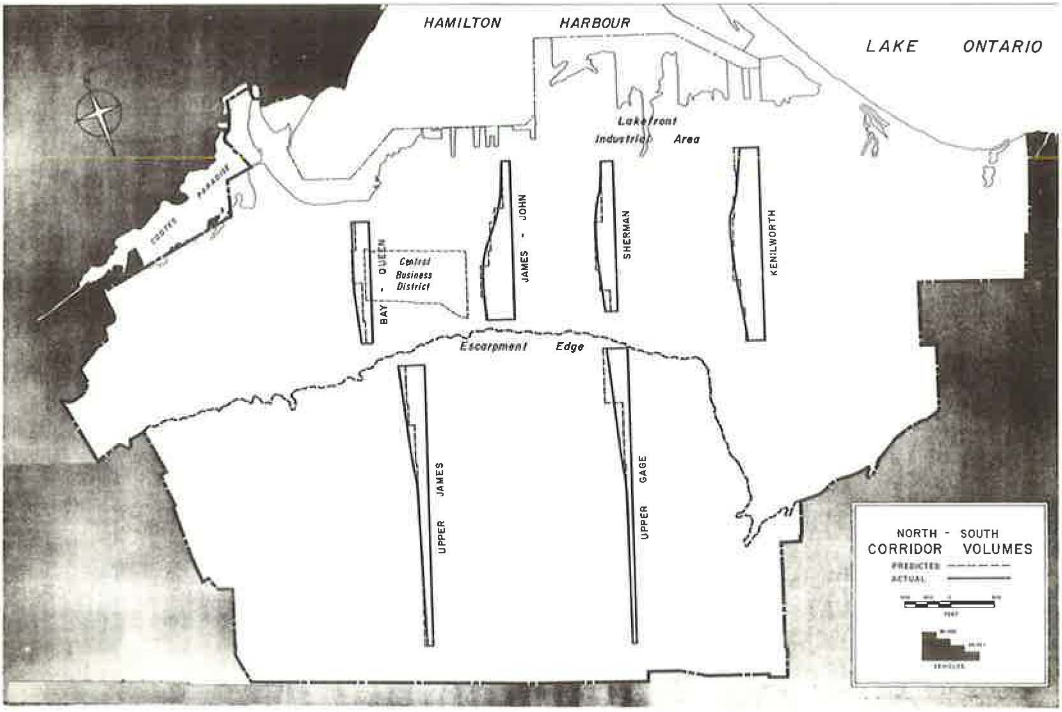


Figure 11.

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