HIGHWAY RESEARCH RECORD

Number 141

Origin and Destination

4 Reports

Subject Classification

55 Traffic Measurements
84 Urban Transportation Systems

HIGHWAY RESEARCH BOARD

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Foreword

The national focus on urban transportation has fostered significant research into this critical problem. The four papers in this RECORD contain information that will be of significant use to those involved in transportation studies, engineers and planners concerned with urban problems, and mathematicians engaged in computer programming and the use of large data masses. Applications of the use of data on trip length, trip purpose, travel motivation, trip-making decisions, and land use are set forth. Census data as a source for urban transportation are also discussed.

Hill and Dodd have analyzed travel trends in the Toronto area over a 10-yr period. Relationships between travel behavior and trip production were studied, and the inherent stability of these relationships was noted. This stability upholds the continued use of origin and destination data as a basis for travel predictions, and of course, the use of these data in the ultimate traffic design of facilities to meet future demands. Decisions as to mode, distance, time, and reason of travel were found to be the principal motivating factors; collectively, these decisions determine travel production.

Factors in work-trip lengths which usually occur at peak traffic periods have been examined by Voorhees, Bellomo, Schofer and Cleveland in a paper based on a NCHRP project. Data from several dozen cities revealed that trip length is chiefly related to the size and structure of the area, the characteristics of the transportation network, and socio-economic factors. Several techniques for estimating future trip-length characteristics are suggested. The value of this paper is enhanced by discussions from several eminent authorities.

The 1960 Census collected information for the first time on the journey-to-work trip, as well as basic automobile ownership facts. Transportation surveys can make extensive use of these data, according to Fisher and Sosslau. More traditional uses are also explained. Improvements, additions and changes in data to be collected in the 1970 Census are suggested.

In the last paper, Shuldiner investigates concepts and procedures currently used in most transportation studies. Despite the three basic categories of procedures available and long experience with some, no unanimity appears. Apparently, no one way is clearly superior, but the best use of all three is furthered by strict attention to the objectives of the analysis and sound basic engineering practice.

Contents

Studies of Trends of Travel Between 1954 and 1964 in a Large Metropolitan Area

DONALD M. HILL, Project Director, Traffic Research Corporation Limited, and NORMAN DODD, Transportation Research Planner, Metropolitan Toronto Planning Board, Toronto, Canada

•SINCE its inception in 1954 the Metropolitan Toronto Planning Board has pursued a progressive transportation planning and research program as one of its many statutory functions (1). Beginning with a worker origin-destination by mode survey in 1954, this was followed in 1956 by a conventional home interview survey (Fig. 1). Both surveys were used to derive travel characteristics of area residents as a first step in the development of a Traffic Prediction Model. The report "The Metropolitan Toronto Transportation Plan for the Year 1980" was published in 1964, and was based largely on the results of traffic prediction studies with the 1956 person travel relationships.

It is accepted practice to assume that the derived travel characteristics will not change so significantly as to invalidate the results of long-term transportation plan studies even where considerable changes are predicted in the social and economic structure of an area. Apart from the suspicions about the predictability of input data there is the question as to the long-term stability of travel characteristics which form the basis of the traffic prediction procedure. Largely because of this fundamental question, a second home interview survey was carried out in 1964 for the purpose of verifying the 1956 travel characteristics (2).

The purpose of this paper is to present some of the comparative results of these surveys to show to what extent the travel characteristics used in the traffic prediction model, which was calibrated to 1956 travel relationships, have changed. Work involved in the analysis of survey data and the development of the model has been undertaken almost exclusively by the Traffic Research Corporation under contract to the Metropolitan Toronto Planning Board.

Sufficient analysis was carried out to validate the travel characteristics incorporated in the traffic prediction model. In fact these analyses are only initial and do not represent, by any means, a comprehensive analysis of all survey data.

URBAN CHANGE 1956 TO 1964

A comparison of travel characteristics obtained from the 1956 and 1964 home interview surveys must, of course, be considered in relation to the socioeconomic changes in the area during this period. It is theorized that the more substantial such urban changes, the greater the likelihood of measurable changes to the 1956 travel characteristics.

Table 1 indicates the magnitude of urban change during the 8-yr period. The population of the study area increased by 33 percent and at an average rate of 56,000 persons a year. Dwelling units increased at a faster rate than population, by 40 percent, and increased the residential acreage by 52 percent. The total acreage of urban development increased from 135 to 170 square miles.

Automobile registrations increased to just over a half million, an increase of 140,000—roughly 38 percent and about equal to the increase in dwelling units, although there is probably no relationship between these two figures. Total vehicles increased by 45 percent.

Paper sponsored by Committee on Origin and Destination and presented at the 45th Annual Meeting.

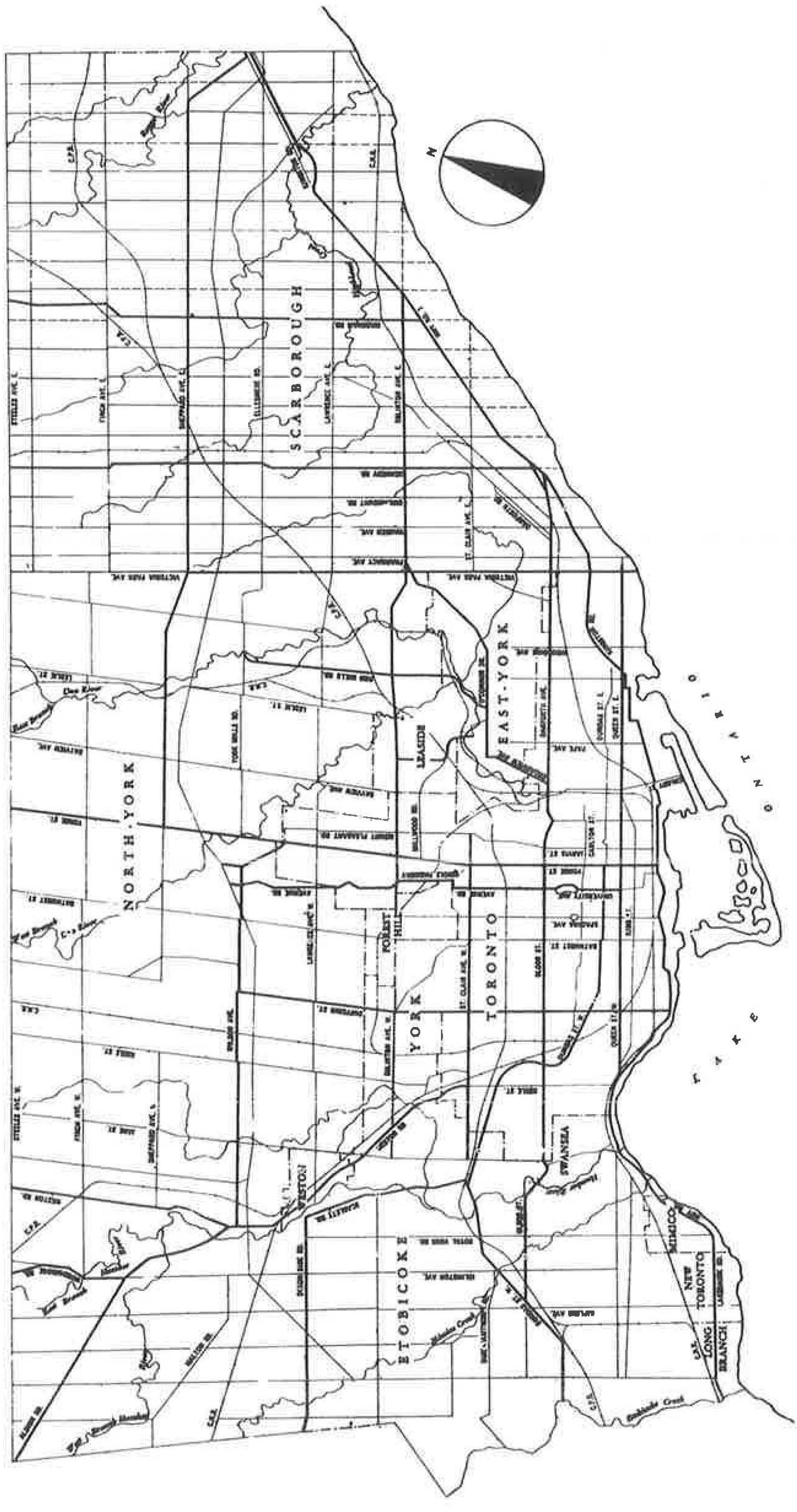


Figure 1. Metropolitan Toronto.

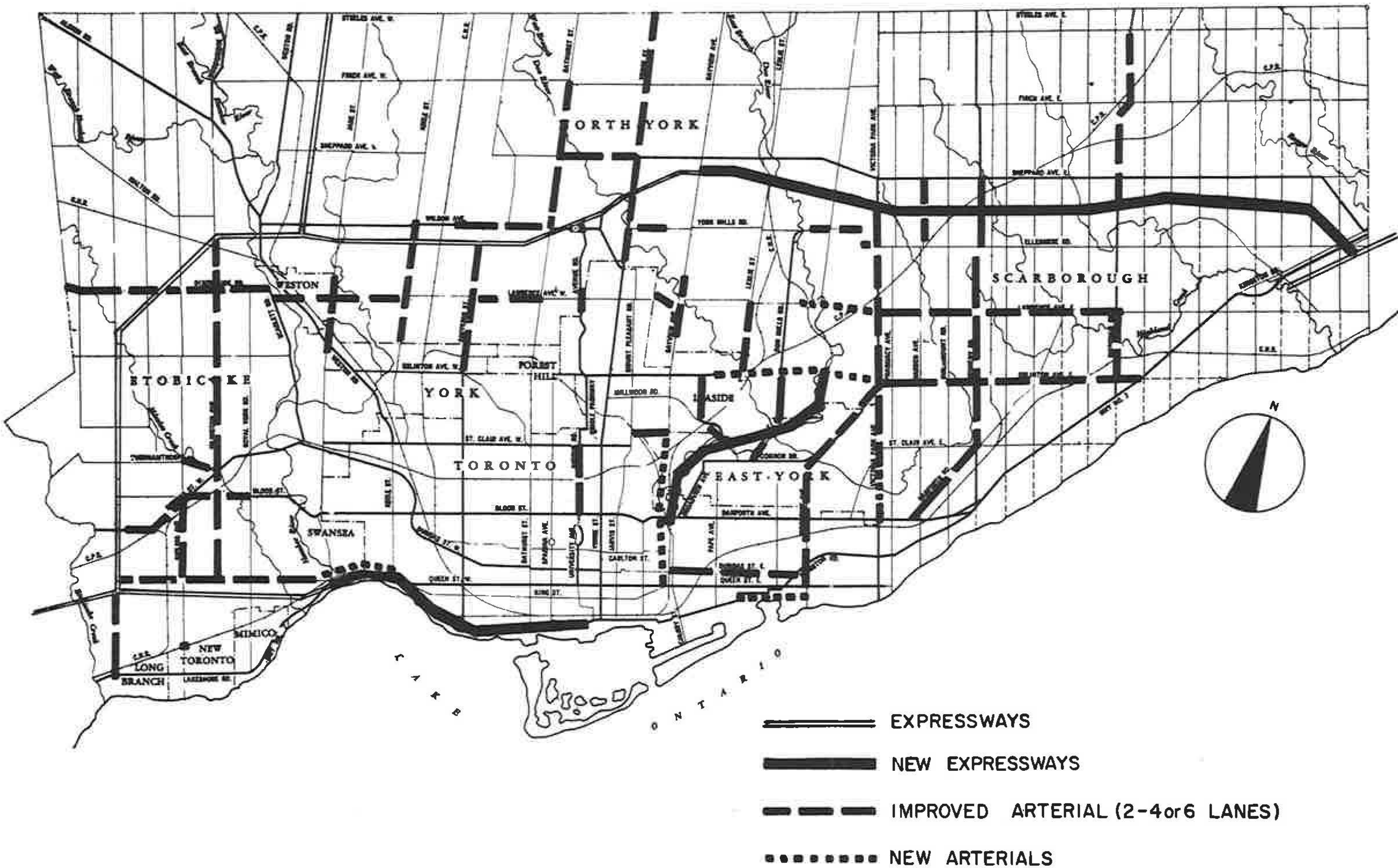


Figure 2. New and improved roads, 1956 to 1964.

TABLE 1

URBAN CHANGE, 1956 TO 1964

Item	1956	1964	± Diff.	Percent Change (rounded)
Population	1,358,000	1,813,000	455,000	+33
Dwellings	342,200	479,000	136,800	+40
Employment	630,200	711,700	81,500	+13
Developed urban area (sq mi)	135	170	35	+26
Auto registrations	363,900	503,600	139,700	+38
Total vehicle registrations	429,300	622,000	192,700	+45
Assessment (billions)	$3.2	$4.6	$1.8	+44
Metro budget (millions)	$82.2	$262.2	$180.0	+219
Expressway miles	26	54	28	+108
Transit annual revenue pass. (millions)	303.8	275.3	28.5	-10
Riding habit, rev. pass/pop	223	160	-63	-28
Transit route-miles	470	595	125	+27
Transit vehicle-miles (millions)	47.0	55.0	8.0	+17
Transit fares (Zone 1)	8 for $1.00	6 for $1.00 (12.5 cents to 16.65 cents)		

TABLE 2

DISTRIBUTION OF POPULATION AND EMPLOYMENT, 1956-1964

Location	1956	1964	Change (1000)	1956-64 (%)	Percent of Metro 1956	Percent of Metro 1964
(a) Population						
City of Toronto	667.6	670.0	+2.4	+0.4	49.0	37.0
Six inner suburbs	241.4	274.0	+32.6	+13.5	18.0	15.0
Six outer suburbs	449.0	869.0	+420.0	+93.0	33.0	48.0
Total	1358.0	1813.0	+455.0	+33.5		
(b) Employment						
City of Toronto	460.2	432.3	-27.9	-6.0	73.0	61.0
Six inner suburbs	68.7	60.7	-8.0	-11.7	11.0	8.0
Six outer suburbs	101.3	218.7	+117.4	+116.0	16.0	31.0
Total	630.2	711.7	+81.5	+13.0		

It has been estimated that during the 8-yr period about $5 billion has been invested in all forms of construction. In 1956 the total budget of the Metropolitan Corporation was $82 million which, by 1964, had increased to $262 million. These figures include $6 million, respectively, for Metropolitan road works. Figure 2 shows new and improved roads, 1956-1964.

The trends in public transit usage have a significant effect on any transportation system. From 1956 to 1964, notwithstanding an addition of 125 route-miles to the system and a 17 percent increase in transit vehicle-miles, the number of revenue passengers decreased by almost 10 percent from roughly 304 to 275 million. Thus, the number of transit trips per head of population decreased from 223 to 160.

Suburban growth has produced significant changes in the areal distribution of population and employment (Fig. 3).

Within the city and inner suburban area there has been only a slight increase in population compared to the 93 percent increase in the outer suburbs (Table 2). The change in central sector employment is even more startling since it shows a substantial decrease of almost 10 percent and an increase of 116 percent in the outer suburban area. This is equivalent to the total increase in employment within the 8-yr period.

These shifts in employment, together with the shifts in residential population, have a pronounced effect on the travel pattern. Preliminary studies indicate that, while trends to the city center have decreased and those to the inner belt have remained stable, the share of the outer area has almost tripled and now practically equals that of the city center. Trips into Metro from outside, while still only accounting for one out

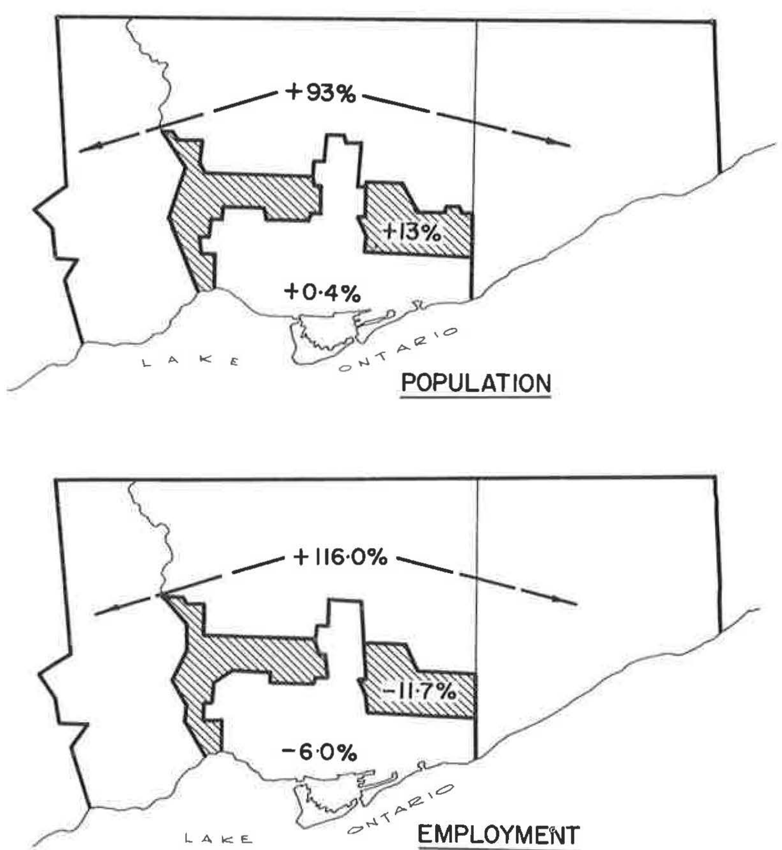


Figure 3. Change in distribution from 1956 to 1964.

of sixteen trips, have almost doubled. Particularly important is the fact that more than one-fifth (21% against 6% in 1954) now move entirely within the outer area.

As a result of these fundamental changes, the old notion that all trips during the morning rush hours are directed from the periphery toward the center has lost its validity. Of all trips, those inbound accounted in 1964 for little more than two out of five trips compared to two out of four trips in 1956.

These figures demonstrate the considerable changes in Metropolitan Toronto which, it is contended, have been substantial enough to influence changes in the 1956 travel characteristics.

TRAVEL CHARACTERISTICS

A research program was initiated to find the relationships between people's motivations to travel and the total production of trips according to the purpose, time of day, duration, method and route of travel. It was recognized that four primary travel decisions were common to the great majority of trips made in the metropolitan area, as follows: (a) Why travel? (b) When to travel? (c) Duration of travel? (d) Method of travel (inclusive of choice of route)?

These travel decisions were highly interrelated (Fig. 4). The purpose for traveling was readily identified with the trip origin and destination and the time of day. Such decisions were also shown to dictate the duration of trip and the method of travel used.

The decisions of why and when people travel appeared to establish the production of total travel during a particular time period of the day. The actual production of trips was highly dependent on the number and characteristics of persons living in each part of the metropolitan area, the number of work places and the number of opportunities for shopping, recreation, etc. Next, the decisions about duration of travel established the distribution of trips between any two particular population and employment centers. Research has shown that the distribution of trips between two centers was directly proportional to the opportunities at each center and inversely proportional to the travel impedances separating the centers. Lastly, the decision about method of travel and the route to follow determined the division of the total traffic between the different transportation modes and routes, such as automobiles, subways, streetcars, buses, or

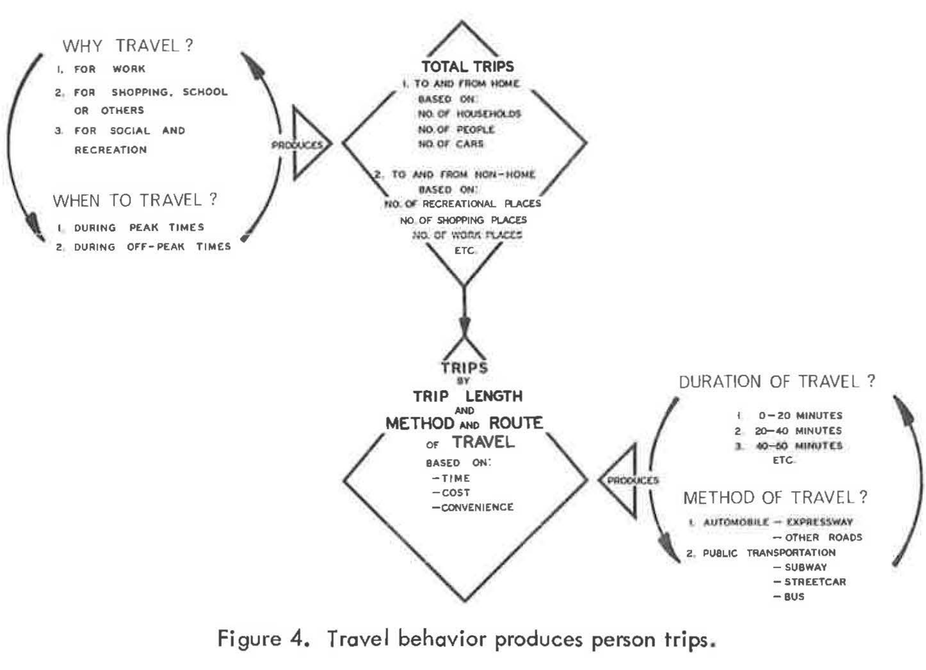


Figure 4. Travel behavior produces person trips.

combinations thereof. Systematic observations have shown that the choice of mode depends on such factors as travel time, travel cost and travel convenience in accordance with the purpose of travel and the socioeconomic status of the traveler.

WHY AND WHEN PEOPLE TRAVEL

The 1964 home interview survey showed that on an average weekday, about 2.5 million trips were made by 1.8 million residents of Metropolitan Toronto. This was 800,000 trips more than reported by the 1956 survey or an increase of 48 percent as compared to the population increase of 33 percent. On a per capita basis this indicates an increase in trip generation per person of 0.1: from 1.3 in 1956 to 1.4 in 1964. This increase does not appear to represent a significant change and would not be considered as indicative of a trend.

Why Travel

The dominant purpose of travel was between home (to and from) and work, as approximately 49 percent of all person trips were made for this reason. Trips between home and shopping, school, personal business or others comprised the next largest purpose for travel. In total, 89 percent of all person trips were home based with at least one end of the trip anchored at home.

The distribution of travel by major travel purpose is based on the data of the 1956 and 1964 surveys (Table 3). The shift between work travel and travel for other purposes during 1956 to 1964 was not significant. The slight shift from non-home based travel to home-based travel was explained by the special refinement of linking serve passenger and change of mode trips to the primary home-based leg of the trip. For example, if two trips are reported, such as one trip from home to serve passenger (school child driven to school) and a second trip from serve passenger to work, these would be combined or linked to form a single trip from home to work, etc. While this procedure was applied with the 1964 survey, it was not adopted in the 1956 survey summaries. Serve passenger and change of mode trips accounted for more than 10 percent of total trips of which approximately two-thirds would ordinarily be classified as non-home based trips, and therefore, should be linked. The removal of the non-home based serve passenger or change of mode trips from the file by linking with the home-based leg of the trip did account for the otherwise apparent shift to home-based travel.

During an average 24-hr period, the number of trips destined for any given area equaled the number of trips leaving that area. There was a distinct directional symmetry of travel associated with the home (Table 4). Of all person trips, 45 percent originated at home and 44 percent were destined to home in the metropolitan area. It was recognized that slightly more travel was destined to work than came home directly from work, while more trips returned from social and recreation to home than went there from home. It was noteworthy that this symmetry of travel appeared to have been maintained during the past 8 years.

TABLE 3

DISTRIBUTION OF TRAVEL BY PURPOSE OF TRAVEL (Daily Travel by all Modes)

Purpose of Travel	1964 (%)	1956 (%)
Between home and work	49	50
Between home and shopping, school, personal business	27	25
Between home and social and recreational	13	12
Total home based	89	87
Non-home based[a]	11	13
Total	100	100

[a]No end at home.

When to Travel

A great variation in travel occurred throughout the day (Fig. 5). The average 24-hour weekday was based on a regular cycle of travel. The peaking of travel in the average morning rush hour was 2.5 times the average hourly travel. In the average evening rush hour, it was 2.7 times the average hourly travel.

TABLE 4

PERCENT DISTRIBUTION OF 1964 TRIPS BY EACH PURPOSE OF TRAVEL[a]

Purpose at Trip Origin	Purpose at Trip Destination (%)							
	Home		Work		Shopping, School, etc.		Social Recreation	
Home	—		25	(26)	14	(13)	6	(6)
Work	24	(24)	3	(3)	1	(1)	1	(0)
Shopping, school, personal business, others	13	(12)	1	(3)	3	(3)	1	(1)
Social and recreational	7	(6)	—		1	(1)	1	(1)

[a]1956 purpose distribution is shown in parentheses.

This cycle had remained approximately stable throughout the decade. There was some evidence, however, that the PM peak period had been extended over a longer time interval. Further, the introduction of evening shopping had resulted in moderate increases in traffic after 7:00 PM.

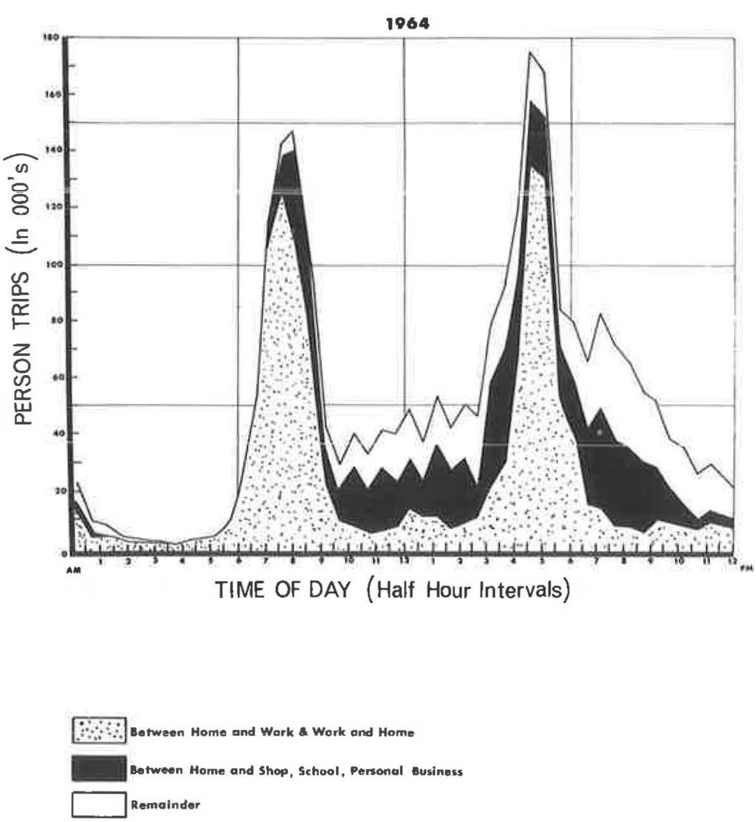


Figure 5. Peaking of travel within the average weekday in Metropolitan Toronto.

Trip Production as Related to Why and When People Travel

The 1964 home interview survey provided recent data on the frequency of travel. A summary of this information permitted the establishment of trip production rates for Metropolitan Toronto. The amount of travel generated by each small geographical area (census tract) was related to the number of people, the number of households occupied, and the number of cars owned by the resident population surveyed. By the statistical method of regression analysis, these relationships were reduced to mathematical equations.

Equation 1

Total Trips Generated at Home on Average Weekday in 1964 to All Purposes = 0.318 × population 5 yrs and older + 0.458 × number of households + 0.890 × number of cars owned (1)

Equation 2

Total Trips Generated at Home During 7-9:00 AM on Average Weekday in 1964 to All Purposes = 0.142 × population 5 yrs and older + 0.352 × number of households + 0.250 × number of cars owned (2)

Both equations showed a high degree of relationship between trips generated at home and the characteristics of the resident population. The correlation coefficient, a statistical reliability measure, substantiated this relationship and showed it to be highly significant. For Eq. 1, the correlation coefficient was 0.98; for Eq. 2, 0.96.

The percent variability associated with each of these equations was generally low (i.e., one root mean square errors as percent of average zonal trip generation) for Eq. 1, percent variability was 13 percent; for Eq. 2, 17 percent.

The coefficients derived for each equation were tested for levels of statistical significance and were found to be significantly greater than zero (i.e., t^2 of coeficients were significant on basis of 95% confidence test).

Applying these equations to a summary (Table 5) of the population characteristics of residents of Metropolitan Toronto, estimates can be made of total traffic produced from home during an average weekday and during the 7:00-9:00 AM period. Typical travel estimates are shown in Figure 6. Close agreement was observed between estimated traffic from Eqs. 1 and 2 and traffic reported by the 1964 home interview

TABLE 5

SUMMARY OF POPULATION CHARACTERISTICS OF RESIDENTS OF METROPOLITAN TORONTO, 1964

Characteristic	Number
Population	1,813,000
Population 5 years and older	1,602,000
Households	479,000
Cars owned	456,000

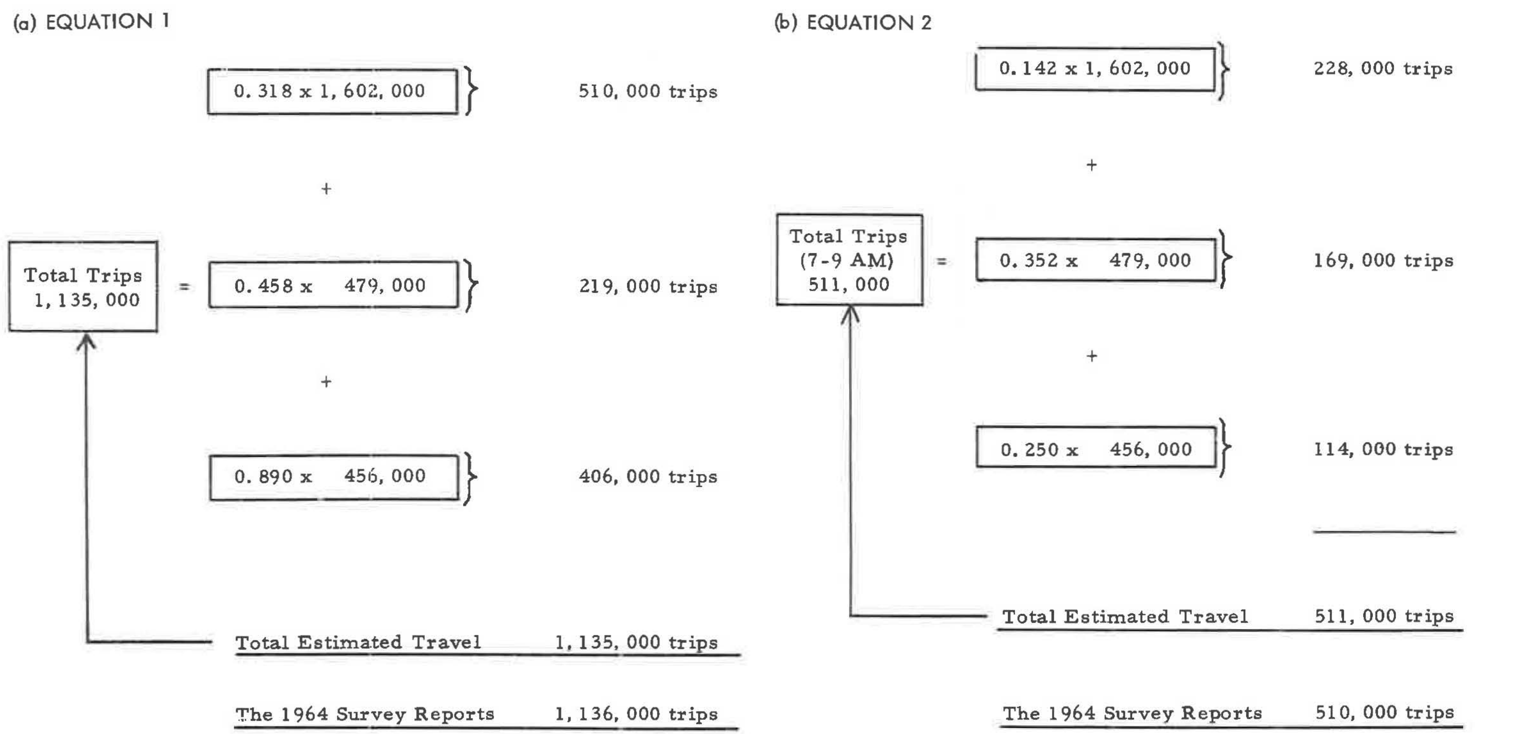


Figure 6. (a) Trips generated at home on average weekday in 1964 destined to all purposes; and (b) trips generated at home during 7:00-9:00 AM on average weekday in 1964 destined to all purposes.

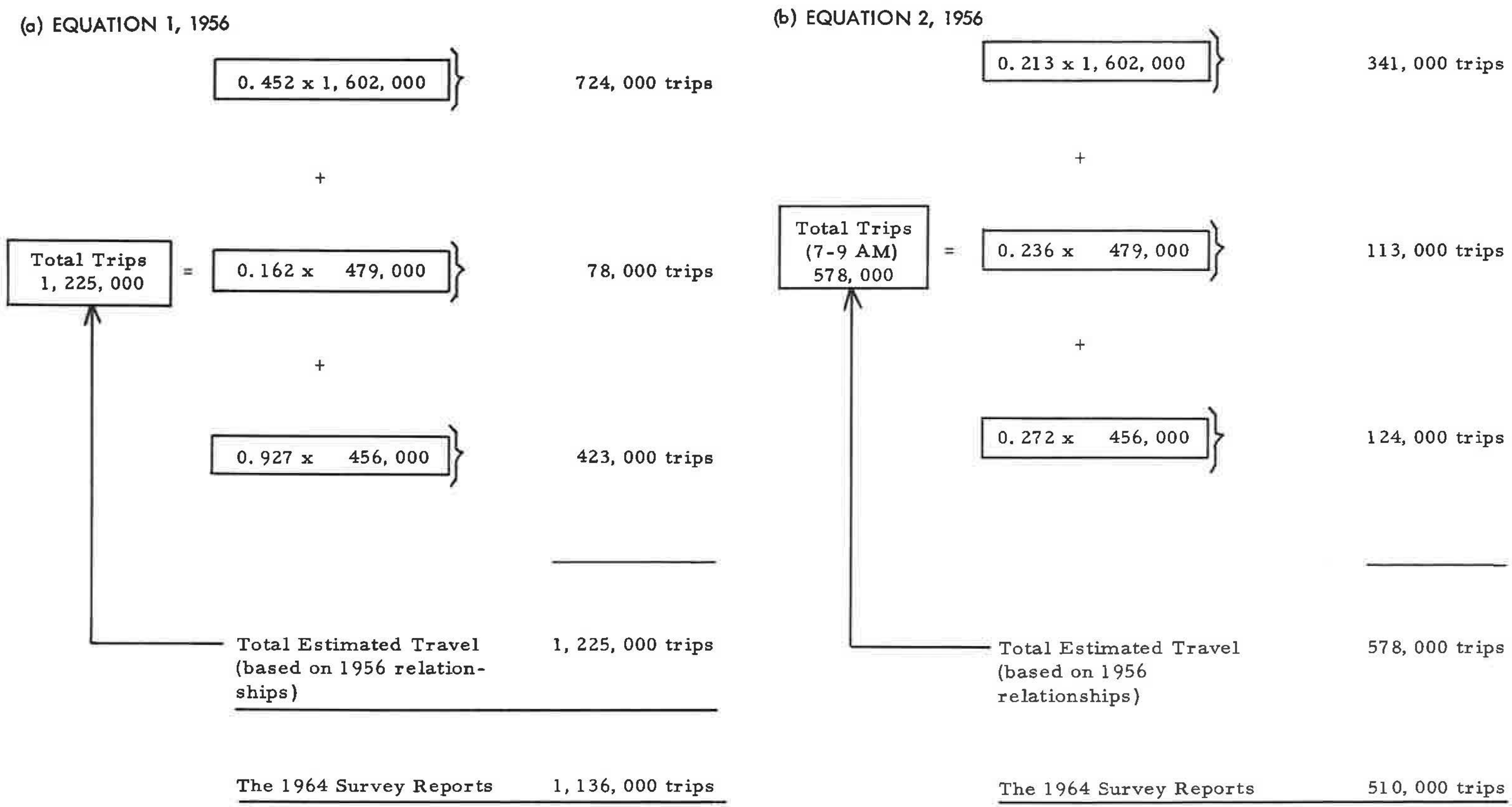


Figure 7. (a) Trips generated at home on average weekday in 1964 destined to all purposes; and (b) trips generated at home during 7:00-9:00 AM on average weekday in 1964 destined to all purposes.

survey. Although not demonstrated here, similar agreement occurred between estimated traffic and survey counts for each of the major trip purposes.

Using the known 1964 population characteristics, travel estimates were obtained from the relationships derived from the 1956 survey (Fig. 7).

A comparison of the 1964 and 1956 equations reveals a change in the coefficients associated with the different household characteristics. The stability of the coefficients associated with cars owned contrasts with the apparent instability of the coefficients associated with population and households. Due to the high degree of correlation between population and households, regression analysis techniques are likely to assign widely varying coefficients, based on different samples of data. This instability of the coefficients is not considered critical, providing it occurs between highly correlated variables. The stability of the coefficient associated with car ownership is deemed important however, and it appears to exist between 1956 and 1964. The slight decrease in this coefficient is not considered significant. A comparison of Figures 6 and 7 indicates that the 1956 relationships overestimate the actual 1964 traffic by 90,000 and 68,000 trips for the all day travel and AM peak period travel, respectively; i. e., by approximately 8 percent for all day travel, and approximately 13 percent for the 7:00-9:00 AM period. The reason for this overestimate is in the 1956 estimating equation for home-based trips destined for shopping, school, personal business and others during the

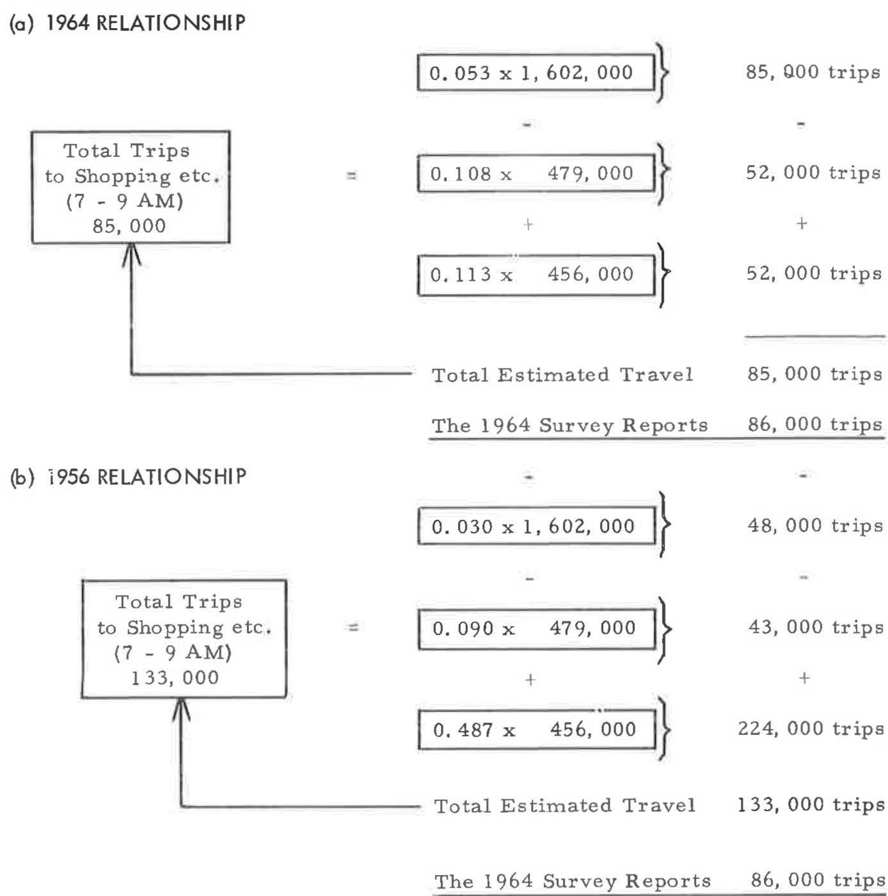


Figure 8. Comparison between 1964 and 1956 relationships to estimate home-based trips to school, shopping and personal business from 7:00-9:00 AM on an average weekday in 1964.

7:00-9:00 AM period. A comparison is made in Figure 8 between the 1964 and 1956 relationships used to estimate home-basedtravel to shopping, school, personal business and others during 7:00-9:00 AM, basedon the 1964 population characteristics.

An overestimate of close to 47,000 home based person trips to shopping, school, personal business and others during 7:00-9:00 AM was disclosed by using the 1956 estimating relationship. This accounted for the majority of the overestimated trip production and it appeared due to a failure to link serve passenger or change of mode trips to the initial home based leg of the trip in the derivation of the 1956 relationships. Over 50,000 person trips during 7:00-9:00 AM were reported in the 1964 survey to be home based and destined to serve passenger or change of mode purposes. By combining the majority of these with their non-home based work leg of the trip, a reduced count of trip generation for other purposes was developed from the 1964 survey. As this procedure was not followed in 1956, an excessive "others" trip estimate would be produced by the 1956 equation.

The production of AM peak work traffic from the 1956 and 1964 equations is similarly based on 1964 household characteristics. The understatement of work trips in 1956, due to the omission of the unlinked home to serve passenger to work trips from the work file, appeared compensated by the higher labor force to population ratio in 1956 than in 1964 (i.e., 0.46 in 1956 versus a ratio of 0.41 today). Accordingly, it is understandable that the 1956 equation reproduces the 1964 work traffic correctly.

Due to the symmetry of travel to and from home, identical equations described the traffic destined to home and its relationship with the household characteristics. Thus the findings applicable to travel originating at home may be assigned equally well to traffic destined to home.

The relationships between non-home based trip production and employment characteristics did not change significantly between 1956 and 1964. The number of trips generated or destined to work opportunities was directly related to the amount of the employment in each area. This relationship attributed 95 percent of the production of these trips to the total employment and the remaining 5 percent to the population in the area. All trips originating or destined to places of shopping, school and personal business were strongly related to population centers and centers of retail and service employment. Social and recreation trips appeared to originate and be destined to retail and service employment, and to residential centers with equal frequency.

DURATION AND METHOD OF TRAVEL

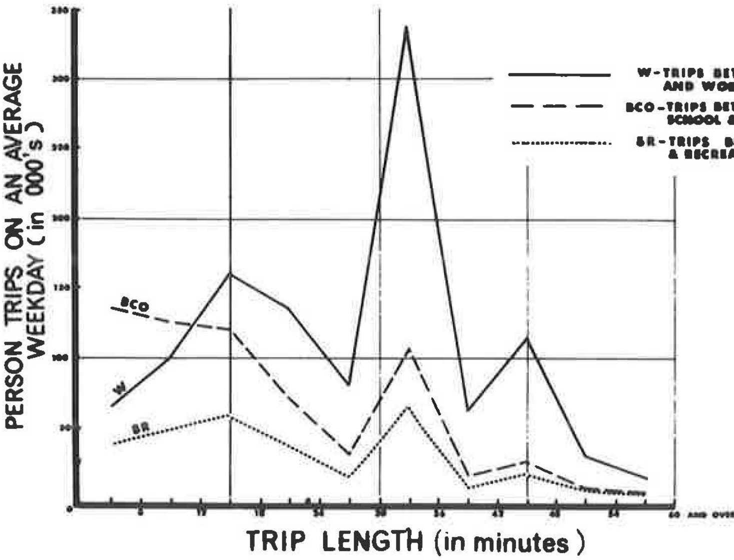
Average Trip Length

The frequency of travel on an average weekday varied with the trip time, and generally, trips of long duration were made infrequently (Fig. 9). Trip frequency generally appears to decline with increasing trip duration. The influence of trip purpose is clearly discerned. The necessity of travel to work was shown by the fact that longer trips were made more frequently, the average trip time being 30 minutes. Shopping, school and person business trips as well as social and recreational trips averaged approximately 15 minutes.

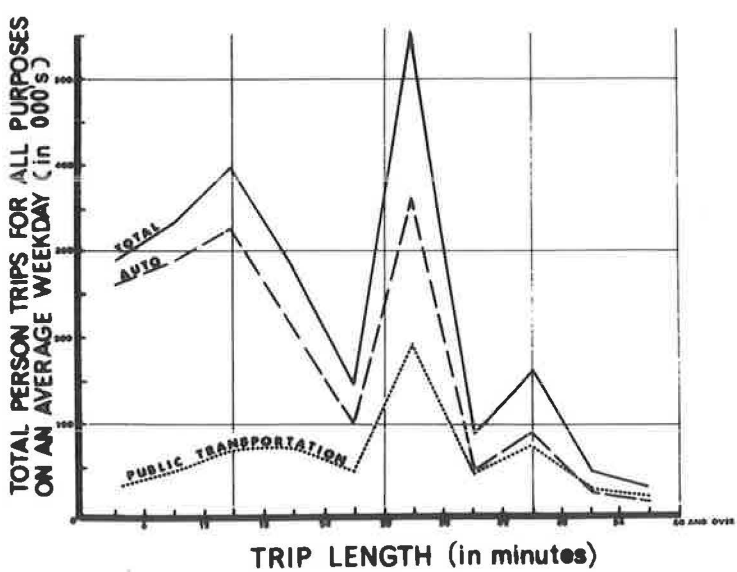
The method of travel was recognized as influencing the relationship between trip frequency and trip time (Fig. 9). While the average trip length was 20 minutes for motor vehicle trips, it was close to 30 minutes for transit trips.

Investigation of the relationships between frequency of travel and the trip length (Fig. 10) disclosed general agreement between the findings of the 1964 and 1956 surveys. People appeared to spend approximately the same time traveling in 1964 as they did in 1956. When the basic relationships were compared in relative manner, similar findings emerged. Table 6 gives the relationships between the accumulative trip frequency observed for each year and the trip length in minutes. The differences observed were small, and were generally considered insignificant.

The findings were particularly significant when one recognized the accelerated development of suburban areas in Metropolitan Toronto and the improvements in transportation made during 1956 and 1964. Time spent in traveling appeared to have remained stable, in spite of the increased numbers of people living in suburban areas



(a) ACCORDING TO PURPOSE OF TRAVEL



(b) FOR TRAVEL BY EACH MODE

Figure 9. Relationship between trip frequency and trip length.

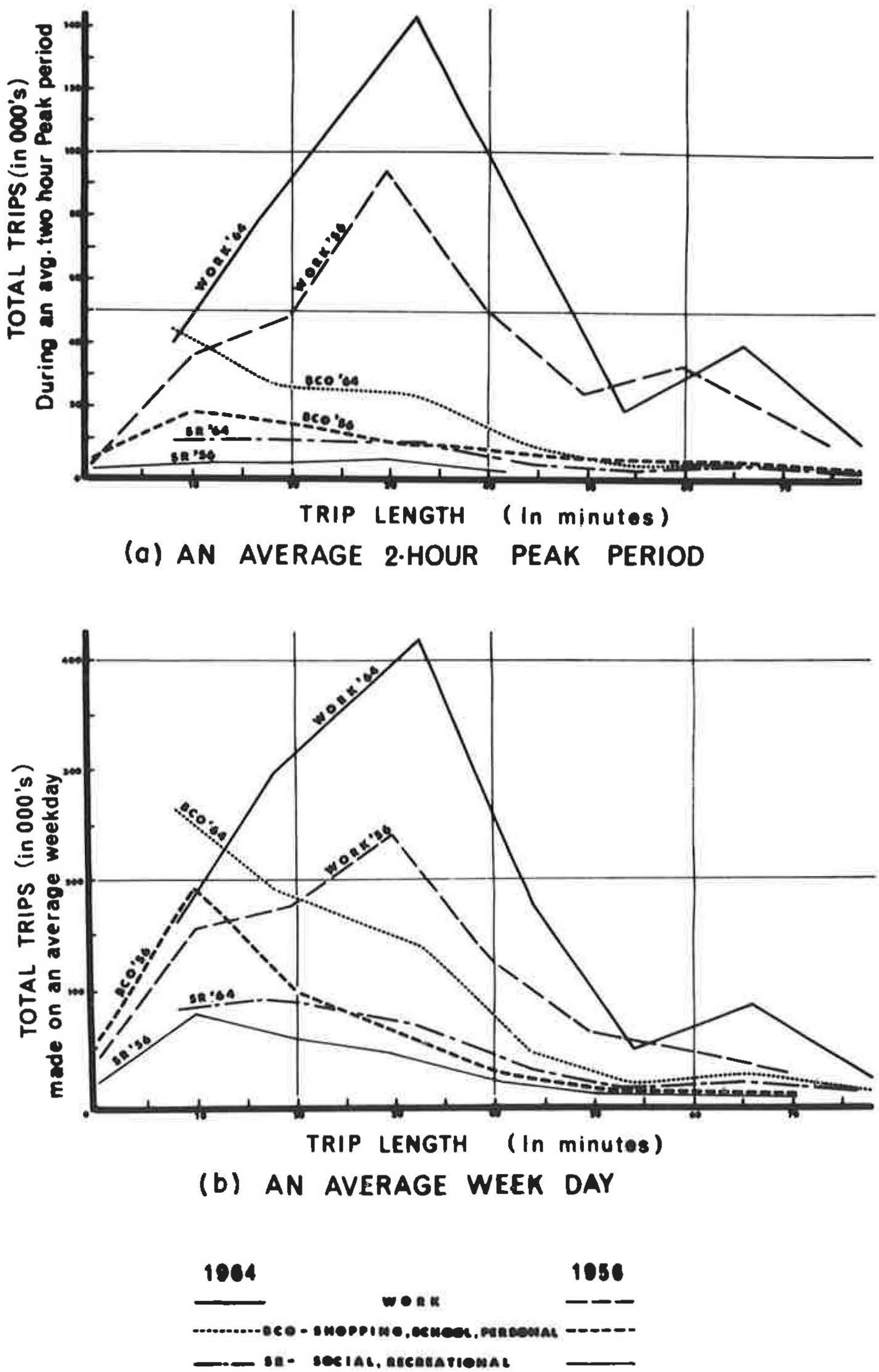


Figure 10. Comparison of the relationship between total trips and trip length.

TABLE 6

ACCUMULATIVE PERCENTAGE TRIP FREQUENCY VERSUS TRIP LENGTH

Trip Length (min)	Work (%) 1956	Work (%) 1964	B.C.O. (%) 1956	B.C.O. (%) 1964	S.R. (%) 1956	S.R. (%) 1964
(a) Trips All Day						
10	15	15	40	35	30	25
20	20	20	25	25	25	25
30	25	25	15	20	20	20
40	15	20	5	5	10	10
50	10	10	5	5	5	10
60	10	5	5	5	5	5
Over 60	5	5	5	5	5	5
Acc. %	100	100	100	100	100	100
(b) Trips in Peak Period						
10	10	10	30	30	20	20
20	15	20	20	20	20	20
30	30	30	15	20	20	20
40	20	20	15	15	20	20
50	10	10	15	10	10	20
60	10	10	5	5	5	—
Over 60	5	5	—	—	5	—
Acc. %	100	100	100	100	100	100

distant from the CBD area. It was expected that the transportation improvements had permitted higher speeds of travel over longer distances. Hence, it was perhaps not surprising that the average trip lengths had remained relatively constant.

Distribution of Trips as Related to Trip Length

The number of trips between any two zones for a particular trip purpose was considered to be dependent on the total number of trips generated for distribution at the trip origin (G_i), the total number of trips attracted to the destination (A_j), and the travel friction or impedence between the origin and destination as measured by the time factor (TF_{ij}).

The following formula was applied to describe this relationship, and hence to determine the trips distributed between each origin and destination zone:

$$J_{ij} = KG_i A_j TF_{ij} \qquad i, j = 1, \ldots, N \text{ zones} \tag{3}$$

where

J_{ij} = number of trips leaving origin i for destination j for the purpose in question;

G_i = total trips generated at origin i for this purpose;

A_j = total trips attracted to destination j for this purpose;

TF_{ij} = time factor for trips made between origin i and destination j for this purpose, that is $e^{-BT_{ij}}$; where B = parameter to be determined, e = 2.718, and T_{ij} = travel time between i and j.

TABLE 7

PERCENT MOTOR VEHICLE RIDERSHIP BY TRIP PURPOSE

Major Trip Purpose	Motor Vehicle Ridership (%)	
	1964	1956
Between home and work	63	54
Between home and shopping, school and personal business	74	71
Between home and social and recreation	84	74
Total purposes	72	60

The constant K in Eq. 3 is an adjustment factor so that the following equalities are satisfied:

(a) Total trips leaving origin i equals total trips generated there; i. e.,

$$\sum_{j}^{N} J_{ij} = G_i$$

(b) Total trips arriving at destination j equals total trips attracted there, i. e.,

$$\sum_{i=1}^{N} J_{ij} = A_j$$

Eq. 3 is well known as "gravity formula," so called because of its similarity to the formula derived by Newton to describe gravitational attraction between two masses (3). All necessary parameters associated with Eq. 3 were first derived from the 1956 home interview survey in Metropolitan Toronto. During December 1964, the basic gravity formula was reestablished with the 1964 home interview survey data, for the AM travel period.

This basic formula (Eq. 3) was reestablished for each of the major trip purposes, i. e., (a) trips between home and work; (b) trips between home and shopping, school or personal business; and (c) trips between home and social recreation. The gravity formula was premised on the relationship between the frequency of travel and the length of travel (in minutes). It was this relationship which described the influence of travel friction on trip distribution and hence established the value of the parameter B of the gravity formula (Figs. 9 and 10).

An analysis of the gravity model formulation resulted in the following findings:

1. The time factor associated with travel to work would be based on B parameter value as established from the travel in 1956; and

2. Time factor associated with travel to other purposes would be based on B parameter value from the 1956 survey.

Choice of Method of Travel

Table 7 shows a significant trend in the use of the motor vehicle as opposed to public transportation. Although little change had occurred in the travel pattern established for shopping and personal business, the increased use of the motor vehicle for work and recreational travel had resulted in an overall increase in motor vehicle usage of 12 percent since 1956. This increase was probably attributable to the rapid rise in the socioeconomic conditions and shifts of the population to suburban and low-density centers.

Approximately 70 percent of all person trips made by private motor vehicles were made as drivers. Thus the average number of persons per car was approximately 1.4, which agreed with the average car occupancy of 1.4 observed in 1956.

Travel Mode Split—Relationships

People are influenced by many factors in their choice of travel mode. These factors will be characteristic of the relative travel time, travel cost, regularity and convenience of service, the socioeconomic status of the population, and trip purpose. Using graphical analysis methods, the influence of each of the factors was investigated separately and trends in transit usage were established.

The comparative advantages and disadvantages of each of the two major types of travel mode (public transportation and the private automobile) were measured by the time, cost and convenience criteria. Other criteria, such as economic status and the trip purpose were considered to affect user reaction to the first three criteria. On the assumption that there were two primary travel modes, it was the intention to distinguish between that freedom of choice of routes and schedules offered by the automobile as opposed to the fixed routes and schedules imposed by all forms of public transportation. Accordingly, railway, subway, bus, and streetcar were all considered facilities of the public transportation mode.

The travel modal split relationships were derived in the form of diversion curves (4). The diversion curves demonstrated in quantitative form how the propensity to travel by public transit as opposed to travel by private automobile was related to five basic determinant factors:

1. The ratio of door-to-door travel time via public transit to the door-to-door travel time via private automobile;
2. The ratio of out-of-pocket cost via public transit to out-of-pocket cost via private automobile;
3. The ratio of excess travel time via public transit to excess travel time via private automobile (this ratio is a measure of the relative level of travel service and convenience);
4. Economic status of trip maker; and
5. Trip purpose.

These factors are described as follows.

$$\text{Travel time ratio} = \frac{TQ + WKQO + WKQD + WQ + TR}{TV + WKVO + WKVD + WVO + WVD} \quad (4)$$

where

TQ = time en route in transit vehicle;

WKQO = time spent walking from trip origin to transit vehicle (D refers to destination);

WQ = time spent waiting for transit vehicle;

TR = time spent transferring between transit vehicles;

TV = time en route in private automobile;

WKVO = time spent walking between trip origin and parking space;

WKVD = time spent walking between parking space and trip destination;

WVO = parking delay time at trip origin; and

WVD = parking delay time at trip destination.

$$\text{Cost ratio} = \frac{FR}{[CF + CO + (PKO + PKD)/2]/NPPV} \quad (5)$$

where

FR = transit fare;

CF = gasoline cost (gallons/mile × distance × cost/gallon);

CO = oil change and lubrication cost (cost of oil change/mi × distance);

PKO = parking cost at origin of trip;

PKD = parking cost at destination of trip; and

NPPV = number of passengers per vehicle.

$$\text{Service ratio} = \frac{WKQO + WKQD + WQ + TR}{WKVO + WKVD + WVO + WVD} \qquad (6)$$

Economic status is expressed in median income per worker, and trip purpose is described individually or in combination. Different sets of diversion curves were used for each trip purpose.

There were 80 diversion curves for each trip purpose. The diversion curves demonstrated the relationships between transit use and the travel time ratios for each of 4 levels of cost ratio, for each of 4 levels of service ratio and for each of 5 levels of economic status (4 × 4 × 5 = 80).

Basic modal split relationships for travel to work were established from the 1954 worker survey and the 1964 home interview survey. These relationships described the correlation between transit use (as opposed to automobile use) and the travel time ratio for each of 5 levels of socio-economic status, 4 levels of cost ratio and 4 levels of service ratio.

The 1954 and 1964 relationships were compared for similarities in ridership habits of the public. Direct comparison of the relationships for 1954 and for 1964 was possible on account of identical procedures of derivation. Also, both sets of relationships were derived for worker income ranges expressed in terms of the 1961 cost of living index (income ranges expressed in 1961 constant dollars). The similarities and dissimilarities between the relationships are shown in Figures 11 and 12.

Based on this evidence, it was concluded that the basic relationships developed from the 1954 survey data were still applicable in the planning process but for the following exceptions:

> Middle income workers appeared to demonstrate a declining preference to ride transit over 10 years, as it became less convenient in comparison with motor vehicular travel. This decline in preference for transit occurred when the transit excess travel times exceed auto excess times by at least one and one-half times. The decline seemed to occur both for cheap and expensive travel by transit.

Provided the transit service was convenient, i. e., when the walks, waits and transfer times on transit were not more than one and one-half the walks and parking delays in motor vehicular travel, people in 1954 and again in 1964 appeared to demonstrate similar preference for transit ridership. Differences for 1954 and 1964 did not exceed 5 percent and hence were generally insignificant. The difference in ridership on less convenient transit between 1954 and 1964 was as high as 30 percent ridership and therefore appeared significant.

The design of the 1964 survey permitted an analysis of the captive ridership on both public transportation and the private automobile. Approximately 56 percent of transit riders who traveled to work could be classed as captive, in that they did not have a driver's licence or no car was owned by the members of the rider's family. In comparison, close to 40 percent of the automobile drivers going to work could be rated as captive, since they indicated their automobiles were necessary in the conduct of their work. Due to the similarity of these captive rates, and the expected close correlation with worker's incomes, the continued use of composite deversion curves (for captive and non-captive riders) seemed justified.

Choice of Travel Route

Route assignment is a term applied to the method of calculating the number of vehicles or persons that would use a given transportation facility under certain given travel conditions.

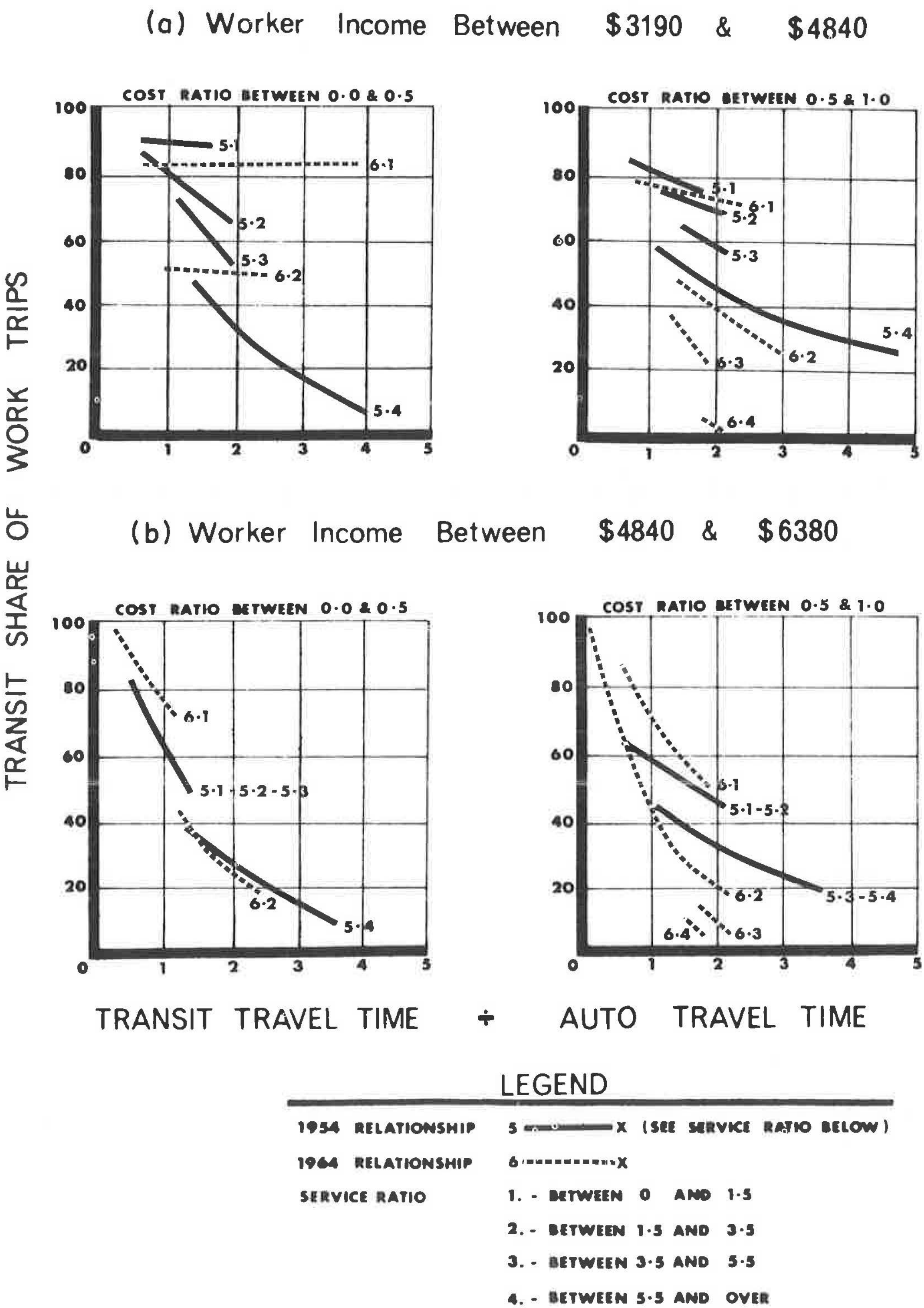


Figure 11. Comparison between 1954 and 1964 modal split relationships for work travel in Metropolitan Toronto.

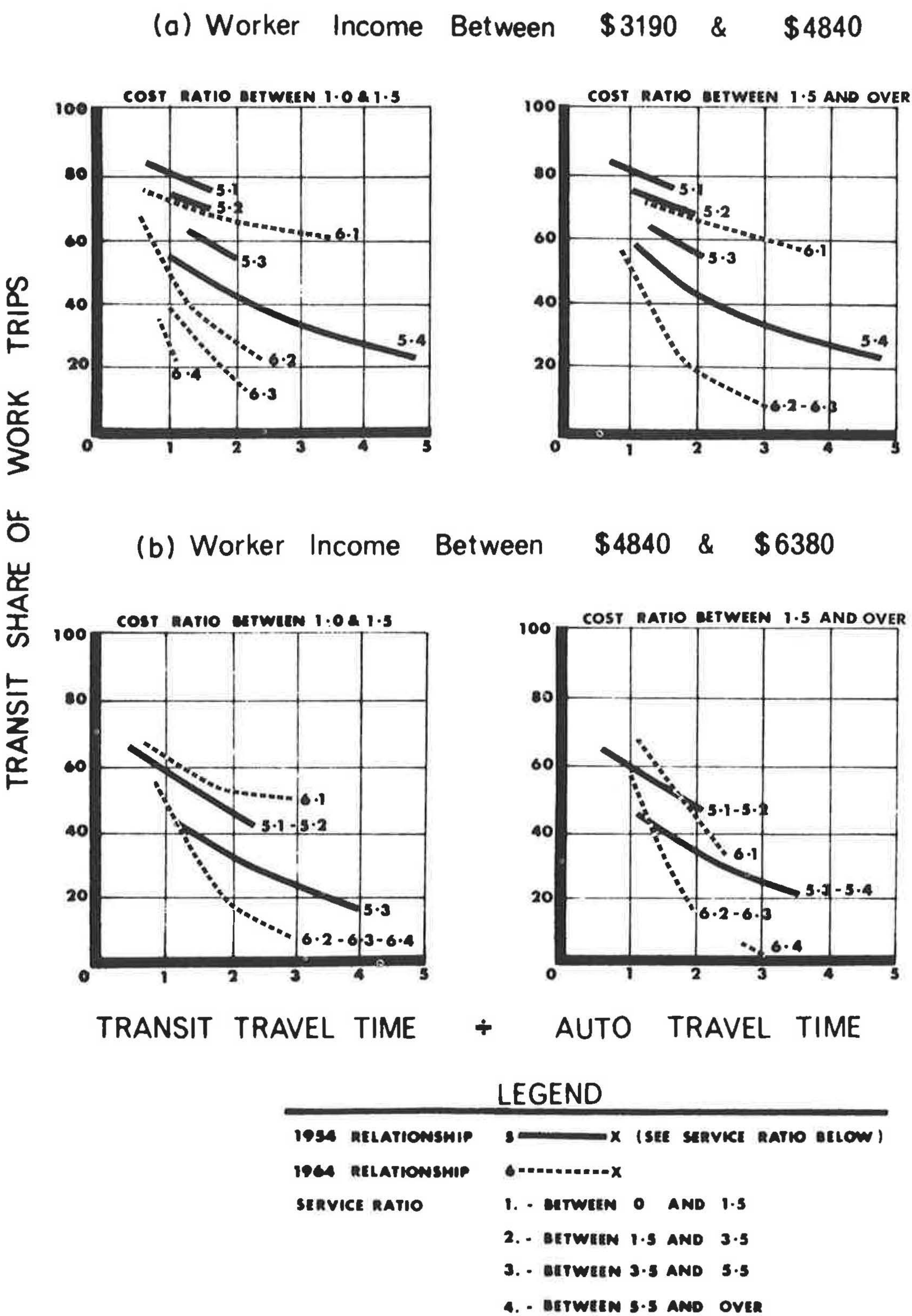
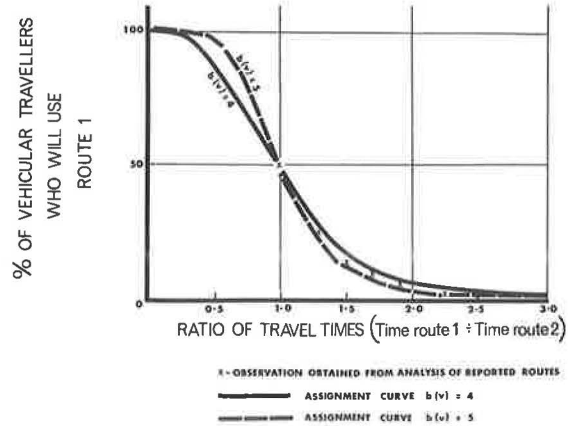


Figure 12. Comparison between 1954 and 1964 modal split relationships for work travel in Metropolitan Toronto.



ASSIGNMENT FACTOR

$$AF_1 = \frac{(T_1)^{-b(v)}}{(T_1)^{-b(v)} + (T_2)^{-b(v)}}$$

Figure 13. Traffic assignment curve showing percent of vehicular travelers who use route 1 when choice is between 1 and 2.

The task of assignment consists of determining the number of vehicles or persons using each of two or more routes for the same travel mode, given the origin-destination interchange movement. The assignment factors are calculated using the route travel times for each O-D pair, by means of the following (5):

$$AF_1 = \frac{(T_1)^{-b(V)}}{(T_1)^{-b(V)} + (T_2)^{-b(V)} + \ldots + (T_n)^{-b(V)}} \tag{7}$$

where

AF_1 = route assignment factor for route 1 (specifying what percentage of private vehicle travelers are using the first vehicle route for the O-D in question);

T_i = travel time via the ith route from the O to the D [i - 1, . . ., n (there is a total of n routes for the O-D pair in question)]; and

b(V) = assignment factor exponent for vehicles which is empirically determined by analysis.

Note:

$$AF_1 + AF_2 + \ldots + AF_n = 1.00$$

For determining assignment factors within a transit mode, b(Q) would replace b(V) in Eq. 7.

As part of the 1964 transportation survey, approximately 6000 Metropolitan Toronto residents were asked to trace their route to work and to give their reasons for their choice. These were used to derive empirically the assignment factor exponent b(V) of Eq. 7.

The alternatives of route choice were established for the main corridors of movement. The following information was assimilated from the survey for each major origin and destination interchange (on a study zone basis): (a) number of alternative routes chosen and their classification according to mix of facilities; (b) frequency of use of each route; and (c) travel time for each major route choice. The analytical study of the basic assignment factor formula (Eq. 7) was carried out by graphical analysis (Fig. 13). It appeared that a b(V) exponent of 4 in Eq. 7 demonstrated the best explanation of route choice. No comparative facts were available from the 1954 or 1956 surveys for this study.

SUMMARY OF FINDINGS

Home interview surveys revealed the movement of people associated with the many different population and employment centers in the metropolitan area. As might be expected, an analysis of the results showed that travel was orderly and regular.

The comparative analysis of survey data collected during two different years approximately 10 years apart demonstrated an overall stability between person trips and the reasons motivating this travel. In particular, the following findings were disclosed:

1. Average production of person trips appeared to have remained unchanged between 1956 and 1964.
2. Average trip length did not seem to have significantly changed between 1956 and 1964. In spite of significant development of suburban areas and many improvements in the transportation system, the time expended while travelling had not changed.
3. Provided transit service was convenient to use, people demonstrated similar preferences to ride public transportation in 1964 as was their habit in 1954.

ACKNOWLEDGMENT

During the course of the study and preparation of this paper, helpful cooperation was received from many quarters. In particular, the authors wish to acknowledge the comments given by H. Von Cube and J. Vardon.

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The authors wish to point out that the conclusions presented in this paper do not necessarily represent the opinions of their agencies.

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Factors in Work Trip Lengths

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This paper analyzes the major factors affecting the length of urban work trips. Evaluation of travel data from a number of cities in the United States and Canada revealed that trip length is primarily related to the size and physical structure of the urban area, characteristics of the transportation network, and various social and economic factors. Some of these concepts were also investigated through the use of simulation studies.

This research has shown that, to improve work trip forecasting procedures and understand travel behavior, the income of the trip maker, the mode of travel, the peak-hour travel characteristics, and the opportunity distribution should be taken into consideration.

•IN recent years the art of planning future transportation systems has become heavily dependent upon the factual analysis of travel behavior. Large digital computers make it possible to consider the effects of detailed alternative land-use and transportation plans on travel demand. One of the most significant characteristics of the demand for travel is the length of the trip, for it is the total of all individual trip lengths which creates the total travel demand and the length of the trip itself which dictates the type of transportation facility. A sound estimate of trip length is essential to transportation planning and the calibration of mathematical models that are used to forecast travel demand.

The National Cooperative Highway Research Program, a joint undertaking of the American Association of State Highway Officials and the Bureau of Public Roads, which is administered through the Highway Research Board, is sponsoring a two-year study of factors and trends in trip lengths. The emphasis during the first phase of the study, upon which this report is based, is on work trip travel (5). The other types of urban travel are covered in the second part of the study.

The data used in the analyses presented in this paper were made available by cooperating transportation planning agencies in the United States and Canada. In addition, a number of the analyses are based on digital computer simulations of urban form and travel behavior. The research was oriented toward identifying the fundamental determinants of urban work trip length. This research found that the three most important factors are the size and physical structure of the urban area, transportation system characteristics, and social and economic patterns.

SIZE AND PHYSICAL STRUCTURE OF THE URBAN AREA

Characteristics of work trip length are closely associated with the size and physical structure of the urban area in which they are made. Figure 1 and Table 1 show the association of urban area population with average automobile work trip duration, length, and average network speed. The deviation of some cities from the general trend of correlation appears to be explained to some degree by their unique structural characteristics.

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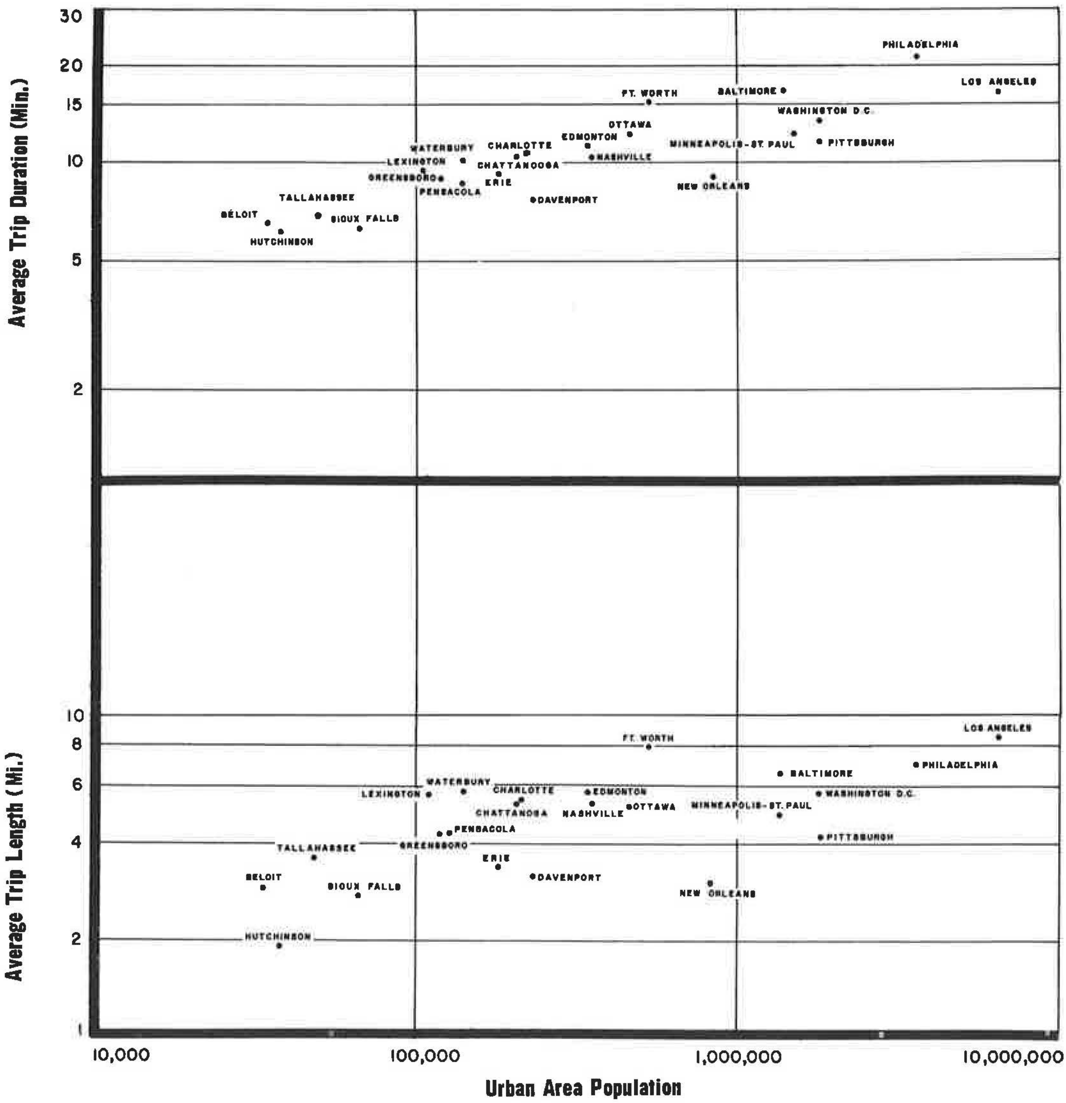

Auto Driver Average Trip Times & Distances exclude terminal time effects.

Figure 1. Average auto driver work trip length, duration, and population—twenty-three cities.

A regression analysis was performed to examine the effect of population upon average work trip duration in data obtained for 23 cities. The developed equation, which used a logarithmic transform, was as follows:

$$\log_e \bar{t} = -0.025 + 0.19 \log_e P$$

where

$\bar{t}$ = average trip duration (minutes); and
P = urban area population.

This can be written as

$$\bar{t} = 0.98P^{0.19}$$

TABLE 1

CHARACTERISTICS OF TRIP LENGTH, DURATION, AND POPULATION[a]

Location	Population[b] (thousands)	Work Trip		Average Network Speed
		Duration[c] (minutes)	Length (miles)	
1. Los Angeles	6,489	16.8	8.7	31.0
2. Philadelphia	3,635	20.1	7.2	21.5
3. Washington	1,808	14.3	5.9	24.7
4. Pittsburgh	1,804	12.6	4.2	20.0
5. Baltimore	1,419	16.7	7.0	24.6
6. Minneapolis-St. Paul	1,377	12.5	5.1	24.5
7. New Orleans	845	9.1	3.0	20.2
8. Fort Worth	503	15.7	8.1	30.9
9. Ottawa-Hull	406	12.6	5.3	25.2
10. Nashville	347	10.8	5.4	30.0
11. Edmonton	336	11.6	5.8	30.0
12. Davenport	227	7.7	3.2	24.9
13. Charlotte	210	11.0	5.5	30.0
14. Chattanooga	205	10.8	5.4	30.0
15. Erie	177	9.4	3.4	21.7
16. Waterbury	142	10.1	5.9	35.0
17. Pensacola	128	8.7	4.4	30.3
18. Greensboro	123	8.9	4.3	29.0
19. Lexington	112	9.1	5.7	37.6
20. Sioux Falls	67	7.0	2.9	24.8
21. Tallahassee	48	7.3	3.7	30.4
22. Hutchinson	38	6.1	2.0	19.2
23. Beloit	33	6.7	2.9	25.9

[a]These data were obtained from various sources and attempts were made to keep them as compatible as possible by removing terminal time effects.
[b]Auto driver trips.
[c]Auto driving time.

The standard error of the regression coefficient was 0.026, and the coefficient of determination, R^2, was 0.71.

New Orleans, one of the oldest and most compact of the cities listed, has an average trip duration or length typical of that normally found in newer cities only one-tenth its size. The duration or length in the spreadout city of Fort Worth is greater than that of New Orleans, while the latter is somewhat larger in terms of population. The physical structure of an urban area seems to have the same general impact on trip length that it has on trip duration.

Average urban population density did not contribute significantly to the explanation of variations in trip durations. A better measure of the density of urban development would probably have shown that increases in trip duration associated with higher populations would be offset if some of the population growth occurred at higher densities.

This expectation was verified in a computer simulation study of a set of hypothetical cities. Three hypothetical cities were constructed with work trip populations of 500,000, 1,000,000, and 2,000,000. Population and employment densities were assumed to decrease exponentially with increasing distance from the downtown. The gravity model was used to simulate travel patterns.

These studies showed that, under a constant population, average trip length decreased as the slope of the urban density curve became steeper. In addition, average trip duration in minutes and trip length in miles seemed to be associated with the fourth root of population, approximately verifying the results of the regression analysis. The results of applying this relationship to available time series trip durations for Baltimore and Washington are shown in Table 2.

Changes in population alone may not always affect the average trip length. From 1958 to 1964 the work trip duration in Broward County, Florida, increased by only 4 percent over its existing average trip duration of 10.5 minutes, even though the population increased by 40 percent (5). This can be explained by the fact that growth did not extend the urban area; instead, the growing population filled in previously unused land.

Opportunity Distribution

To measure and analyze urban structure effectively, an "opportunity distribution" was determined for certain urban areas. This measure is the frequency distribution of separations (travel times) between homes and jobs. This distribution was determined by assuming that travel time had no effect on the work trip distribution. (In actual practice, this was done by making travel time, F, factors equal to 1.0 in the gravity model trip distribution procedure.) An important aspect of this measure is its ability to measure opportunity separation in terms of time or distance. Thus, the distribution considers city structure and network speed.

Figure 2 shows the opportunity distribution for three urban areas. The first distribution is Erie, Pa., where the opportunity distribution is quite limited. Pittsburgh has a broader distribution but is still not as widely spread as the Seattle-Tacoma area. These patterns affect trip length, since Erie has an average trip duration of 9 minutes, Pittsburgh has one of 13 minutes, and Seattle-Tacoma one of about 20 minutes.

These patterns can also be observed within a city. Figure 3 shows the 1948 opportunity distribution for three zones in Washington, D.C. Zone 48 is near the CBD, zone 255 is several miles from the downtown area, and zone 298 is in the suburban area. This pattern is reflected in the average trip duration developed for each of these zones. Zone 48 had a trip duration of 8.0 minutes, zone 255 had one of 12.8 minutes, and zone 298 one of 17.4 minutes (terminal times were omitted for the selected zone average trip durations shown).

Figure 4 illustrates what happens to the opportunity distribution for a city over time; in this case, Washington, D.C., between 1948 and 1955. The mean and variance of the opportunity distribution increased. However, the average trip duration did not increase as fast as this change, since average trip duration is probably more related to nearby opportunities than to those which are farther away.

There were developed two indices to measure changes in average trip duration over time based on the effect of changes in the work opportunity distribution. The first index was quantified by applying travel time factors, with time raised to the second power,

TABLE 2

TRIP DURATION CHANGES IN BALTIMORE AND WASHINGTON

City	Year	Population	Average Trip Duration (minutes)	
			Actual	Predicted
Baltimore	1945	900,000	14.6	–
	1962	1,400,000	16.7	16.3
Washington	1948	1,100,000	12.6	–
	1955	1,600,000	14.3	13.9

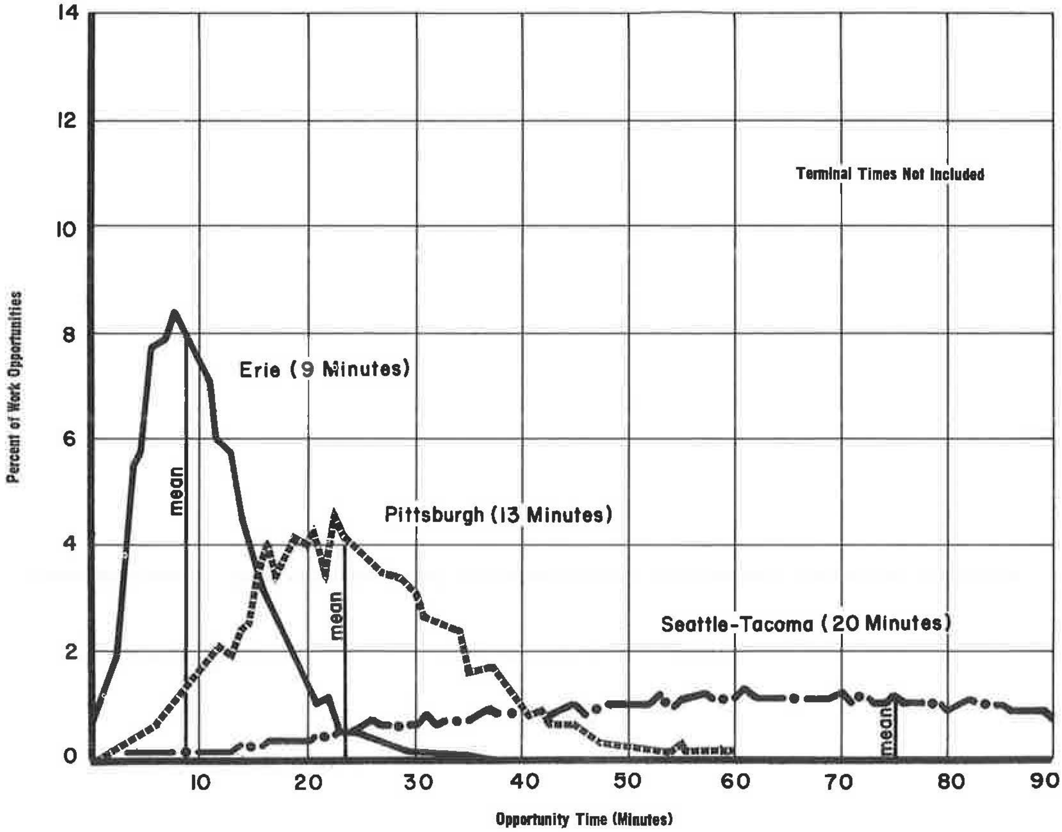

Figure 2. Opportunity distributions across cities, approximate average trip duration (minutes).

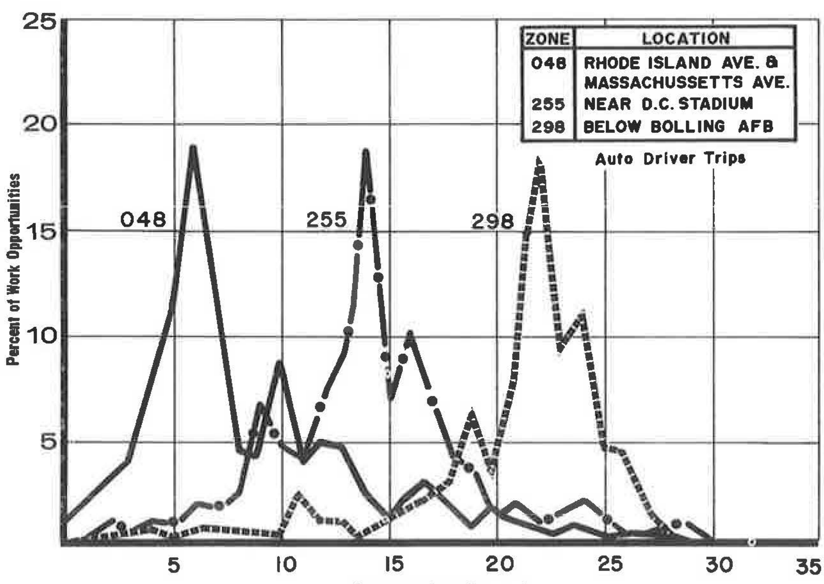

Figure 3. Opportunity distributions for selected zones in Washington, D.C., 1948.

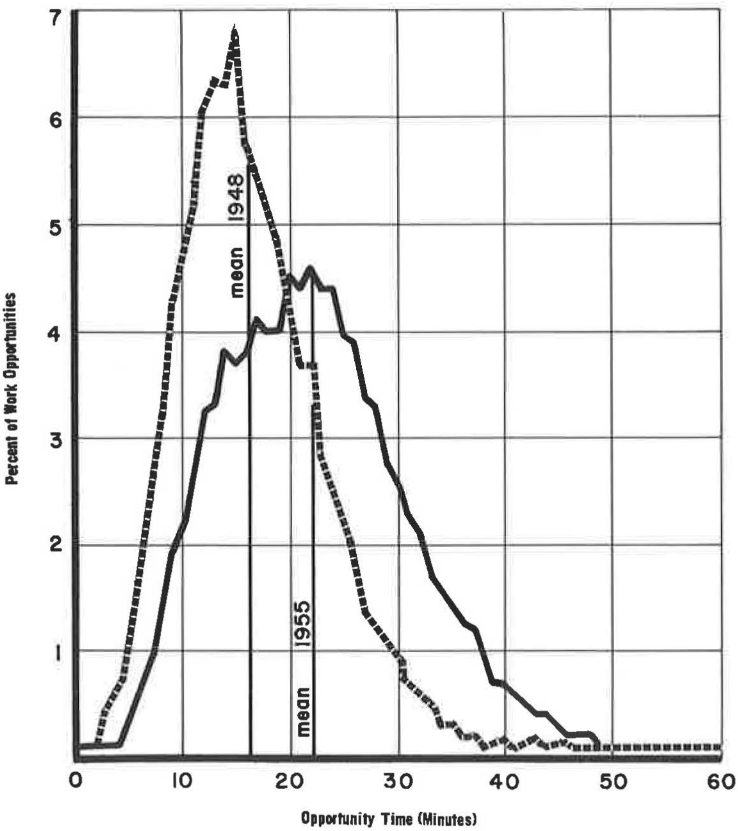

Figure 4. Opportunity distribution for Washington, D.C., 1948/1955.

to the opportunity distribution for the two time periods. The second index was calculated by raising the ratio of the means of the work opportunity trip distributions of the two time periods to the 6/10 power. These rules concerning the opportunity distribution were based on data observed from several cities and the results of the simulation study.

The basis for the first index is shown in Figure 5, which shows a plot of the trip length index (travel time factors of $1/t^2$ applied to the opportunity distribution) vs the average trip duration for five cities with populations of 800, 000 or greater. Although the data are far from sufficient, the plot is approximately linear. It should be noted that the 15 percent increase resulting from a change in this index for Washington, D. C., between 1948 and 1955 closely approximates the 14 percent increase that actually occurred (a seven-minute terminal time was assumed).

The second index was obtained from results of the simulation study and work opportunity distributions for seven urban areas. The relationship between average opportunity time ($\bar{o}$) and average trip duration ($\bar{t}$) from the simulation study, using travel time exponents of one and two and actual relations for seven urban areas, is shown in Figure 6. In applying this observation to time series data from Washington between 1948 and 1955, it was found that it did not give quite as good results as did the gravity model using travel time factors equal to $1/t^2$, because any rule related to a change in the mean of the opportunity distribution will not be as accurate as one related to an entire change in the distribution.

The arrangement of opportunities around a given zone also had an effect on travel characteristics. Figure 7 shows the relationship of travel time to the ratio of actual over probable trip distribution for three selected zones in Washington, D. C. These

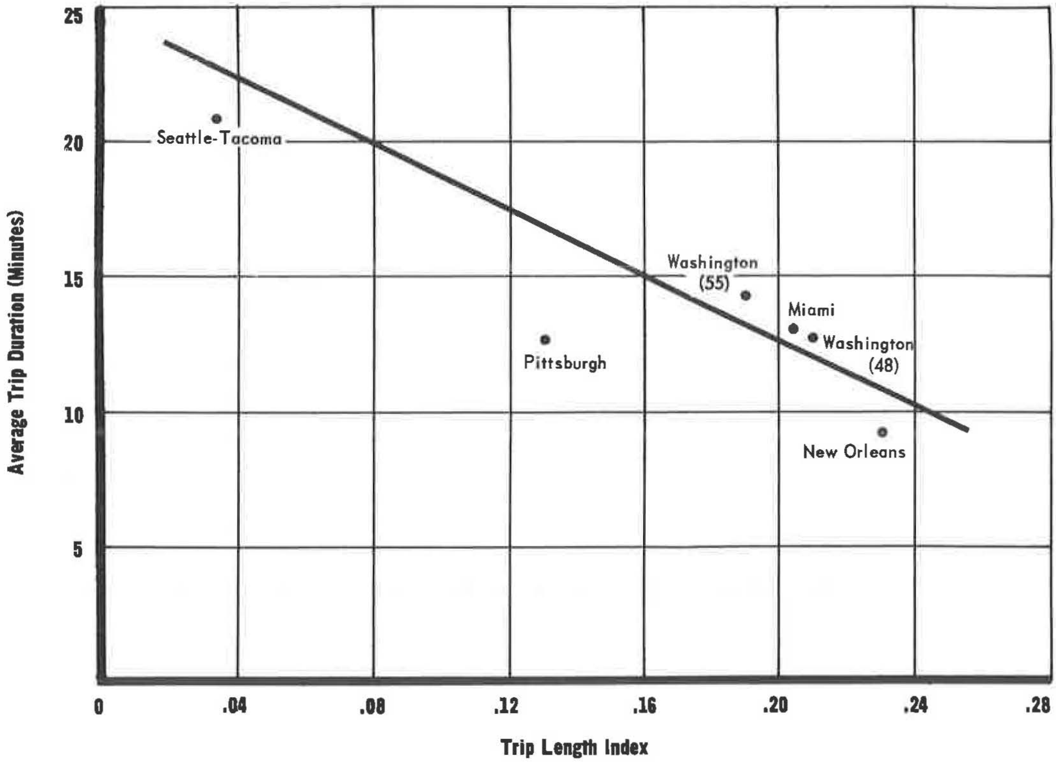

Figure 5. Trip length index vs average trip duration.

three zones give a representation of the mean and extreme ends of the opportunity trip distribution of 8 of 11 selected zones analyzed. Figure 8 shows that the shape parameter of the travel time factor distribution decreased as the mean of the opportunity distribution increased. This relationship implies a greater weighting of nearby activities as spatial opportunities arrange themselves at greater mean opportunity times from a particular zone. This observation seems to indicate that the L factor in the opportunity model or the F factor in the gravity model should be modified for variations in the opportunity distribution. Even though such an improvement may have a limited impact on trip length forecasts, it may improve existing trip distribution models. There might be developed a new model that takes into consideration the opportunity distribution and travel impedance. This hypothesis should be explored and tested for applicability on a system-wide basis using a more exhaustive statistical sample.

TRANSPORTATION SYSTEM CHARACTERISTICS

This research also indicated that the transportation system and its operation had a significant impact on the work trip length (see Fig. 1). Although Los Angeles had the longest trip length in terms of miles, the average travel time to work is only three-fourths that of Philadelphia, because the average speed on the highway network in Los Angeles is higher. The average travel time in Fort Worth is about the same as that in Baltimore, while the actual length of the trip in miles is considerably different. Again this is largely due to the difference in speeds of the highway systems in these areas. This was further demonstrated in a regression analysis based on data from 23 cities, which showed that the average network speed was correlated with trip length measured in miles. The following equation was developed:

In Boston, a need for similar adjustment factors has been observed. It is due in part to intracommunity attitude characteristics. Los Angeles, however, a "one-newspaper town," does not exhibit a tendency toward community separation. The persistence of such travel patterns in spite of improved transport services indicates the slow rate at which local traditions change. Although it is difficult to predict the occurrence and effects of such phenomena, the possibility of their existence should not be overlooked in the process of travel forecasting.

The effects of the spatial distribution of families in various income groups was found to be of considerable importance in determining home-job linkages. Workers from families of specified income levels do not select their work trip destinations from the field of all available job opportunities. Instead, they must be oriented towards jobs at their own income levels. This implies that a meaningful income stratification of trip opportunities might be helpful in reproduction of urban travel patterns, especially where there are strong patterns of economic segregation.

In Washington, D. C., failure to recognize these linkages resulted in an incorrect simulation of corridor volumes (2). There was a significant difference in the average work trip lengths for people in different income groups in the Northwest Corridor. An

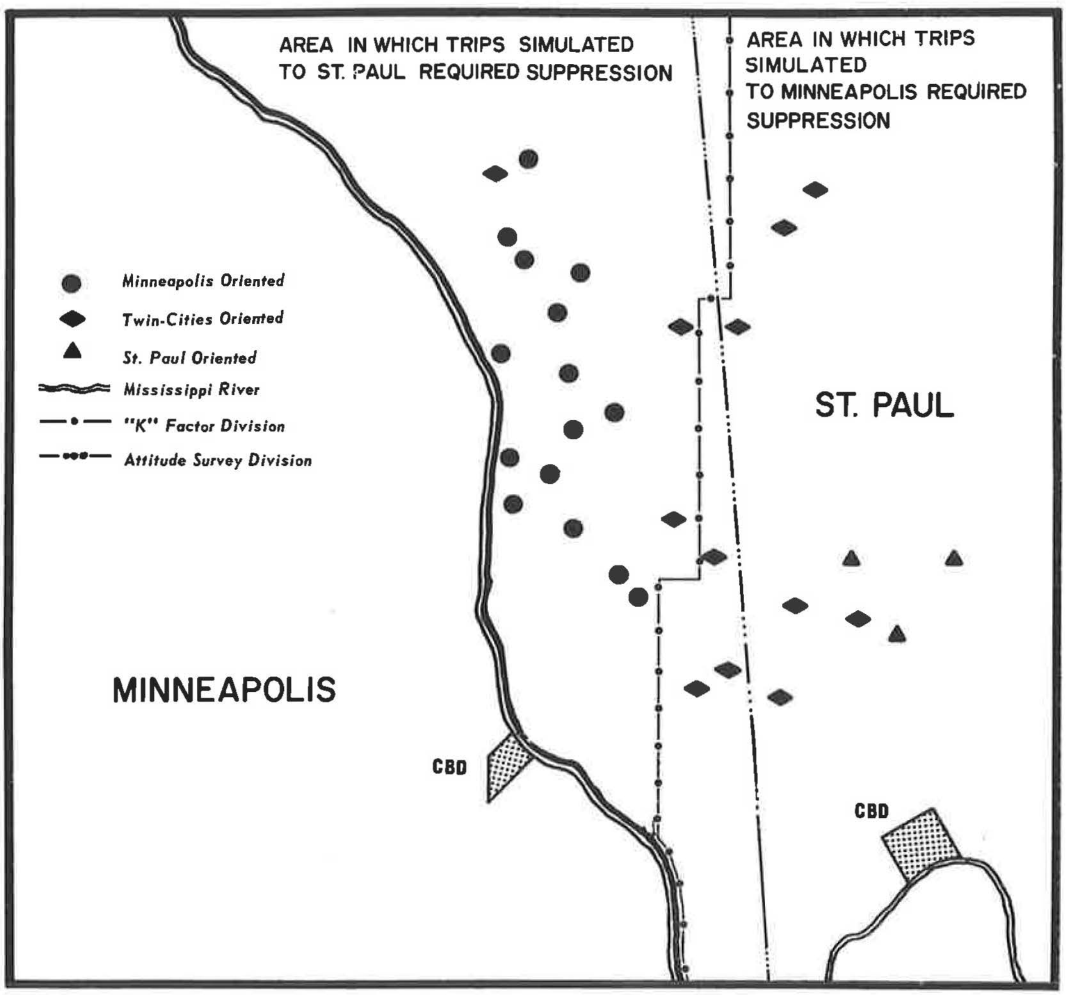

Figure 10. Twin Cities attitude orientation.

income-based stratification of the work trip matrix resulted in a better simulation of travel patterns and effectively estimated the average trip lengths for each income group, although the same travel time factors were used for each of the strata (Table 4).

PREDICTING TRIP LENGTH

In attempting to predict trip length in the future, every effort should be made to evaluate the three factors that have been discussed: size and physical structure, network speed, and socio-economic factors. Estimates should be made of the changes that will occur in these basic factors. Probably the best way to do this is to develop the opportunity distribution for today and estimate it for the future on the basis of population and employment distribution and assumed network speeds. Two of the variables, size and physical structure and network speeds, are thus considered together. If these changes look reasonable in light of historical trends and anticipated growth of the area, then the change in trip length is approximately proportional to the ratio of the future and present means of the opportunity distribution raised to the 6/10 power.

An examination of expected spatial changes in the socio-economic characteristics should also be made. While such changes are slow to occur, major shifts can bring about changes in trip lengths and should, therefore, be given adequate consideration in the forecasting process. The influence of these factors may be accounted for through the use of empirical correction factors or stratification of the work trip matrix.

The following guidelines can be used to approximate the changes that will occur in the mean of the work trip distribution as a function of these three basic factors.

1. Size and physical structure: (a) if an urban area grows by extending its present population and employment density patterns, the change in average work trip duration will probably be proportional to the fourth root of population change (Case 1, Fig. 11); (b) if an urban area grows largely by the filling in of unused land areas, while maintaining its same basic shape, there will probably be no material change in trip lengths (Case 2, Fig. 11); and (c) if an urban area develops by concentrating additional population and employment in the downtown area and/or in other sections of the metropolitan area; the average work trip will probably decline (Case 3, Fig. 11)—simulation studies have shown that this decrease might be as much as 10 percent.
2. Network speed: (a) change in the average trip length (miles) for uniform density cities will probably be directly proportional to the square root of changes in network speed; and (b) change in the average trip length (minutes) will probably be inversely proportional to the square root of changes in network speed—experience, however, has shown that peak hour speeds have not greatly changed in larger metropolitan areas.
3. Socio-economic: (a) wider distribution of income in an urban area could change trip length as much as 10 percent; and (b) elimination of historical and social influences could change length by 5 percent.

TABLE 4

AVERAGE WORK TRIP TIMES
WASHINGTON, D.C., 1955
(Northwest Corridor)

Median Family Income ($)	Average Work Trip Length (minutes)	
	O-D Survey	Stratified Model
0-4,999	15.2	16.4
5,000-6,999	24.6	25.1
7,000-9,999	20.0	19.4
10,000	21.3	21.2

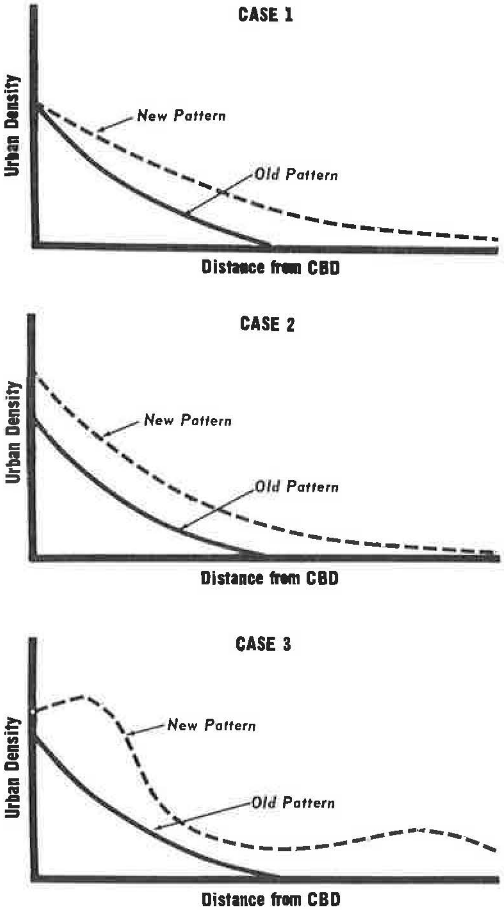

Figure 11. Urban density vs distance from CBD.

In applying these guidelines to any particular urban area, care must be exercised in insuring that proper values for the variables are used and that the distinctive characteristics of the city are considered.

PREDICTING THE WORK TRIP LENGTH DISTRIBUTION

The previous analyses were concerned primarily with the average trip duration and length. A more complete picture of trip length is obtained when the dispersion around the mean (the standard deviation) is considered. An investigation was undertaken to identify a mathematical function which considers both the mean and standard deviation in synthesizing the actual work trip length distribution. Figure 12 shows the form of the work trip distribution observed in most urban areas. The gamma distribution was found to fit such data very well. The parameters of this distribution are the values of the mean, $\bar{t}$, and the standard deviation, σ_t, of the work trip distribution

$$f(t) = K\left(t^{(\bar{t}^2 - \sigma_t^2)/\sigma_t^2}\right)\left(e^{-(\bar{t}/\sigma_t^2)t}\right)$$

where

$f(t)$ = the relative frequency of trips of duration, t;
K = a constant;
e = the base of natural logarithms;
$\bar{t}$ = average trip duration; and
σ_t = standard deviation.

To use the gamma distribution as a tool in estimating future trip distribution, it is necessary to establish the mean and variance (σ_t^2) of the work trip length distribution. It has been shown that the mean of the future work trip length distribution can be estimated by using one of the established guidelines. The change in variance can be approximated by using the relationship between the mean and the variance developed in Figure 13. Thus, with estimates of the mean and the variance it is possible to construct the work trip distribution approximately, using the gamma distribution as a tool in the forecasting procedure.

IMPLICATIONS FOR FORECASTING

The results of this research indicate that additional refinements in forecasting procedures and data collection may be desirable in order to predict accurately the complex movements of people in urban areas.

Stratification of the work trip by various categories of trips should help advance the understanding of travel behavior and the growth and decay of cities, as well as improve land-use models. In large cities, an income stratification would appear almost essential.

Separation of trips by mode of travel, as well as by time of day, may be warranted in large metropolitan areas. This means that peak-hour networks for both the highway

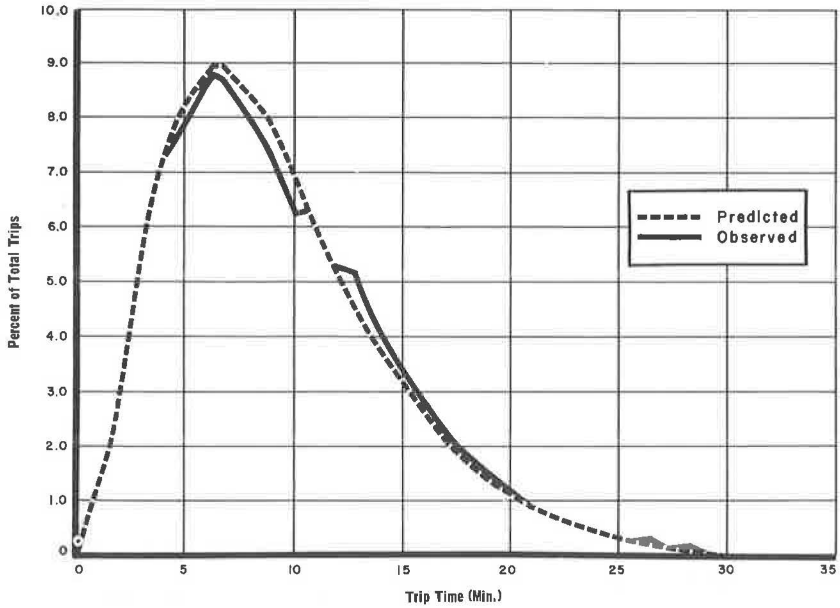

Figure 12. Auto-driver work trip distribution, Erie, Pa.

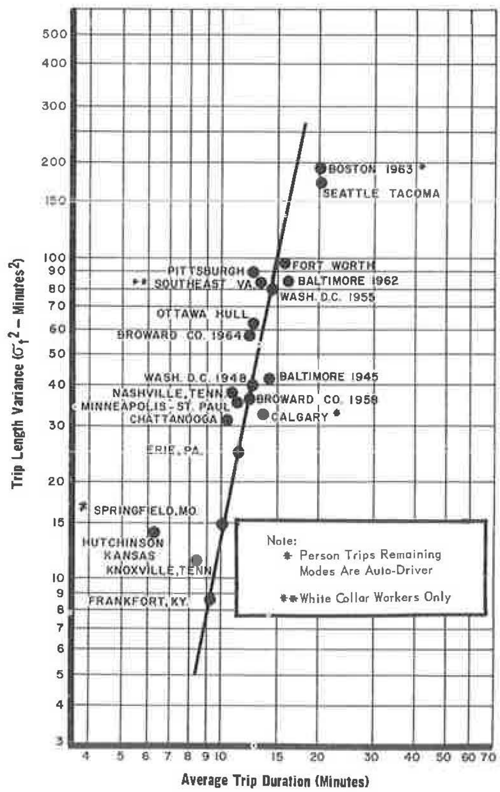

Figure 13. Work trip length variance vs average trip duration.

and transit systems could be used to predict work trip travel patterns.

To maintain a realistic relationship between peak-hour speeds and volume forecasts, consideration of capacity constraints and incremental traffic assignments by time-of-day may be needed. Attempts should also be made to use travel costs rather than travel time to measure the effect of zonal separation in the trip distribution procedure.

Extreme changes in the future spatial arrangement of opportunities around zones within the system might be analyzed with respect to their impact on developed trip distribution procedures. This analysis is especially important where the affected zones constitute a large proportion of total trip generation.

These conclusions also imply that there may be need for a higher level of sophistication in future data collection. More information on the socioeconomic characteristics of travelers, especially their incomes, will be useful and could be gathered in conjunction with the origin-destination surveys. In addition, transportation system inventories should include data on peak-hour characteristics of the highway and transit networks.

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Discussion

LOUIS E. KEEFER, Transportation Planning Consultant. —There will always remain some curious questions concerning the distance from work that people will live. Putting it this way deliberately suggests that we are not simply talking about the length of urban work trips, as if they have some life of their own, but about people and where they choose to live with respect to where they work.

This introduces socioeconomic ramifications which are only indirectly measured in terms of distance or travel time frequencies. For this reason, perhaps, the work trip is among the most popular "traffic" phenomena to attract the attention of non-traffic technicians. Many studies have been made. Still, I suggest that the following questions remain unanswered.

When only the head of the household was the breadwinner, it was easy enough to talk about average work trip lengths. Now that at least half of the nation's wage-earning families cash at least two paychecks, can we meaningfully talk about averages, without distinguishing primary from secondary wage earners?

In deciding where the family will live, to the extent that the decision is affected by place of employment, one would presume that the primary wage earner would most heavily weight the decision. Would this leave the secondary wage earners to find employment wherever convenient? This line of thought would suggest that, other things being equal, the overall average work trip length would have decreased over the last two decades.

Of course, it should be established, first, whether or not the home location is at all affected by the distance to work. Perhaps it is not. If not, then in a sense the average journey length becomes a random variable, and attempts to describe it by mechanical measures must fail. All we would know are the probabilities, under given circumstances, of people finding suitable homes at given distances from work. Presumably these would vary among metropolitan areas according to personal taste, history of housing development, topography, and many other variables not readily subject to measurement.

The increasing segregation of races is creating a trend toward longer work trips. A very excellent discussion of this in Lapin's "Structuring the Journey to Work" suggests that whites working in the central city are forced to live farther and farther out in the suburbs, while nonwhites must reverse-commute to the suburbs and mixed fringe areas in order to find the lower-skilled jobs not usually available in sufficient quantity to them in the central city. Since an end to segregation is not yet in sight, how can this be accounted for by transportation planners?

What about increasing car ownership? In a National Cooperative Highway Research Program project we are conducting, work trips to over 50 major plants in a dozen different cities have been considered through transportation study O-D data. These data show that car owners make considerably longer trips than noncar owners. When the latter get a car, will they not be tempted to move farther from the plant areas in which they work? If existing car owners' residences remain the same, then the average trip length to any given plant would tend, we assume, to increase.

What is the effect of increasing worker skills? We know that professional and technical people now tend to make the longest work trips; if a greater proportion of the work force assumes higher occupational categories, will not the average journey length increase? This is perhaps the same as asking about the effect of the continuing rise in real family income. The net result may be a move from city to suburbs, and hence a longer trip length.

Contrast this experience with the "returnees"—the families who tire of suburban living and return to the city. Realtors consider this an important market for city housing, and the trend is encouraged by provision of more expensive housing in or near CBD's. How much would this inwards movement, and its probable shortening of work trips, offset the longer trips of the less affluent moving outwards?

The effect of improved travel facilities has been much bruited about. Some maintain that as long as speeds increase, the same worker can live farther away and still take no longer in time to get to place of employment. And—that since he can, he will. Assuming this, doubt has been cast on the planning effectiveness of transportation studies which did not postulate that the total vehicle-miles of travel would increase far more quickly than the total trips in an urban area. Do the critics know or are they guessing?

Looking at just one aspect of the problem, one might argue that new travel facilities would actually shorten many trips. For example, in lieu of round-about arterial connections, a more direct trip by freeway, even allowing for distance diverted to use it, might be no longer overall. Moreover, a freeway may more easily cross major travel barriers, such as mountains and river valleys, than would an older arterial highway. This may be stretching a point, but it seems too easy to assume that freeways will always increase average journey lengths to work.

As the density of development increases in the growing suburban areas, longer trips become less necessary. Does not the changing proportion of suburban versus central city employment reduce the relative frequency of the long commute? Everyone can recognize that circumferential work trips to suburban plants and offices need not be long. If people can live and work in the suburbs, in effect, why should we immediately assume that they should want to work farther from home even if there are new freeways to carry them?

Then there is the puzzling evidence (a) that total trip production rates per family are increasing, while (b) the average annual mileage per car owned has remained constant. This certainly suggests that the auto trips (for all purposes) are actually getting shorter.

We know that the number of transit trips is decreasing; we suspect that car loading factors are decreasing (in effect, auto passenger trips are decreasing relatively). If this is correct, then the number of auto trips must be increasing. And, if we do not question the annual mileage estimates of the Bureau of Public Roads, it seems to follow that auto trips must be getting shorter.

Assuming that work trips are holding constant, or getting longer, then the various kinds of other trips must be getting shorter. This is not difficult to believe: the general aversion to walking is pronounced. Driving trips are now readily substituted for many walking trips of only one or two blocks. Somehow it seems we have the knowledge to untangle all this.

What is the psychology of the work trip? Some say that it is a necessary time-space transition from place of employment—a chance to change gears. How long should this take? Perhaps no less than 15 minutes; no longer than 30 minutes? What are the long range mental health effects of long commutes?

If these questions could be resolved, perhaps we would learn that we may always be talking in terms of some fixed time range. If so, and if travel times really do not change much (because of the sooner-than-expected congestion on the new freeways), then we may be wasting time worrying about changes in trip lengths. Within practical limits they may not change enough to affect transportation planning one way or another.

Finally, we might double check some of our methods of measurement and what they mean. Most of our work deals with airline trip distance. Should not we really be talk-about over-the-road distance? And is it not true that this is not collected in most surveys, and never accurately established? Clearly, any comparison of trip lengths should seem to account for differences in the airline to over-the-road factor from city to city. But how important are such mechanics?

ANTHONY R. TOMAZINIS, Institute for Urban Studies, Philadelphia. —Although I am going to repeat statements already made previously, I feel that the importance of more accurate knowledge on trip length variations in metropolitan regions is such that it requires stressing in every possible occasion until the people involved take it seriously into account. Trip lengths are certainly the result of the influences of a number of forces and factors. Trends might also be distinguishable if significant variations do persist over the years. In terms of ramifications, we should be prepared to take into account all the significant and verifiable associations between trip length on one hand and land-use pattern and/or transportation system characteristics on the other. It is, indeed, encouraging that this significance of trip length variations began to be increasingly recognized and our scientific knowledge and concern began to include more than merely the measurement of the average size of trip length and the simple simulation and projection of it, within a framework of complete uncertainty.

The present attempt to relate auto driver work trip length with measures of population size, average highway network speed and socioeconomic factors is in concept meaningful and reasonable. Since this is the first real attempt in relating these variables, one might normally expect an initial definition and expression of the pertinent variables and a utilization of the generally known statistical tools to be part of the undertaking. The rather good results of the correlations with population size and average system speed indicate the meaningfulness of the selected variables and of the statistical tools in use. However, strong evidence of needed additional work is obvious in improving the grossness of the present results, in reducing the number of irrelevant statements and in the predictive part of the present work where rapidly drawn suggestions prevail and where simple models are put to use. The simplistic tool of the fourth route of population is, for instance, too easily misleading in spite of any incidental coincidence of limited results. The application of the gamma distribution is indeed an ingenious application of more advanced statistical theory in the field of urban traffic. However, the results as they stand right now are more speculative than concrete. The gamma density function depends extensively on the values of (a) and (b) parameters and for certain extreme occasions the function takes the form of a completely inappropriate frequency distribution function. This discussant had the benefit of reading also the report of the research project (5) and therefore could see that the researchers were fully cognizant of the nature and the difficulties of the gamma distribution. However, the results at present leave much to be desired with regard to the standard deviation and the mean of the trip length. An additional observation should perhaps be made in reference to the manner in which the socioeconomic factor and the "opportunities" variable were treated. Admittedly these variables are some of the most elusive and difficult to be incorporated in any quantitative analysis. However, the indirect treatment of the socioeconomic variable with the help of a discussion on the K-factors of the gravity model and the brief exploration of the opportunities variable is reasonable and perhaps indicative of tendencies, but completely insufficient for the needs of the occasion.

With regard to future research which appears more appropriate in following up the work reported in this paper, it appears to me that emphasis should be placed in three aspects of the problem. First is the matter of variables to be related. Additional work is required in defining the variables in a more meaningful manner and in measuring them according to more than one method. It appears, for instance, strange that density of development and size of developed area are not part of the predictive equation. Alternative configuration and testing of such variables might easily prove that these variables are indeed closely related (perhaps in a causative manner) with the average trip length in a region. Average regional income and the degree of dispersion of population and jobs should also be considered as variables to be taken into account in the basic correlation.

Second is the matter of statistical tools to be used or developed. It seems to me that this project has demonstrated once more that we are approaching the moment when statistical tools explaining directly transportation and traffic phenomena will be developed. The gamma distribution has primarily been proven useful in analyzing problems of weekly sales, in connection with certain inventory models and with the Poisson probability law. It might or might not prove to be of any relevance to traffic and transportation problems. The same concern might be expressed with regard to the other available probability laws such as the normal curve, the exponential distribution, the rectangular distribution, the beta distribution, the geometric probability law or the Bernouli, binomial or negative binomial frequency distribution which from time to time are proposed. What I am trying to say is that it is time to finance and organize an effort which will develop the probability laws which are directly expressive of traffic and transportation phenomena. Data are plentiful by now and previous research in this field plus previous developments in the statistical theory have already prepared the ground work for the job.

The third item which seems to be relevant to such second and third generation research on traffic and transportation problems is the need of adherence to a vigorous and well thought out research design and reporting in order that aimless motion and incompleteness of tests will be brought to the minimum and that reporting will be accurate, well documented, and limited to what has been researched.

Concluding my remarks, it seems appropriate to stress that we should continue research on methods of trip length projection and that we should be prepared to accept as a rule that future travel demand projections should soon include checks which will be based on independent projections of the average trip length and of its standard deviation for the major types of trips in the region. The present paper makes a significant contribution indeed toward this objective and opens several avenues for the needed additional research work.

GARY R. COWAN and JOHN K. MLADINOV, Puget Sound Regional Transportation Study. —The paper examines lengths of work trips in (and within) different urban areas and attempts to draw some conclusions as to how work trip lengths are related to some characteristics of the urban area.

There are a number of different ways to approach the problem of discussing a paper such as this. One way is to examine and dissect the paper in fine detail, probing to determine the adequacy of the specific techniques and data sources used in the research process and in testing and developing the conclusions set forth in the paper. At another level one may evaluate the paper and its conclusions in such abstract terms as consistency, applicability, relevance, and importance. Is the paper trivial or does it represent a substantive contribution? Does it have some universal or general application or is it really irrelevant to the urban transportation planning field? At yet a higher level of evaluation one may appraise a paper in terms of further and wider implications which may be drawn from its conclusions. All three levels of evaulation are important and have a valid role to play in the appraisal of any scientific work. Any one level is probably no more important than any other.

In a short discussion, it is obvious that it is not possible to do full justice to this paper at all of these levels. This is of some regret since, in a sense, this paper may well be one of the most important papers to be presented at HRB meetings in recent times. This stems not so much from what it says but more from the standpoint of what its longer range implications are.

At the second general level of appraisal, the most important single conclusion cited by the paper is that the average trip length and also the frequency distribution of trips around this average, are not constant between urban areas, given variations in their physical, spatial, and socioeconomic structures. Subsidiary conclusions are that this variation in average trip length is related in regular and quantifiable ways with such factors as the population of the urban area and the transportation network speeds.

At the first level of criticism, and given no more data for appraisal and evaluation than has been directly presented in the paper, it cannot be said that all of the subsidiary conclusions have been substantiated. For example, does the paper in any acceptable scientific sense establish that the average trip length in an urban area is related, either directly or indirectly, to the fourth root of the urban population? The substantiating data and analysis are not present for critical examination. However, our own experience and explorations into this topic do support the main conclusion that, given changes in the urban structure, the trip length frequency distribution will alter. The extent to which the trips will alter, however, is a matter which has not, in our estimation, yet been established.

The differences in average trip length are ascribed to differences in the urban areas, with the regression analysis showing that trip duration is approximately related to the fifth root of the population. It is indicated, however, that the so-called simulation study was the basis for the conclusion that the average trip length in an urban area is related to the fourth root of the population. Our own work has been cast and formulated in such a manner that it has been concluded that differences in average trip length are brought about as a mechanical property of the gravity model, itself, given differences in urban structure. To put the matter differently, the research in this paper has led to the conclusion that variations in the urban structure cause variations in the trip length and trip length frequency distribution, and that these variations are both real and directly associated with the variations in the urban structure. On the other hand, results from the direction our efforts have taken seem to support the hypothesis that variations in the trip length frequency distributions which develop through application of the gravity model, while associated in some manner with differences in the urban structure, are not solely due to these differences per se, but rather can be explained by the mechanical properties of the gravity model itself when applied under varying conditions. Thus, a spurious result is obtained, with the effect of the model properties not being separable from the effect of the change in the urban structure. Our two different approaches have led to different conclusions since we have, in each case, limited our investigations to a particular aspect of a many sided and complex problem. The truth of the matter will probably turn out to be that, in the real world, some of both approaches are operative. That is, to some degree we are both right.

In the larger view, it is really irrelevant as to which of us is correct, or more nearly correct. This is because one fundamental fact stands out in the light of reality. This is that we cannot escape from the unalterable conclusion that a gravity model calibrated to today's conditions cannot be used for tomorrow's conditions, unless tomorrow's conditions are identical with today's. This latter condition is, of course, most unlikely.

This leads us to the third level of criticism, that is, the wider implications to be drawn from the conclusions in the paper. This paper constitutes nothing less than a wholesale assault upon current practice in the application of the gravity model, with all of the widespread ramifications that this implies. It has long been a fundamental tenet in the application of the gravity model that a properly calibrated model will be valid for the future. For instance, it is pointed out in the Bureau of Public Roads' manual on the gravity model that Voorhees' earlier work in Baltimore and the Bureau's more recent work in Washington, D. C., indicate some basis for making this assumption. This paper now asserts that this tenet is flatly wrong. The Puget Sound Regional Transportation Study modified this tenet in the application of the gravity model for the very reason expressed in this paper; that is, that a gravity model calibrated to today's conditions cannot be applied directly to tomorrow's conditions. To our knowledge, the

Puget Sound Study is the only group to introduce such a modification. It is obvious that this assertion bears momentous implications. With more than 200 urban areas in this country involved in transportation studies, a significant number must be using the gravity model. If they are abiding by the fundamental tenet, the results of applying the gravity model to future conditions must be considered erroneous.

Under its own impetus the practice of transportation studies is rapidly expanding and becoming more involved and complex. At the same time, in line with the "Great Society," the federal government is adding its impetus. We are no longer simply planning transportation systems, we are designing urban areas (or at least we think we are). The federal government is becoming wholeheartedly behind us, and indeed, is egging us on. Just reading the program for this year's HRB meeting and noting the number of sessions which bear upon this topic emphasize the growing interest and concern in urban design. While we in the transportation planning field are at the forefront in the urban design field, it is at a time when it is demonstrable that we cannot deliver a key element in the design process.

It is to the credit of the authors of this paper that they have attempted to solve the problem of the missing key element by showing how one might predict the manner in which the future trip length frequency distribution will differ from the present. Of course, if there is any truth at all to our contention that the formal properties of the model are such that when applied to a changed future structure of an urban area will develop spurious changes in the trip length distribution over and beyond that resulting from the change in the urban structure, it is obvious that the procedure suggested by the authors cannot provide the whole answer. This attempt by the authors is, again in our view and based only on the data presented in this paper, not successful, at least in the sense of being scientifically credible. Incidentally, our own solution to the problem, must be treated in the same way. We did something plausible, but our actions had no objective scientific basis.

The tenor of these remarks should make it clear that we believe, even at this late date, that we really do not know anywhere near enough about trip distribution models, except in the somewhat negative sense of being able to demonstrate that all available ones introduce as many questions as they seem to answer. In view of what we have been purporting to undertake, nothing less than the design of urban regions, this fundamental weakness of this most critical tool to transportation planners constitutes a crisis of awesome proportions. We need more and better research into a fundamental tool in our stock in trade and we need it immediately. To be useful such research must be more thoroughly documented than the paper at hand. Nor can such research be subject to the extraneous effects introduced by the mechanical properties of a model if the research is to be meaningful. Our needs are critical.

It is gratifying that this group of authors has developed a serious question as to the validity of the present day gravity model application. We in the Puget Sound Regional Transportation Study wish to join them in this. However, we are not satisfied that the research described in the paper under discussion has brought an answer nearer to hand.

To those engaged in the transportation planning field the earlier remark about the importance of this paper should now be obvious.

ALAN M. VOORHEES, SALVATORE J. BELLOMO, JOSEPH L. SCHOFER, and DONALD E. CLEVELAND, Closure—Keefer raises a relevant point with regard to the fact that the measurements of trip length need to be standardized. We know from transportation studies which we have conducted that different transportation zone configurations and varying procedures for estimation of intrazonal and terminal times greatly affect the measurement of work trip length distribution.

In response to Keefer's comments that we are talking in terms of "fixed time ranges" for average work trip lengths, we find no indication of this in the research we have conducted. In fact, we have found that the average work trip length can change upward, downward, or may change very little because some of the influencing factors may offset each other. We agree with Douglas Carroll that the trip length of the future depends upon many factors which are quite complex. However, our research has developed some guidelines which can be used to make estimates of how the trip length is likely to change in the future. Therefore we feel that it is no longer necessary to assume that trip length will remain static.

In reply to Dr. Tomazinis' comment that average urban density of development for the metropolitan area was not considered, it should be pointed out that we did consider average urban density. This variable, however, was eliminated because it did not add significantly to the multiple regression equations used to predict average work trip length. Overall urban density differences between the areas investigated did not account for observed changes in their respective work trip lengths. Density of development by location within the metropolitan area does influence the average work trip length. This was pointed out in Figure 3, which showed work trip opportunity distributions for selected zones in Washington, D. C. These three zones had different opportunity trip length distributions and, hence, had different density patterns surrounding them. It was also stated that the mean opportunity trip length and average work trip length were interrelated.

With regard to Dr. Tomazinis' comment that average regional income for the entire metropolitan area was not considered it should be noted that average regional income was not felt to be as meaningful a measure of work trip lengths as income by location within the metropolitan area. Table 2 points out the 1955 average work trip times for Washington, D. C., in the Northwest Corridor. Median family incomes of these workers were found to be directly related to average work trip lengths measured in minutes. Higher income areas were found to have longer average work trip lengths.

Dr. Tomazinis also mentions that the dispersion of employment was not considered in this analysis. We did consider it by the incorporation of the opportunity trip length distribution. This measure was quantified by calculating the mean of the trip length distribution generated by using employment as the attraction index and friction factors equal to one, along with standard gravity model trip distribution procedures. The variable was found to be significant and was included in the developed guidelines for predicting the mean work trip length.

Mladinov and Cowan expressed concern over substantiation of this research document. This paper has been documented by presentation of relevant tables, figures, and source materials. Inferences made from data available and based on professional opinion have been clearly stated and separated from the conclusions based on regression analyses, etc. Additional documentation of the simulation study methodology referred to by Mladinov and Cowan can be found in "Factors Influencing Work Trip Length," a document to be published by the Highway Research Board.

Mladinov and Cowan raise some very meaningful and serious questions about the gravity model itself. We feel that there are serious deficiencies both in the gravity model and opportunity model, which have been utilized thus far in many of our transportation studies. Based on changes in the opportunity distribution, both F travel time factors and L factors can change. This finding was recognized in an earlier work by Tomazinis and Wickstrom in the development of a comprehensive transportation flow model for the Penn-Jersey Transportation Study. Trip distribution models should consider not only traveler cost impedances and opportunity distributions but also land activity forecasts. The transportation planning process works by a series of interconnecting feedbacks. Much of the work done on transportation studies we are presently conducting points to this intricate feedback in trip generation, mode split trip distribution, and assignment.

In response to Mladinov and Cowan's comments concerning simulation studies and their validity in this analysis, it should be noted that it is difficult to put a city in a test tube and observe changes in it over time. It is very difficult to reach precise conclusions because of the complexities of the many cities analyzed. Inferences were made from available data and the results of this simulation study to produce the guidelines outlined in this paper.

If a metropolitan area changes dramatically in terms of network speeds and structure, careful checks should be made on the forecasted work trip lengths using the guidelines presented in this paper. We have found that extreme care must be exercised in the development of future network speeds in the gravity model so that proper travel time factors can be applied for any given zone-to-zone movement.

The real issue raised by all discussants seems to be one of sensitivity of the trip distribution model, which determines future trip length, to errors incurred in projection of its basic parameters. How sensitive is the trip transfer matrix to changes or errors in using travel time factors for tomorrow's conditions? This sensitivity is important to know and understand because it affects major decisions about transportation planning. The continuing programs of the transportation studies will monitor and check over time the reasonableness of the model parameters and assignment procedures so that planning capital works programs can be accelerated or decelerated based on their periodic evaluations.

Census Data as a Source for Urban Transportation Planning

RONALD J. FISHER and ARTHUR B. SOSSLAU, Tri-State Transportation Committee

•POPULATION, housing and numerous other socioeconomic data collected and published by the United States Bureau of the Census decennially have been a valuable source to urban transportation planning studies for analyses and forecasts. In 1960, information was collected for the first time on the journey-to-work and automobile ownership. These data have greatly enhanced the value of the census for urban transportation planning studies. In addition to the printed reports, the 1960 Census data are also available on computer magnetic tapes for use by other agencies.

The Tri-State Transportation Committee, financed by Connecticut, New Jersey, and New York, the Federal Government through the U. S. Bureau of Public Roads, and the U. S. Department of Housing and Urban Development, has made considerable use of census data both in printed form and on magnetic tapes. In addition to analyses made, a number of reports have been prepared, covering the journey-to-work in the Tri-State Region, as well as tape files that can be readily used by other agencies in the region. The experience gained in the use of this source may be of value to others contemplating its use.

The purpose of this paper is five-fold:

1. To present the uses made of the census data by the Tri-State Transportation Committee.
2. To indicate possibilities for the use of future censuses.
3. To describe the census data sources available on magnetic tape.
4. To discuss the limitations of the data for transportation planning.
5. To help those interested in the census as a data source for transportation planning to form suggestions for improving future censuses.

USES OF CENSUS DATA

A considerable number of uses and analyses of the census data have already been undertaken by the Tri-State Transportation Committee, including:

1. Selection of the Tri-State cordon line.
2. Selection and verification of home interview sampling accomplished from utility company records.
3. Study of trends in population and housing units from 1940 to 1960.
4. Examination of travel-oriented characteristics, such as mode choice and trip length.
5. Comparison of data obtained from the Tri-State 1 percent home interview survey with comparable data from the census to check the validity of the survey.
6. Examination of residential mobility characteristics.
7. Preparation of displays and reports that have provided insights into work travel and related characteristics, which will be further analyzed from the home interview survey.

Selection of Cordon Line

The choice of the Tri-State cordon line was predicated on the following basic factor: the area thus enclosed would include all continuous urban development as well as most of the expected population increase estimated for the future (1980). The two items

Paper sponsored by Committee on Origin and Destination and presented at the 45th Annual Meeting.

considered in determining the extent of urbanization in the Tri-State Region were population density and car ownership. These data were gathered from printed census sources. Figure 1 is a plot of population density per acre by municipality for the Tri-State Region. It is a good indication of population dispersion from highly intense urbanization centering on Manhattan to a suburban and then rural density as the distance from the center increases. It provides a visual idea of the area that should be encompassed by a cordon line.

The census also provided a more usable indication of car ownership by geographic area than was readily available from automobile registration sources. Figure 2 shows the per-acre distribution of automobiles by county and again provides a visualization of a cordon line location.

Population and auto availability data as well as criteria on roadside interview station locations permitted a number of tentative lines to be established, each with an encompassed population determined from the census. The tentative cordon lines were used to determine the extent and shape of the study area. Between the tantative cordons, segmented population figures were calculated to evaluate the addition of certain land areas to each preceding cordon line to determine if each particular population increase was warranted. The line finally chosen is shown in Figure 3.

Selection and Verification of Home Interview Sample

A 1 percent home interview survey was collected from households within the cordon line shown in Figure 3. A number of sampling frames were used as sources for selection of a 1 percent probability sample of living places in the cordon area.

Within New York City, the census provided the basis for the sample selection. In cooperation with another public agency, which had already completed the necessary preparatory work, a 1 percent clustered area probability sample was selected. The sampling frames were defined by two strata:

1. The civilian, non-institutional population living in housing units and other special dwelling places in existence according to the 1960 Census of Population and Housing. Census block data were used for this purpose.
2. Housing units built during the period between the 1960 Census and February 28, 1963, as represented by occupancy certificates obtained from the New York City Department of Buildings.

Outside of New York City, the records of the various electric utility companies were used as a sampling frame. However, some towns were not covered this way. Instead, these enclaves were sampled by means of a block field listing procedure. Immediately after the selection of the sample from the frame, various checks were applied to insure its reasonableness when compared to published sources. Again, census data on housing units by municipality were used after updating by building permit data for this comparison. Any large discrepancies were checked in detail.

Study of Population, Housing and Employment Trends 1940-1960

As a preliminary step to understanding past growth, and as an aid to the forecasting of future population, housing and employment characteristics of the residents of the region, a "county level" minimum comparability file has been developed and made operational. This magnetic tape file contains 18 data items including: "population"—all persons by 5-year age groups; "housing units"—total by race and tenure; and "labor force"—occupation by sex and industry. The file was prepared from published and unpublished U.S. Census sources for 1940 and 1950 and from census tapes for 1960. It covers all 25 counties in the Tri-State Region. The data stratifications used by the census for the three periods have been compressed and regrouped to provide definitional consistency and comparability over the period 1940-1960.

Selected items can be retrieved as needed, in phase with the requirements of the Tri-State Transportation Committee's analytical progress. The file has been used in preparation of a first projection of total regional and county populations to 1985, preparation of a series of county population density maps over the 1940-1985 period, and

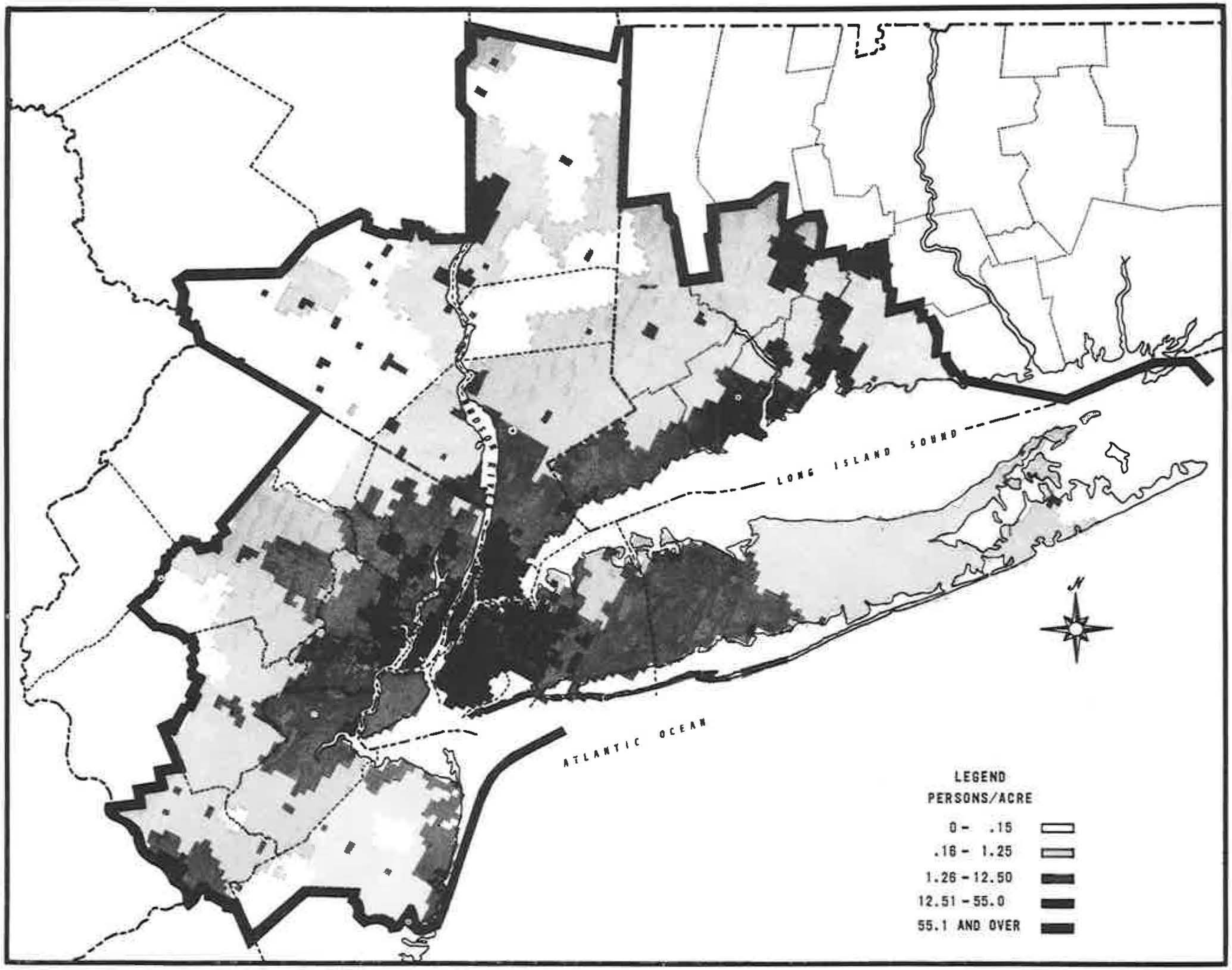


Figure 1. Population density by municipality.

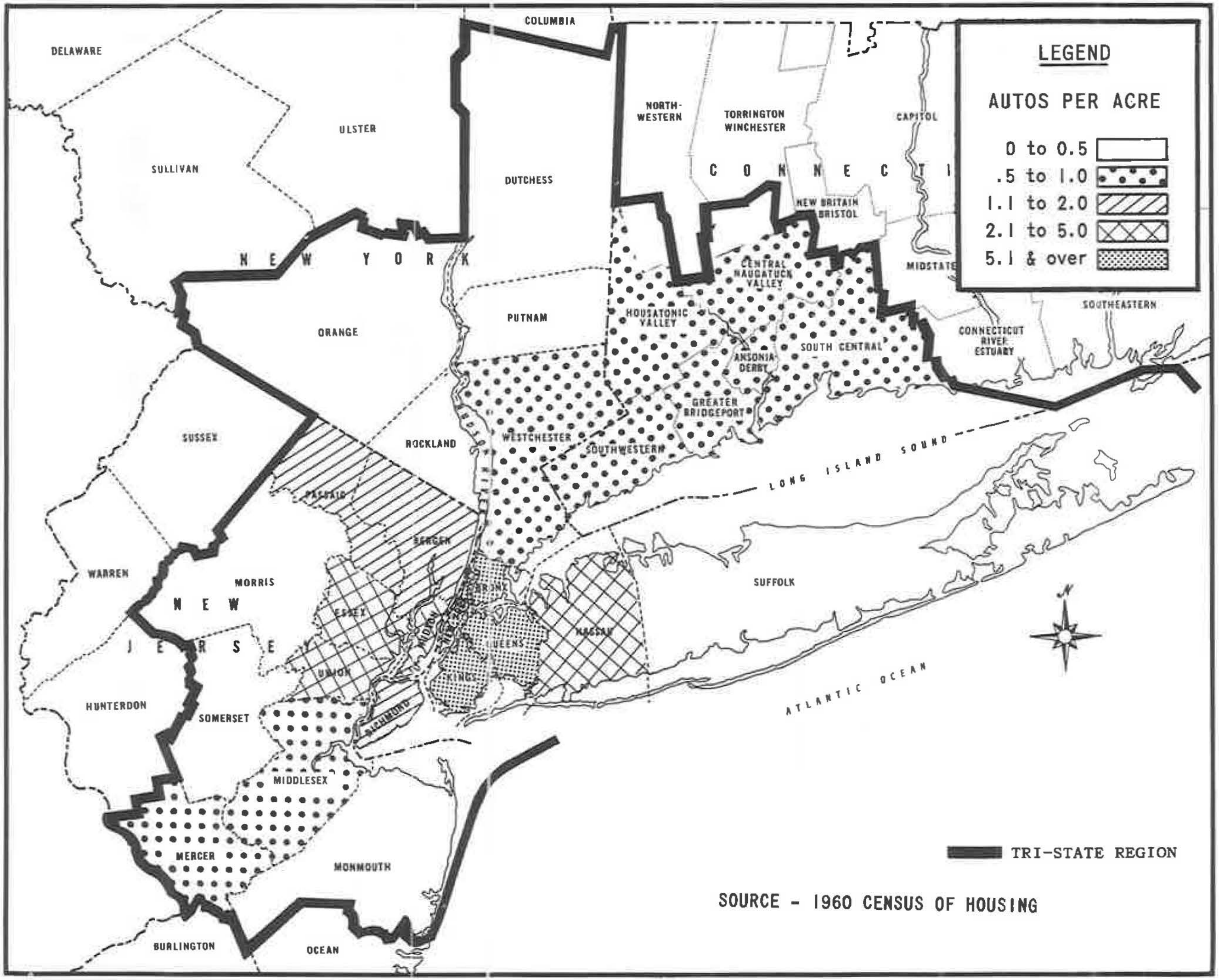


Figure 2. Autos per acre by county.

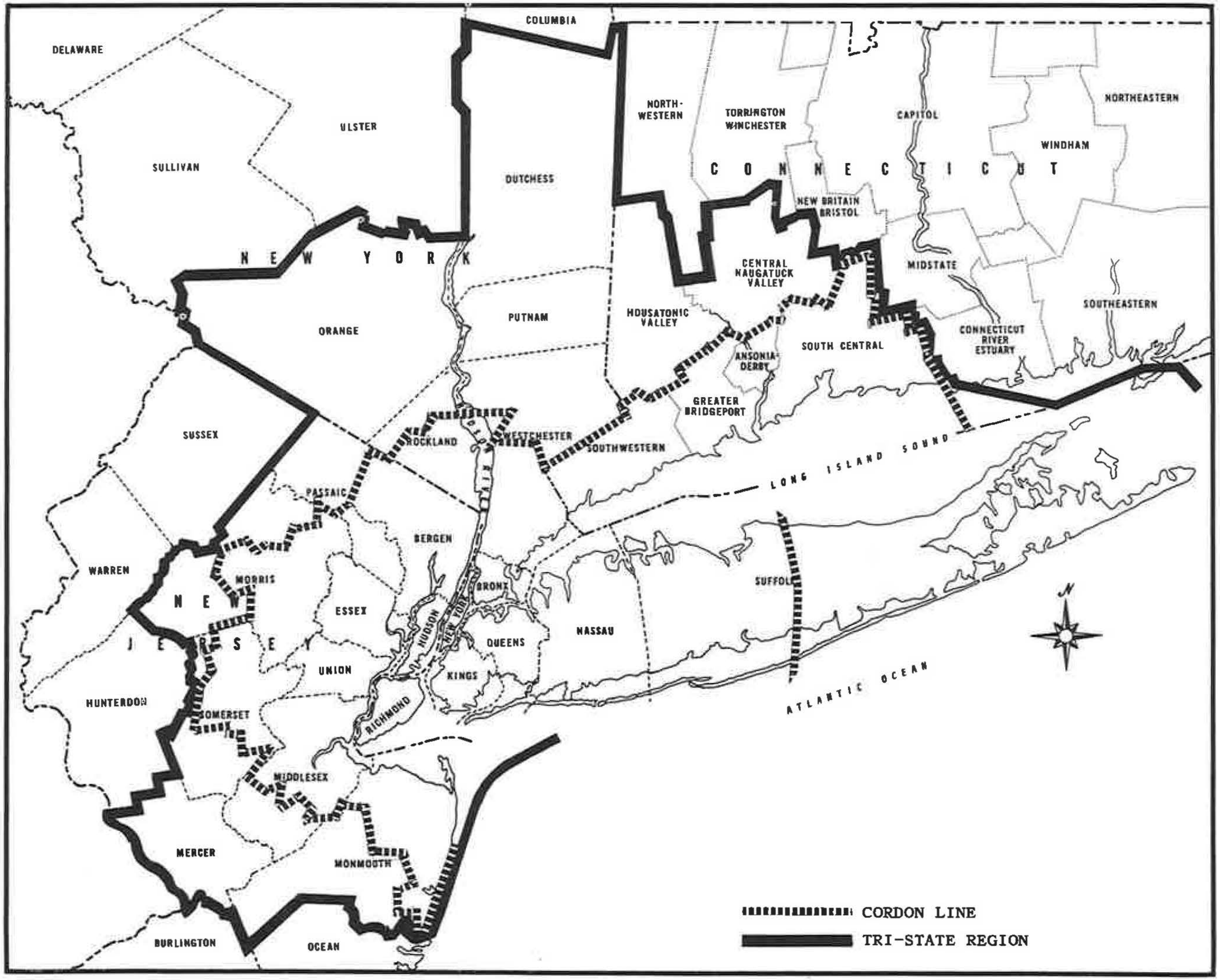


Figure 3. Tri-State cordon area.

preparation of preliminary estimates of the number of occupied housing units by structure type by county as an input to the interim traffic estimating procedures developed by Tri-State. The file also assisted in estimating the 1985 distribution of families and unrelated individuals by income class and in preparing preliminary sketches of land development alternatives.

More detailed analysis to which this file will be put include such efforts as age-cohort survival techniques of population projections, and intensive investigation of relationships between population distribution, composition (age, sex, race, etc.) and developments in income, employment, occupation and levels of education.

Travel Oriented Characteristics Such as Mode Choice and Trip Length

Although the level of areal detail available in the census journey-to-work material is at present gross (being composed of counties and major cities within the Tri-State Region), analysis of trip lengths by workers using different major modes of travel and of varying socioeconomic characteristics was made.

For the Tri-State Region, the 29BB census file was consolidated to 3332 records. Each record contained a residence code, a work place code, and information on the number of journey-to-work trips by mode, by sex, by age, by occupation and by income. The geographic areas were counties and major cities (groups of towns in Connecticut) and amounted to 67 zones in the Tri-State Region, 47 of which had complete employment coverage. The approximate geographic centroids were determined for each zone, and their coordinates were entered in each zone-to-zone record. From these data, the distances between the residence and work places were calculated and entered in each record, making possible the calculation of average trip lengths for each mode and socio-economic characteristic in the record.

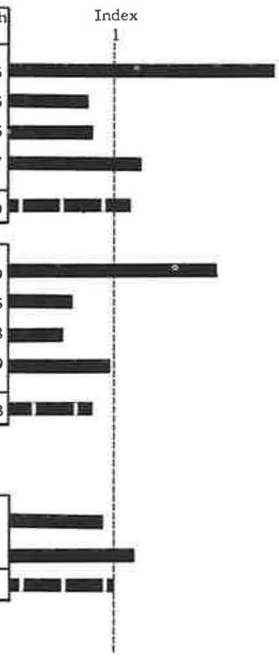
On the basis of these data, a few limitations must be placed on trip lengths. First, people reported the place worked the longest during the week prior to the interview, if they had more than one job. Data were recorded at the usual place of residence even though the respondent may have been interviewed elsewhere. This tends to increase the trip lengths. Second, the gross areal detail tends to increase all average trip lengths. Third, only the primary mode is recorded from the respondent's interpretation of the mode involving the longest travel distance. Average trip length for a mode would be different if each leg of a multi-mode trip could be given weighted consideration. Finally, the data do not completely cover all employment in the Region. Only data for Standard Metropolitan Statistical Areas (SMSA's) with populations of 250,000 or more (there are seven SMSA's in the Tri-State Region) were processed by the Bureau of the Census. Approximately 90 percent of the Region's workers are represented in the 29BB tapes.

Consequently, the trip lengths developed from present census sources should best be viewed on their relative significance rather than their absolute value. An index, derived by dividing the average trip length for all workers using mass transit or auto and carpool into each subpopulation defined by mode or socioeconomic status, was calculated for this purpose. The data proved useful, since they offered information on trip lengths before the Tri-State travel surveys were processed.

Figures 4 through 8 show the results of the trip length analysis. A recapitulation of the basic findings from these trip length data follows:

1. People using some form of mass transit for work trips travel 30 percent less on the average than those using auto or carpool.
2. Considering just the railroad commuters in the portion using mass transit, one finds longer average trip lengths than in any other grouping of workers analyzed.
3. Workers grouped by income or mode and income indicate longer trips are made by higher incomes.
4. Trip lengths vary slightly with age.
5. Males are likely to make a longer trip than females of the same age or occupation, or traveling via the same mode.

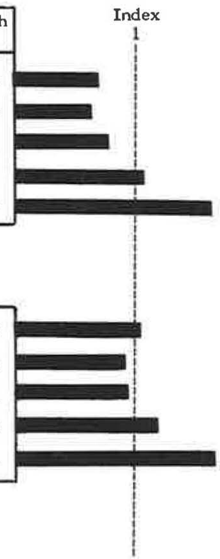
	No. Workers	Trip Length Index*
Males:		
Railroad	236,577	2.496
Subway & Elevated	1,027,417	0.705
Bus & Street Car	408,335	0.756
Auto & Carpool	1,980,051	1.227
Total Males	3,652,380	1.109
Females:		
Railroad	59,179	1.919
Subway & Elevated	630,221	0.665
Bus & Street Car	453,940	0.568
Auto & Carpool	538,193	0.909
Total Females	1,681,533	0.763
Total Mass Transit	2,815,669	0.857
Total Auto & Carpool	2,518,244	1.159
Grand Total	5,333,913	1.000



*THE BASE FOR COMPUTING THESE INDICES IS THE AVERAGE TRIP LENGTH OF ALL WORKERS TRAVELING VIA MASS TRANSIT OR AUTO AND CARPOOL.

Figure 4. Average trip lengths for the journey-to-work in the Tri-State Region, by sex, by mode.

	No. Workers	Trip Length Index*
Mass Transit:		
Earning $1 to $1999	441,513	0.714
" $2000 to $3999	912,845	0.674
" $4000 to $5999	762,884	0.801
" $6000 to $9999	414,527	1.134
$10,000 & Over	181,205	1.719
Auto & Carpool:		
Earning $1 to 1999	239,613	1.063
" $2000 to 3999	455,416	0.960
" $4000 to 5999	801,021	0.991
" $6000 to 9999	696,704	1.263
$10,000 & Over	252,804	1.761

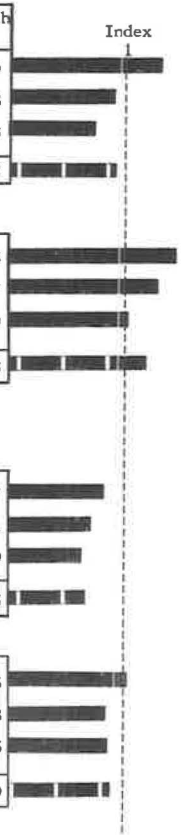


* EXCLUDED FROM THIS DISTRIBUTION ARE WORKERS NOT REPORTING MODE AND WORKERS WITH NO EARNINGS.

** THE BASE FOR COMPUTING THESE INDICES IS THE AVERAGE TRIP LENGTH OF ALL WORKERS TRAVELING VIA MASS TRANSIT OR AUTO AND CARPOOL.

Figure 5. Average trip lengths for the journey-to-work in the Tri-State Region, by earnings, by mode.

	No. Workers	Trip Length Index*
Male via Mass Transit:		
Professional & Manager	403,430	1.349
Sales & Clerical	389,597	0.943
Other & not Reported	861,994	0.788
Total	1,655,021	0.962
Male via Auto & Carpool:		
Professional & Manager	548,951	1.475
Sales & Clerical	321,032	1.317
Other & not Reported	1,084,926	1.039
Total	1,954,909	1.208
Female via Mass Transit:		
Professional & Manager	126,085	0.817
Sales & Clerical	561,818	0.711
Other & not Reported	442,711	0.619
Total	1,130,614	0.685
Female via Auto & Carpool		
Professional & Manager	131,655	1.016
Sales & Clerical	241,631	0.853
Other & not Reported	158,583	0.876
Total	531,869	0.899

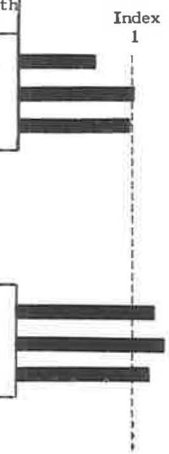


* EXCLUDED FROM THIS DISTRIBUTION ARE WORKERS NOT REPORTING MODE AND WORKERS IN THE ARMED FORCES.

** THE BASE FOR COMPUTING THESE INDICES IS THE AVERAGE TRIP LENGTH OF ALL WORKERS TRAVELING VIA MASS TRANSIT OR AUTO AND CARPOOL.

Figure 6. Average trip lengths for the journey-to-work in the Tri-State Region, by sex, by mode, by occupation.

	No. Workers	Trip Length Index*
Male via Mass Transit by Age:		
14 to 24	194,080	.763
25 to 44	690,136	1.011
45 & Over	773,377	.974
Males via Auto or Carpool by Age:		
14 to 24	169,209	1.193
25 to 44	1,053,802	1.271
45 & Over	739,855	1.140



*THE BASE FOR COMPUTING THESE INDICES IS THE AVERAGE TRIP LENGTH OF ALL WORKERS TRAVELING VIA MASS TRANSIT OR AUTO AND CARPOOL.

Figure 7. Average trip lengths for the journey-to-work in the Tri-State Region, by mode, by sex, by age.

6. Trip lengths for people who moved to a different house between 1955 and 1960 are slightly longer than those who did not move.

7. People who moved into the Tri-State Region since 1955 or lived in a different county in a different SMSA in the Tri-State Region in 1955, traveled 80 percent farther to work than people in the Region who had not moved.

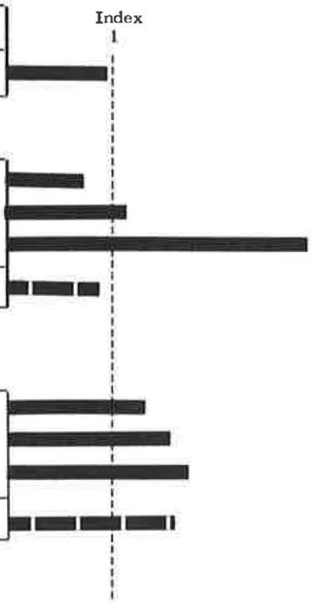
In addition to the trip length analysis, tabulations were produced from 29BB journey-to-work tapes for each of the 47 zones having complete data coverage in the Tri-State Region that show the cross correlations between the percentage of workers using mass transit and the following socioeconomic characteristics: age, sex, earnings and occupation.

Due to the rather large data areas, only a limited overview was possible. However, this overview provided groundwork for more detailed work trip analysis to be undertaken with the extensive travel surveys made by the Tri-State Transportation Committee. A summary of the findings will be presented here.

The propensity for males and/or females in particular age groups to use mass transit for work trips is shown in Figure 9. These data are further stratified as to population density at place of residence and place of work for internal trips, at place of residence for export trips, and place of work for import trips. Figure 9 also shows the relationship of the captive rider market to mass transit usage. The females as a group are more apt to use mass transit than males. Mass transit usage dips for both sexes in the 25 to 44-year old age group.

Figure 10 shows the relation between worker earnings and mass transit usage. Internal and import worker streams at this rather gross level of detail show an inverse relationship between earnings and mass transit usage. Figure 11 shows that this is mostly caused by an unusually large portion of workers with high earnings going to Manhattan. In general, a larger portion of the export workers with high earnings are

	No. Workers	Trip Length Index*
Same House in 1955	3,388,453	.964
Dif. House Same County:		
Ctr. City Same SMSA	1,116,033	.720
Ring Same SMSA	498,542	1.106
Outside This SMSA	30,897	2.678
Total	1,645,472	.872
Dif. House Dif County:		
Ctr. City Same SMSA	430,744	1.277
Ring Same SMSA	86,694	1.492
Outside This SMSA	461,035	1.750
Total	978,473	1.520



*THE BASE FOR COMPUTING THESE INDICES IS THE AVERAGE TRIP LENGTH OF ALL WORKERS TRAVELING VIA MASS TRANSIT OR AUTO AND CARPOOL.

Figure 8. Average trip lengths for the journey-to-work in the Tri-State Region, by residence in 1955.

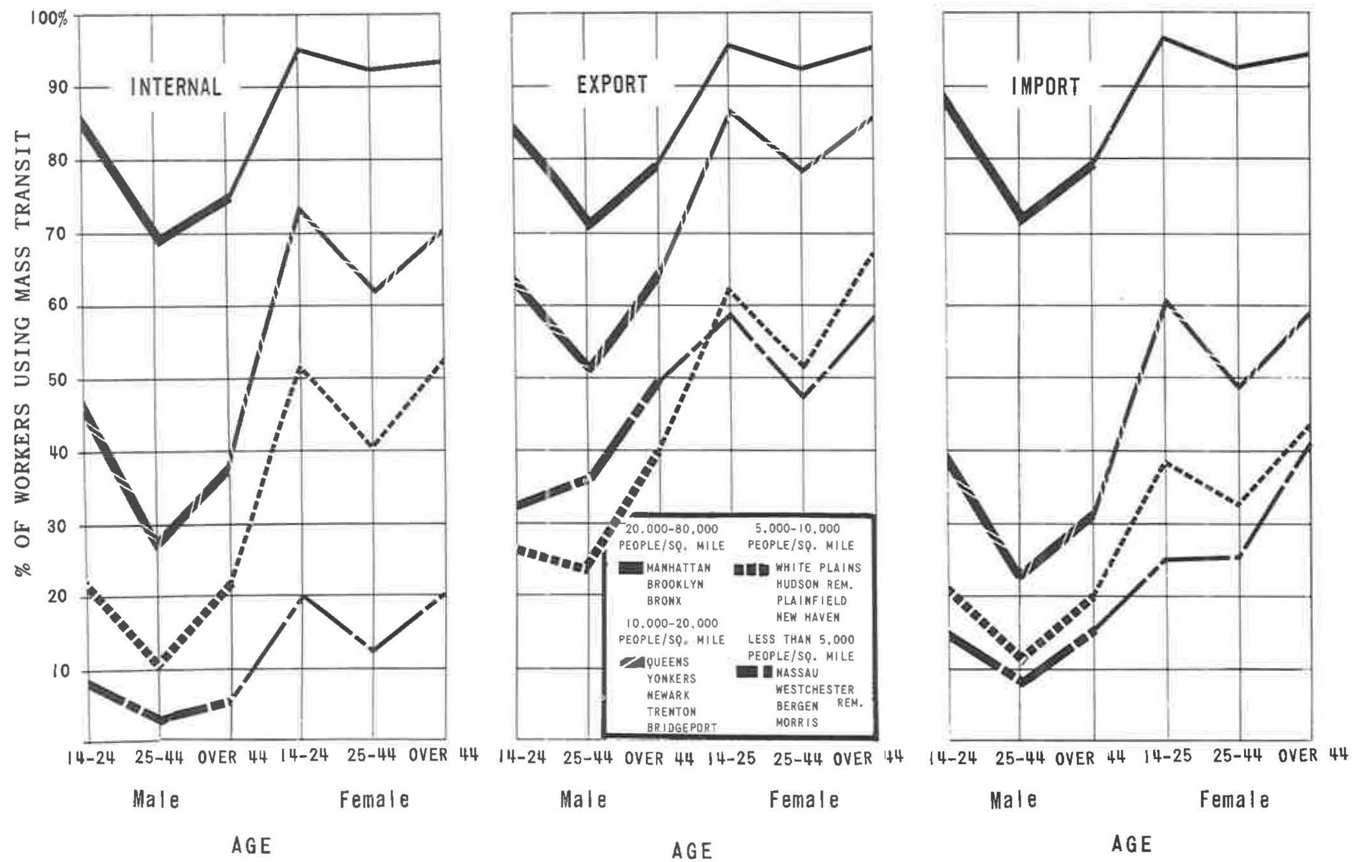


Figure 9. Mass transit usage by age, sex, population density.

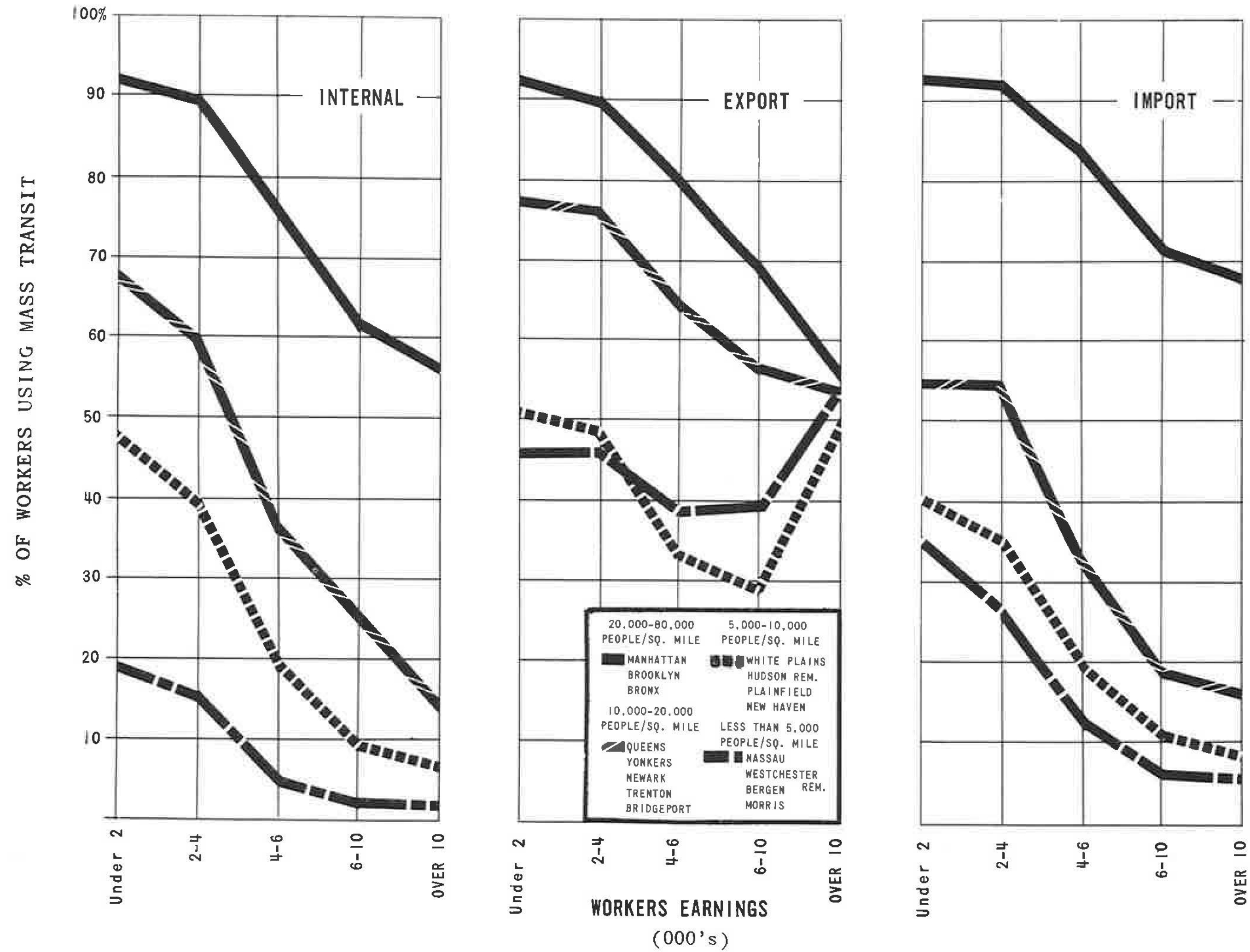


Figure 10. Mass transit usage in different density and income strata.

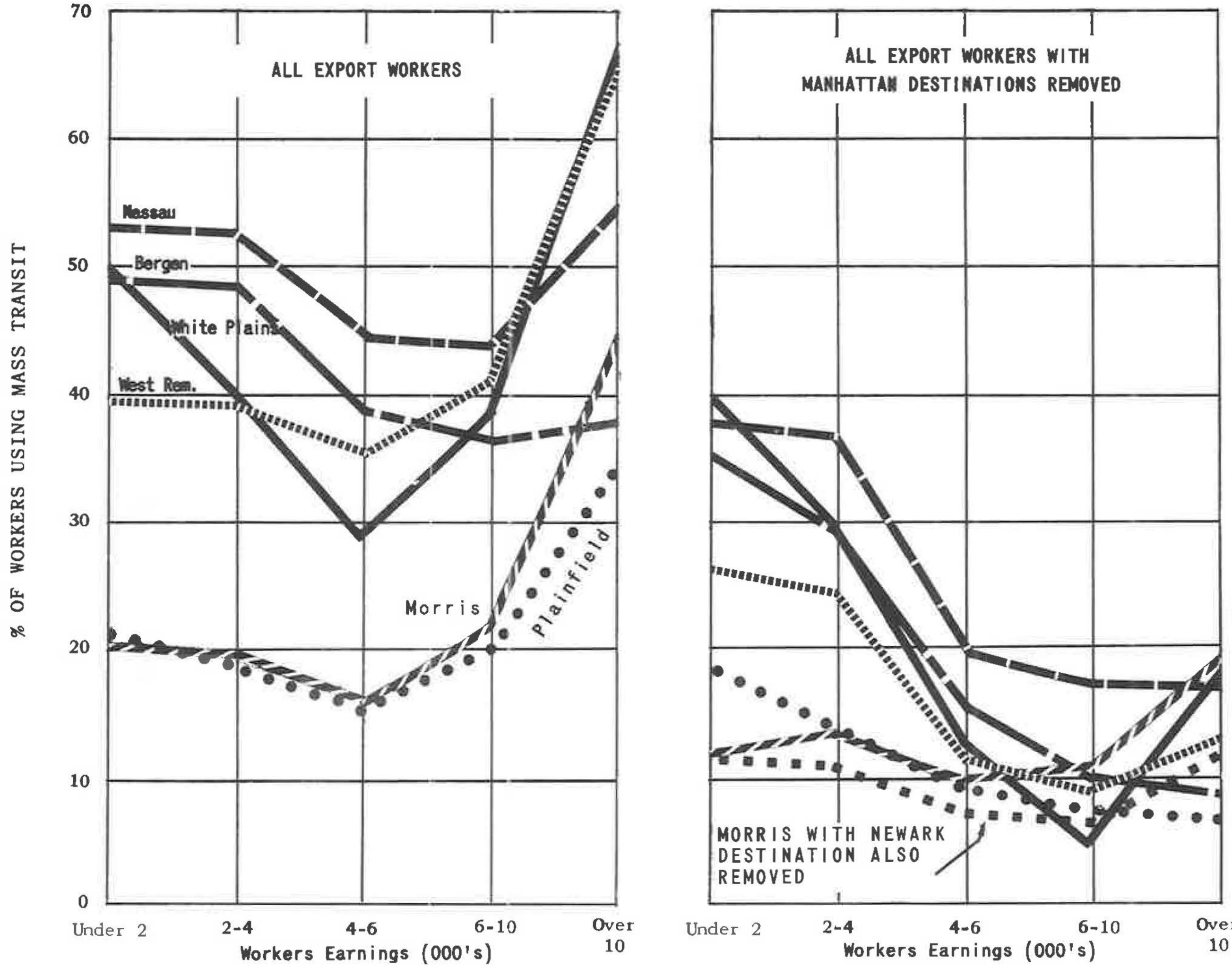


Figure 11. Manhattan influence on mass transit usage.

destined for highly dense areas. It appears that at this gross level of detail mass transit usage decreases with rising income when the density of the destination does not increase greatly over the origin.

Figure 12 shows the mass transit usage to Manhattan from each of the three states in the Tri-State Region. It gives an interesting hint of how the cost, relative comfort and convenience of transit service influence the market. At low levels of income, the rate of mass transit usage to Manhattan is less in New Jersey and Connecticut than in New York. In New York State, the rate of mass transit usage is inversely related to income and the graph is very similar to the one plotted for Manhattan's import workers. Rising mass transit usage with rising income is very evident in Connecticut.

Again, looking for the relationship at a lower level of detail, Figures 13 and 14 show mass transit usage between particular origins and destinations. Unfortunately, this is the lowest level of detail available on the census computer tapes.

Comparison of Survey Data With Census Data

A traditional use of the census data is currently being undertaken by the Tri-State Transportation Committee. That is, the comparison of home interview survey results with that of the census. The Tri-State home interview sample contains 1 percent of the households in the region. The census contains some comparable items on a 25 percent and 100 percent basis. Reasonableness checks of the survey data with the census provide an indication of the completeness of the survey and the validity of the sample. The types of items which will be compared by geographic area include:

1. Population by age and sex;
2. Number of dwelling units;
3. Number of dwelling units by the number of units in the structure;
4. Income;
5. Occupation and industry of resident workers;
6. Number of vehicles available;
7. Number of families with 0, 1, 2, and 3 or more vehicles;
8. The distribution of the first work trip on a gross area basis, such as county;
9. Various ratios obtained from the above items such as persons per household and cars per person.

The Census data are for 1960; the home interview survey is for 1963. Care must be taken that apparent differences are not due to changes occurring during the three years and that adjustments are provided where necessary prior to comparison. With this consideration in mind, many data items will be compared on a proportion basis as well as absolute values. For example, the proportion of workers to Manhattan from a residence area such as Brooklyn will be compared as well as the total number of work trips from Brooklyn to Manhattan.

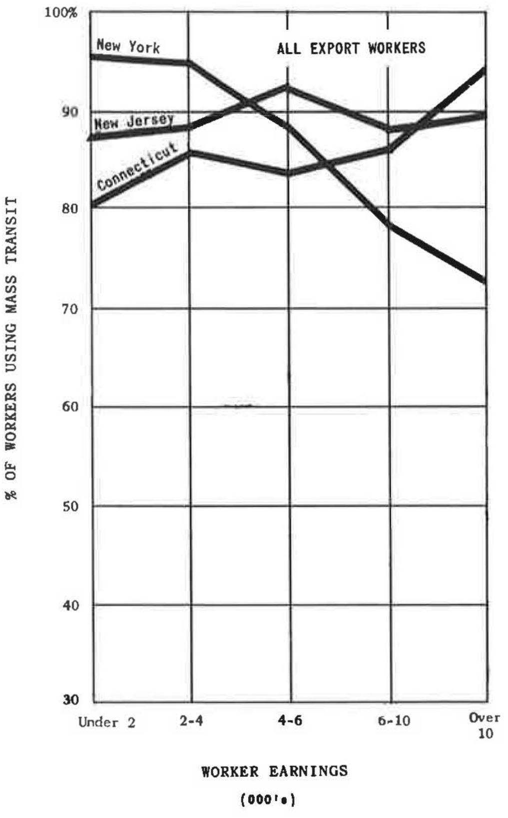


Figure 12. Mass transit usage to Manhattan from portion of each state in Tri-State Region.

Residential Mobility

In the 1960 Census of Population, mobility data were collected for all persons five years and older living in a standard

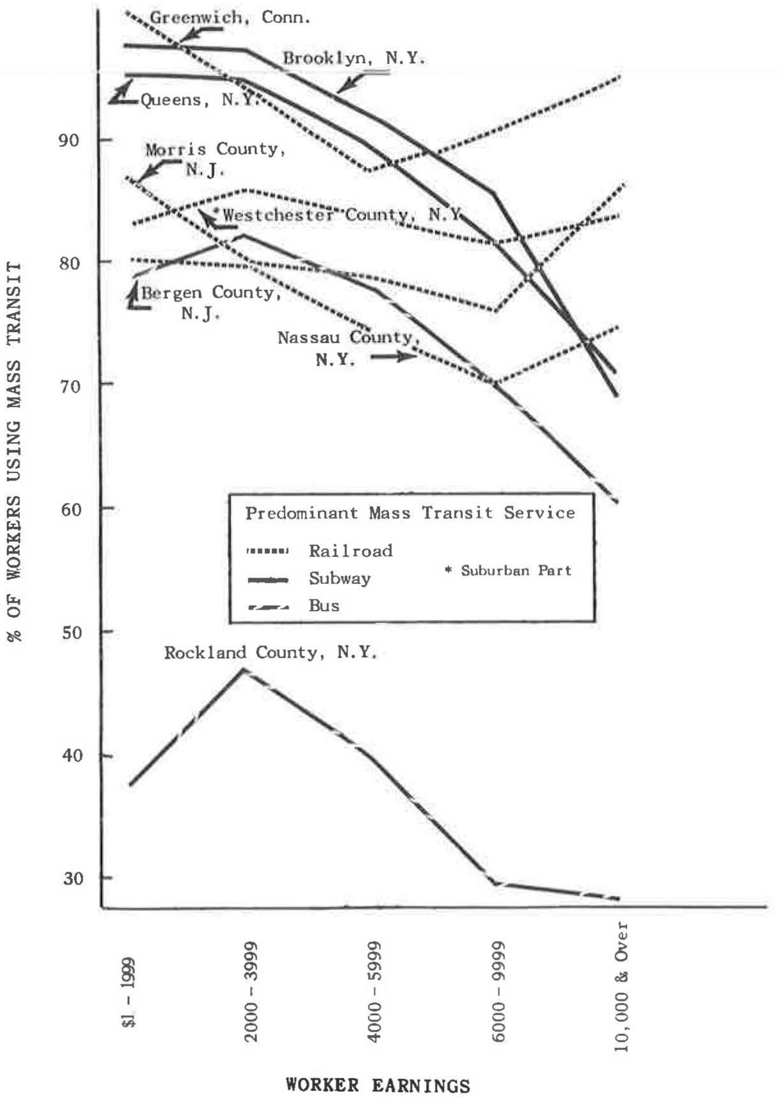


Figure 13. Mass transit usage to Manhattan from selected origins.

metropolitan area. These data describe the residence of these persons on April 1, 1955, according to the following classifications:

Residence in 1955 for Persons 5 years old and over, 1960

- Same House as in 1960
- Different House in U.S.
  - Central City of this SMSA
  - Other Part of this SMSA
  - Outside this SMSA
    - North and West
    - South
  - Abroad
  - Moved, Residence in 1955 not reported

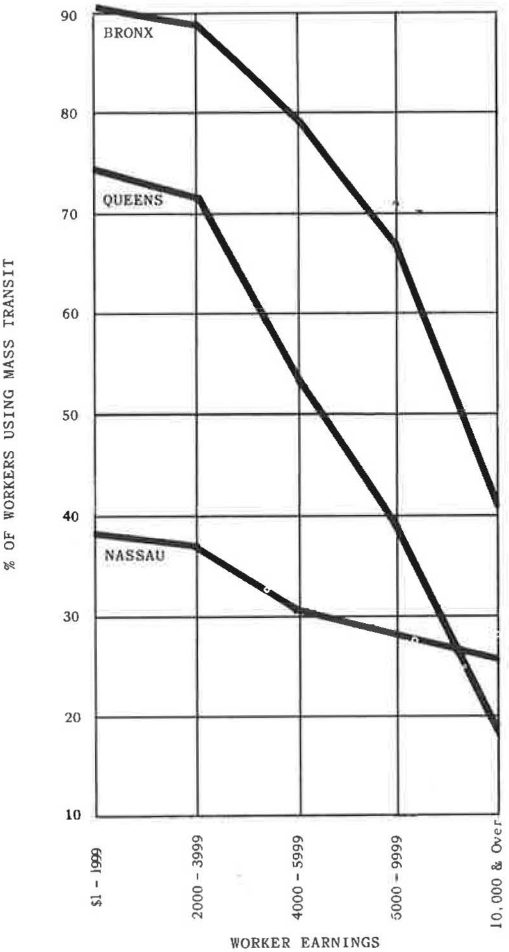


Figure 14. Mass transit usage to Brooklyn from selected origins.

These mobility data viewed at the county or city level enable the analyst to take an overall view of the residential movements within the region. An analysis of the relative stability of the population by geographic area is useful for forecasting population and employment related characteristics.

Data for the New York SMSA are used to illustrate some of the findings from a preliminary probe that can be derived from the census on mobility patterns. For New York City, movement (1955 to 1960) has been within, with 88 percent of the moving population (persons who reside in a specific house or apartment in New York City in 1960 but resided elsewhere in the U. S. in 1955) contained in the city. In fact, more people migrated to New York City from abroad (foreign country, Commonwealth of Puerto Rico, or a possession of the United States) than entered this area from the United States outside the New York SMSA. The counties outside New York City may also be compared as to trends in the five-year period 1955-60 (see Table below).

This mobility may also be viewed at a lower level using the census tracts as basic units. At this level, Table H-2 of U. S. Census of Population and Housing (PHC 1) reports the year moved into the present housing unit by the following stratifications: (a) 1958 to March 1960, (b) 1954 to 1957, (c) 1940 to 1953, and (d) 1939 or earlier.

Use of the census 29BB computer tapes yields additional data in explaining the effect of mobility patterns. The tape output describes the universe of workers who have moved since 1955 into the following two categories: (a) moved within the county, and (b) moved into the county. In addition, the above groupings are also stratified into: (1) central city, and (2) ring of the SMSA under study.

County	Persons Residing in County 1960 but in Diff. House in U.S. in 1955		All Persons (% Persons that have not changed residence 1955-60)
	% from N.Y.C.	% from Total N.Y. SMSA	
Nassau	50	89	58
Suffolk	38	89	48
Rockland	32	79	47
Westchester	23	83	54

Preparation of Displays and Reports

Summarization and analysis of the census material was undertaken by the Tri-State Transportation Committee shortly after interviewing for the travel surveys was started in the field. During the period in which the Tri-State survey data were collected, coded, edited, factored and summarized, the census data offered a source for obtaining insights into work travel and related characteristics which would be further analyzed from the home interview survey. The material also proved useful for some immediate action, or short-range planning work, undertaken by the Committee and for answering specific questions concerning transit usage in a few locations in the Tri-State Region.

The data, in magnetic tape form, also lend themselves readily to the preparation of automatic data displays on the Tri-State modified EAI model 3500 data plotter. The basic source for the automatic plots was the 29I census file. This tape contains detailed population characteristics for the 4103 census areas (generally tracts) in the Tri-State Region. For a number of data items, inputs were prepared for the plotter that would allow plotting a different symbol for each of 20 ranges established for each item. These symbols are plotted at the geographic centroid of each census area. A final display is prepared manually after analyses of the plot.

A later advancement of this technique provided for the assignment of grid squares to each census tract with the subsequent automatic plotting of a completed color display.

The tract data from the 29I census tapes also allowed XY data plots to be automatically prepared by a 1401 computer on a 1403 printer. For example, a plot was prepared relating percent auto usage to automobiles per household as shown in Figure 15.

A number of descriptive reports prepared from the census material presented a good first picture of the journey-to-work that would be subsequently brightened by the Tri-State travel surveys. Their titles are listed as follows along with a brief annotation.

1. Journey-to-Work in the Tri-State Region, May 1964: Describes work travel in the Tri-State Region from three viewpoints: (a) those workers leaving each county to work (export), (b) those workers coming into each county for work (import), and (c) those living and working in the same county (internal). A square trip table containing 24 counties is contained for mass transit trips, for automobile trips, and for total trips.
2. Journey-to-Work in the New York City SMSA: Describes the characteristics of workers using public and private transportation by a number of socio-economic characteristics, including income, occupation, sex, and age. The subgroups described are those who live and work in New York City, those who live and work in a suburban county, those who live in the suburbs and work in New York City, those who live in New York City and work in the suburbs, etc. Figure 16 is a sample display for those who live and work in New York City.
3. Characteristics of Workers by Place of Residence—Interim Technical Report 4014-3442: Set of tables for each of 47 counties and major cities in the Tri-State Region (for which complete coverage in the journey-to-work survey is available) containing the number and percent of workers by mode, occupation, income, hours worked, age and sex, housing, schooling, mobility, and class of worker. The data are listed by place of residence for three worker groups: internal, export and total workers.
4. Characteristics of Workers by Place of Employment—Interim Technical Report 4014-3442: Same as Item 3 except data are summarized at the employment place rather than residence and the three worker groups are internal, import, and total employees.
5. Characteristics of Mass Transit Users by Place of Residence—Interim Technical Report 4014-3442: Set of tables for each of 47 counties and major cities containing information on the users of mass transit. The number of transit users are presented by age and sex, occupation and sex, earnings, age and occupation. The percent of each group using mass transit is also included. The workers are further subdivided into internal workers, export workers and total workers.
6. Characteristics of Mass Transit Users by Place of Employment—Interim Technical Report 4014-3442: Same as Item 5 except data are summarized at the employment

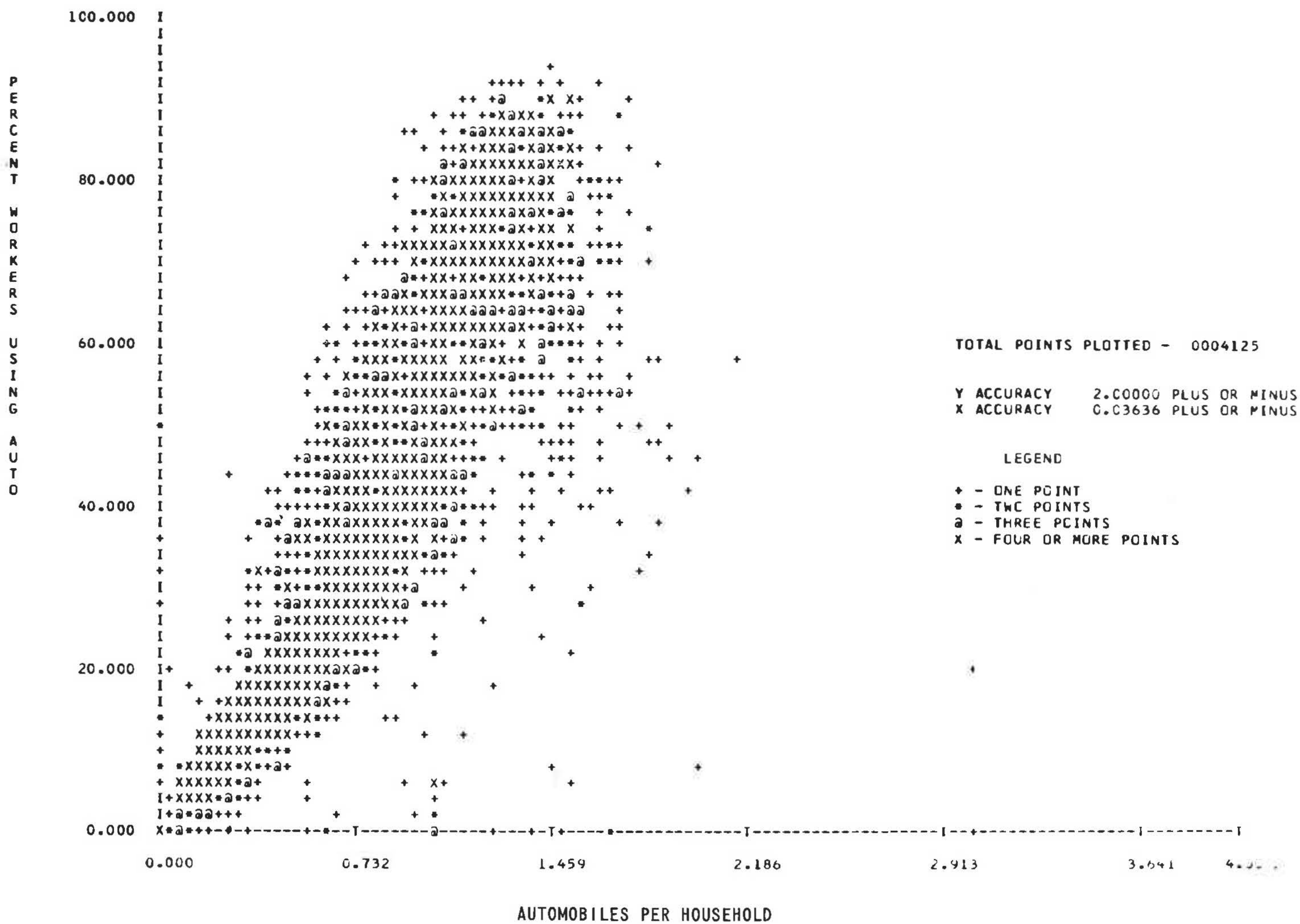


Figure 15. Percent of workers using auto vs autos per household.

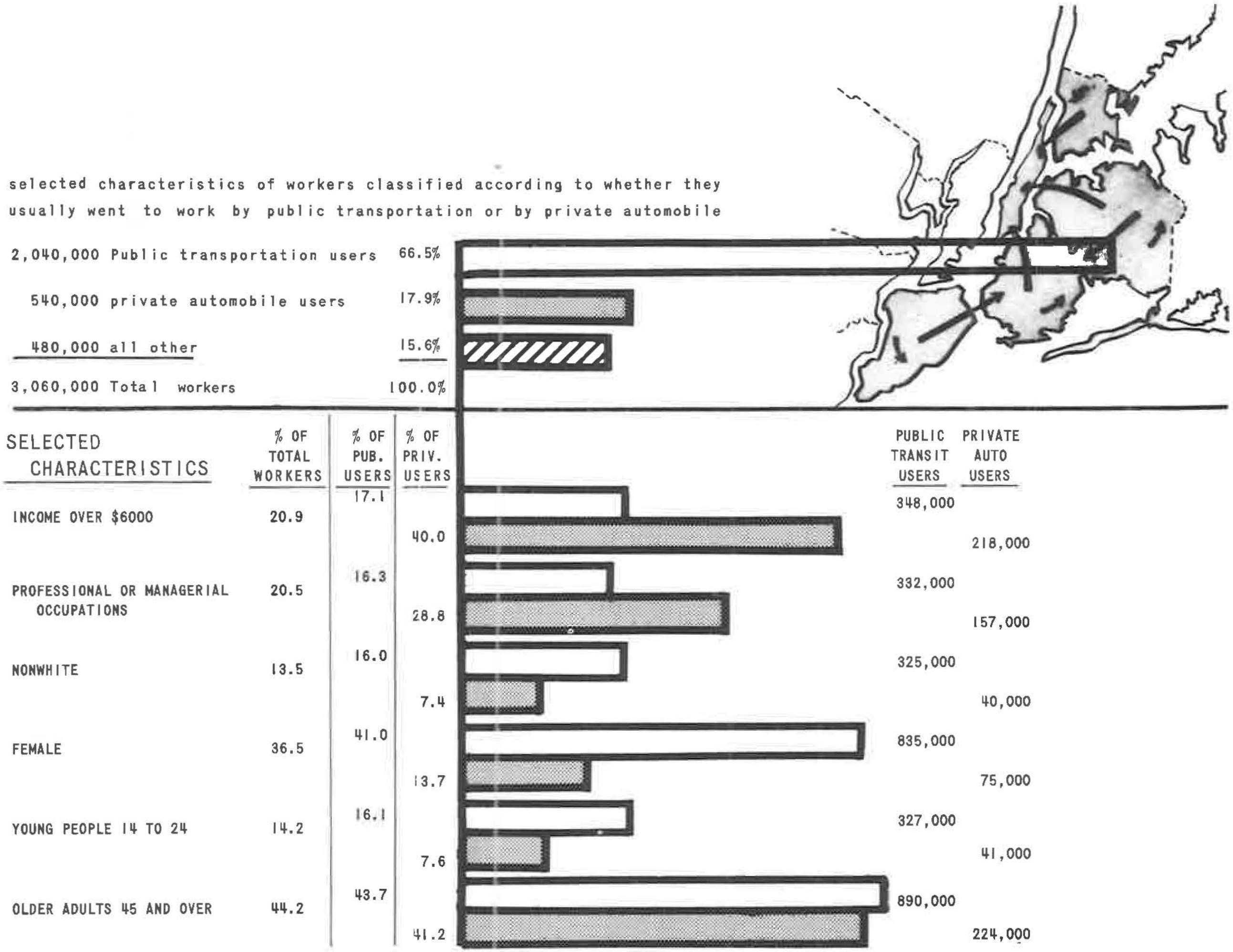


Figure 16. Employed persons living and working in New York City.

place rather than residence. The three worker categories are internal, import, and total employees.

7. Employment by Industry in the Tri-State Region—Ronald J. Fisher, Tri-State Transportation Committee Technical Bulletin, May 1965: Summarizes the workers by industry reported in the census journey-to-work survey for each of the seven SMSA's in the Tri-State Region and compares these with the Chicago, Philadelphia and Pittsburgh SMSA's. Also shows the relative number of workers in each industry category by geographic area within the Tri-State Region.

In addition to the foregoing reports, the tapes obtained from the Bureau of the Census and processed by Tri-State have been used by several agencies in the Tri-State Region. One such use was for determining the impact of New Haven Railroad passenger service discontinuance on the highway system. The data have also been used in the study of possible inconveniences that might result from the elimination of certain stops on a New Jersey railroad.

The data from these same sources are also being analyzed in connection with an extensive mass transportation demonstration project in the Queens-Long Island sector of New York. The Port of New York Authority is using the data as a source for predicting Hudson River crossings. The data have also provided useful material for inclusion in talks before local civic groups.

USE OF FUTURE CENSUS MATERIAL

The work of a number of transportation planning studies has determined those characteristics that appear to be the most reliable indicators of trip generation in an urban area. These can usually be broken into two categories: (a) resident end characteristics, (b) nonresident end characteristics.

At the resident end, the total trips generated by the residents of an urban area appear to be strongly related to automobile availability, population density, housing type, income, family size, distance from the central business district, and accessibility. Residential destinations also have been found to be related to these same variables. Other indicators have been used but are generally correlated with one or more of the variables listed above. In fact, use of all seven variables as shown above would probably be a folly since they are also very much correlated with one another.

At the nonresidential end, the variables which have been found useful in estimating the number of trips generated are: employment by industry or occupation, retail sales, the floor area or gross area of various land use types, and accessibility. Again, other variables can be added to the list, but generally with little gain, and inclusion of all the above would again probably be a mistake.

The variables mentioned for residential and nonresidential trip estimation fall into two general categories: (a) those related to the characteristics of the population, and (b) those related to the transportation system and the land development of an area. The Bureau of the Census has provided much of the former data in the past and can provide even more useful data for future planning work.

The purpose here is to outline a hypothetical procedure for estimating trips in a region (one that is not far different from those used by a number of transportation studies) and show how census data can be useful to such a procedure.

Trip Model

1. The total trips generated by the residents of an urban area (and trip destinations to residential land) are equal to some function of car availability and net residential density (structure type, such as single-family, two-family, three- and four-family, and multi-family structures may be a substitute variable).

$$Gr_i = f(AA_i, d_i)$$

where

Gr_i = trips generated by the residents of zone i;
AA_i = autos owned by the residents of zone i; and
d_i = net residential density of zone i.

2. Automobile availability is equal to some function of family income and net residential density.

$$AA_i = f(I_i, d_i)$$

where

I_i = median income of residents of area i.

3. The trip destinations at nonresidential land are equal to some function of the employment density and number of employees by industry type.

$$Gnr_i = f\left(\frac{E_i}{A_i}, e1_i, e2_i, \ldots, en_i\right)$$

where

Gnr_i = nonresidential trips to zone i;
E_i = total employees in zone i;
$e1_i$ = employees in industry 1 in zone i; and
A_i = area of nonresidential land in zone i.

For sake of discussion, it is assumed that the mode of travel used by the residents of an area may be forecasted by the above variables and system characteristics such as cost and speed, and that the estimation procedures developed are based on data collected from travel inventories. These procedures are then used to forecast travel to some future year based upon estimates of population, employment, automobile ownership (based on income and density), and the land area to be allocated to residential and nonresidential uses by area. Intermediate year forecasts are also made, perhaps on a five-year basis. Future censuses will allow a critical review of the forecast by providing, at least once every ten years, those variables upon which the trip estimates rest. That is, every ten years rather complete information on population, income, automobiles available, and, hopefully, employment data by small areas such as census tracts will be available. All of these data were available by census tract in the 1960 census, except for employment data at the work place in sufficient areal detail.

Employment data were available from the journey-to-work survey, for what is similar to the first work trip, by occupation and industry, but at a gross level of detail (generally county and major city). Of course, the number of workers by occupation and industry was available at the residence by tract, but this is of no value to the specific purpose of estimating nonresidential trip generation. What is desired is the number of employees by work place to as small an areal definition as possible. Such data are now difficult to bring together from other sources.

The trip estimating process relates travel to certain variables, including population, employment, automobile availability, and income. These variables must be forecast as the foundation for the travel estimates. They are also key elements to land-use forecasting. One of the best uses to which data from future censuses can be put is the evaluation of long-range forecasts on an incremental basis. At least once every ten years the incremental forecasts of population, employment, income and the journey-to-work can be compared to what is actually happening as reflected in the census data. Studies can be made of any discrepancies between the estimates and the actual values and a means developed for adjusting the long-range forecasts. Models for estimating future travel and land development can be adjusted and reused during the census years to sharpen estimates and estimating procedures.

Also, in addition to the possible widespread application of census data in model work, there is a more limited use possible in metropolitan areas that are evaluating rather sizable expenditures for public transportation. Mass transit is a rather specialized service mainly encouraged by the congestion at peak hours. At the present time, a model approach has not been very successful in representing work travel, which is the greatest portion of peak-hour travel in most urban areas. Obtaining what is nearly equivalent to the first work trip coded to detailed residence and work place locations will provide the major portion of the traffic data for cost-benefit studies of public transportation facilities now being proposed in many areas to relieve congestion. However, the array of origins and destinations actually occurring may be too widely scattered to be attracted to public transportation, which can only serve a limited number of origin and destination points. Detailed work trip data could provide the precise information to analyze the worker transportation market and the capital expenditures that are justified to service this demand for transportation. A developing transportation and data communications technology is bound to have profound effects on this market, and future censuses could provide invaluable evidence of the ensuing changes.

LIMITATIONS ON USE OF DATA FOR TRANSPORTATION PLANNING

It is natural that certain problems will arise in the use of a data source intended for such universal use as the U.S. Census. The complexity of such a massive data handling operation is probably beyond the imagination of most.

The limitations found by the authors in their use of census data, although narrowed in scope to their particular analyses, may help others in their use of this data source. Also, consistent with the Bureau of the Census policy to improve each succeeding census, certain present limitations may be rectified in future censuses.

Definitive Documentation

The major source of documentation is at the beginning of each published tabulation. General data collection procedures are explained, and definitions are given for certain populations included in the tabulations. This documentation is helpful when working with the magnetic tapes used to produce these tabulations. Also, the tape layout is described by the Bureau of the Census Decennial Operations Division and Demographic Operations Division Technical Memoranda. However, there are data on these magnetic tapes that are not defined in either of these documents. Certain definitions have been obtained through recontact with the Bureau of the Census and research through census procedural manuals. There is no single source of documentation—such as a user's manual—for data on magnetic tape.

Tape Format

The data from the 1960 Census were available at the Bureau of the Census on UNIVAC tape. Other tape formats must be specially requested and conversion paid for by the user. For example, the authors obtained a conversion to magnetic tape for use on IBM equipment. The first conversion was done at the Bureau of the Census. These tapes then required additional handling and programming for conversion from the XS3 and binary languages to the BCD language for use on the IBM 1401. This process involved many transmissions with the Bureau of the Census. Tapes had to be replaced, because they would not read into the computer, or because they had "garbage" instead of valid records. The 1960 data cannot be obtained for any computer system in a "Go" status that would allow the user to make a minimum of summary checks before using.

Comparability with Earlier Censuses

A limited number of data items are carried consistently in published tabulations from earlier censuses. It was not until 1960 that data were available on computer tape.

Consequently, these earlier data must be transferred to a computer media from printed sources by the user, if he wishes to do any trend analysis work.

Record File

The procedure to identify a record on Census Tape Series 29I is rather complex. The file was normally found in sort: by state, by county, by minor civil division, by place, by tract prefix, by tract basic and by tract suffix. This identification requires 20 characters, some alpha and some numeric. Certain areas do not have officially designated census tracts and a pseudo-tract was created. Pseudo-tracts comprise wards in untracted cities of 25,000 or more, separate urban places of 2,500 or more, and the remainder of minor civil divisions or census county divisions in untracted areas. In some instances, data records have been found for places that have no defined boundaries. Also, there are 30 tracts in the area studied by the authors that are for crews of vessels and do not represent data for a physical portion of land in the study area. Those types of data are possible in any area with port facilities.

Geographic Identification

The record identification for each of the census tape series links the data to a particular geographic location through the use of a coding manual, general map, and in the case of the Census Tape Series 29I, a census tract map. This procedure allows only a very limited display of data on a map for a particular area, because of the laborious task of manually determining the geographic location for the display of data. Map coordinates are available for census tracts on the Universal Transverse Mercator (UTM) grid system, but now must be inserted in each record by the user. These coordinates are a key part of the Damage Assessment System for the Office of Civil Defense, Department of Defense, and are published in the National Location Code Manual.

Another ingredient that is important in this visual display of data is the area of the census tract involved. This information must be obtained from sources outside the Bureau of the Census.

Areal Detail

Population and housing data and auto availability are available by census tract. A limited amount of journey-to-work data, occupation, industry, mode, and 13 work destinations, are given at the place of residence of the worker by census tract. These 13 work destinations are gross areas, such as a whole county or major city. Only the total number of workers going to each of these work destinations is given.

Additional journey-to-work data are available on Census Tape Series 29BB at the place of employment and place of residence. The level of areal detail is major city, county, or remainder of county, except in the New England States where towns are used. These places of employment and residence are identified with a Universal Area Code on the Census Tape Series 29BB. They range in size, for the area studied by the authors, from one square mile to 922 square miles. The population of people living in these areas ranged from less than 1000 people to over 2.5 million. Individual records for some of the very small populations could be aggregated; however, there was no way to obtain a lower level of areal detail in the large areas. Significant variations in the choice of mode for work trips from such large areas as Queens County, N. Y., with a population of 1.8 million people, are lost in the data record, which is for all of Queens. Trip length analyses have obvious limitations when using such large summaries.

The table on page 69 gives a summary of the areal detail for the census tape data.

Areal Coverage

It was mentioned in the discussion of areal detail that 13 places of work were given for a particular census tract by place of residence on Census Tape Series 29I. The same 13 places of work were usually used for all the census tracts in a particular county. These places of work differed between counties and, in the area studied by the authors, there were 85 different employment areas. There were overlapping definitions

	Enumeration District	Census Block	Census Tract	Universal Area Code
100% Data	29A	34	29B	
25% Sample			29I[a]	29BB

[a]This tape contains some 100 percent data and place of work to 13 places of work about equal in size to UAC's.

for an employment area. For example, in New York State, Manhattan was carried as a separate employment destination, but in Northern New Jersey, New York City (the five boroughs) was one destination. In other words, an employment area may be uniquely defined in census tract records by place of residence for one county, aggregated with other employment areas for census tract records in another county, or not included as an employment area.

More universal and complete coverage of employment is possible from the Census Tape Series 29BB. The limitations of areal detail have been mentioned. In addition, the data were only processed to this gross level of detail for workers who either live and/or work in a Standard Metropolitan Statistical Area (SMSA) of 250,000 or more people. For example, the people who lived in Pike County, Pa. (which is not even in a SMSA) but worked in Manhattan, are contained in a record for the New York SMSA. The reverse commute would also be contained in a record for the New York SMSA. Those who commute between Pike County, Pa., and Somerset County, N.J., are not available in a record, because neither place is in a SMSA of over 250,000 people. In the area studied by the authors, sizable portions were missing employment data such as that for Somerset, Middlesex, and Monmouth counties, N.J., a 1092-sq mi area with a 1960 population of 874,000 people. These data on Census Tape Series 29BB were prepared by the Census Bureau for 101 SMSA's in the United States with 250,000 or more population in 1960.

General Data Limitations

The population of workers described is defined as anyone 14 years or older who worked at least once in the week prior to being interviewed in the 1960 census or was then a member of the Armed Forces. Distributions of these total workers do not include members of the Armed Forces by occupation or by industry. This population of workers is a cross between the average daily employment traditionally studied in a travel survey and total employment statistics compiled by certain state agencies. It does not include the location of second jobs; just the one place of work where the most hours were spent is recorded. This is roughly equivalent to the first work trip from a travel survey.

The mode data are for the primary mode. If more than one mode was used in getting to work, the mode involving the greatest travel distance as judged by the respondent is recorded.

The data are carried at the person's usual place of residence, even though he may have been working in another area at the time of the census. For example, a person who has an apartment in Manhattan for ease of commuting during the week, but actually lives in Boston or Florida, would be recorded as commuting from Boston or Florida.

The cross tabulation between socioeconomic characteristics of the worker and the mode used is limited to auto or carpool and public transportation modes. The workers using each of these two modes are distributed by: white or non-white, sex, age, by sex and occupation (three occupation categories), and by earnings.

There are a limited number of cross tabulations for workers irrespective of mode. Occupations are divided into 13 categories for each sex. Workers are divided into family heads and other relatives and then by income category for each. The primary means of transportation to work by eight mode categories is given for each sex.

Included in most of these cross tabulations and in straight distributions of the workers are data in an unreported category. The magnitude of these data have been found to range from 1 to 10 percent of the total population involved. In some cases, these may be distributed in proportion to the reported information by the user. Of course, this is impossible where the unreported information is in two or more sub-populations in a cross tabulation.

Usually summations of each distribution in a universe should be made to determine the correct base for ratio computations. For example, the total number of workers in a record on the Census Tape Series 29BB may be obtained from the summation of just three fields in the record. However, this total will not allow 100 percent coverage for the mode data, unless the unreported mode is carried as a mode category. On the Census Tape Series 29I, the total number of housing units derived by summing over the distribution by number of units in the structure (25% sample) does not always agree with published totals (100% data) or the totals derived by summing over the distribution by condition and plumbing (100% data).

The Census Tape Series 29I does not include a population distribution by age. Consequently, it is necessary to process Census Tape Series 29B to obtain these data.

SUGGESTED IMPROVEMENTS FOR 1970 U. S. CENSUS

Although the Bureau of the Census has collected data that have been of significant value to transportation studies in the past, the adoption of questions on automobile availability and the journey-to-work (collected for the first time in the 1960 census) has enhanced the value of the source and indicates the desire of the Bureau of the Census to provide data for special purposes, such as transportation planning. Professionals have had a chance to use the newly collected data and should be in a position to analyze its value. Additional improvements would further enhance the value of the data to users and make their analyses easier. The authors have found the data to be a valuable source. Certain limitations have been observed and suggestions formed, which may be an aid in developing criteria for improving the value of the data collected in the 1970 census.

The authors present these suggestions with full knowledge that other factors must be considered. The authors have no information as to the cost and logistical problems involved.

Suggestions for making the next census more readily usable are based on the use made of the census data by the authors and the limitations presented in the previous section.

1. Employment data, which are used as a basic variable by many transportation studies, are difficult to obtain since coverage in various sources is usually not complete. The census journey-to-work question in the 1960 census obtains a large portion of an area's employment. However, the data obtained contain information on only a single work trip for each employee, if made at least once during the week prior to the census. Missed are second jobs and workers who are ill or on vacation. It may be possible that the journey-to-work question in the 1970 census be framed similar to the following:

   If you are employed: (a) Where did you work yesterday, and what mode of travel did you use? Both of these would be for the primary job. (b) If you hold more than one job, where are the other jobs located? (c) If you did not work yesterday, where is your regular place of employment?

2. It is further suggested that the employment places obtained from the preceding questions be coded to some smaller geographic area than Universal Area Code zones. Since the population data are coded to the census tract as a major aggregation level, perhaps it would be possible to use tracts or combinations of them for coding employment data.

3. The mode of travel currently includes the category, "auto or carpool." To be consistent with the usual modes collected in home interview travel surveys, it is suggested that "auto driver" and "auto passenger" be considered as separate modes.

4. At present the census publications and tape files are limited to journey-to-work information for Standard Metropolitan Statistical Areas of 250,000 and over population. In the Tri-State Region, for example, this covers only 90 percent of the total workers journeying to work. It is proposed that complete coverage be provided at least for those areas that are included in the study areas of the urban transportation studies, established in conformance with the requirements of the 1962 Highway Act.

5. Automobile availability is provided at the census tract level in the 1960 census. However, the rate of sampling was variable, from 5 to 20 percent, although the journey-to-work data were collected on a uniform 25 percent sample basis. Since auto availability is of considerable usefulness, it is suggested that it be collected on a uniform 25 percent sample basis.

6. Cross tabulations are not available to any great degree on the 1960 census tapes. Even though a minimum of cross tabulations results in a great increase in the size of the data records, consideration should be given to increasing the number of cross tabulations. The form of the cross tabulations will not be described here, since the possibilities are so great that a consensus from users must provide the combinations desired.

7. It is recognized that only from the past census has the Bureau of the Census been in a position to supply data in magnetic tape form to other agencies. Although layouts have been provided for each file, the uninitiated have experienced much difficulty in determining exactly what is available in each tape file, the definitions of various terms, and the coverage provided. Since much use may be made of tape files by agencies other than the Bureau of the Census, it is hoped that considerable additional effort will be expended in the 1970 census to prepare detailed descriptions of the tape files, including data coverage and definitions used. A user's manual for the tape files would be very helpful.

8. It is suggested that magnetic tapes be processed to be handled on all manufacturers' computers to eliminate the time-consuming process of conversion from the census tape to other tape forms at the time of request.

9. The Bureau of the Census might consider establishing a service unit within the organization to provide users with assistance in both the use and possible correcting of discrepancies found on the tapes. Such help was readily supplied to the Tri-State Transportation Committee by the Bureau of the Census; however, it was felt that this help was provided by people who were pulled away from their usual responsibilities.

10. Control totals for the fields contained on the census tapes should be provided along with the tapes supplied to allow the user to insure that they have been processed correctly in his subsequent uses. Machine-read errors will be more readily apparent.

11. It would make it easier for the user if the exceptions to obtaining control totals were eliminated. The data should be adjusted for, not reported. Where 100 percent sample totals are available, a distribution determined from a 25 percent sample should be adjusted to this control total.

12. Consideration should be given to establishing, as soon as possible, officially designated census tract boundaries in all transportation study areas.

13. The establishment of geographic identification for each tract in the form of coordinates in the data records should be considered.

14. One computation of the gross areas of census tracts and placement in the respective records should be considered.

15. It is suggested that two data files be prepared for use in transportation planning. One file should contain pertinent population and housing data; the other should contain the journey-to-work data.

16. Finally, for the convenience of the user, a distribution of the total population by age groupings should be included in the population and housing data file.

The aforementioned suggestions, which have been formulated by the authors' use of the census material, do not necessarily represent those of the Tri-State Transportation Committee. Others in the organization are using the data and may also form suggestions. The implementation of improvements to the data in the census for transportation planning uses is an evolutionary process, which must be based on past uses and evaluations, as well as foreseeable uses. In no way should the limitations and suggestions discussed be considered as a criticism of the Bureau of the Census. It is hoped that this discussion will help users of census material to form suggestions for the 1970 census and interest others in becoming census data users.

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Land Use, Activity and Non-Residential Trip Generation

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•THE planning of facilities to serve adequately the transportation needs of a community requires accurate forecasts of the amount of traffic which will be imposed upon these facilities. In recent years an orderly procedure for planning, designing, and evaluating systems of urban transportation has evolved. Often referred to as the urban transportation planning process, this procedure has as a fundamental requirement the estimation of the amount and characteristics of traffic which will be generated by the various uses of land in the community. These estimates must apply not only for conditions which pertain at the time which the traffic, land use, and other surveys are conducted, but also for periods 20 to 25 years or more in the future.

Much of the data upon which travel estimates are based are derived from detailed interviews conducted at a sample of dwelling places in the study area. In contrast to the wealth of data available from home interviews, a very limited amount of trip information is gathered directly at or for non-residential land uses. As a consequence, estimates of non-residential trip attractions are generally based on observed associations between measures of land use or site activities obtained from special surveys or public records and travel information obtained from interviews at the home.

The utility of transportation systems planning rests significantly upon the accuracy and functional validity of these associations. The problem of forecasting future non-residential attractions is particularly nettlesome. While estimates of household characteristics such as income and auto ownership can be used as fairly reliable indicators of future residential trip productions and, perhaps, of overall travel demands in an urban area, no such fundamental and clear-cut relationships between non-residential activities and trip attraction have been established. Thus, only the broadest of statements can presently be made regarding the effects which technological, marketing and other basic changes in the structure of non-residential activities will have upon future trips to non-residential land.

For these reasons, an exploratory study of the concepts and procedures used in recent urban transportation studies to derive non-residential trip attractions was undertaken (1). A large number of study reports as well as technical memoranda and other internal documents of a few of the larger studies were reviewed. In addition, extensive discussions and meetings were conducted with engineers and planners actively engaged in trip generation analysis. The material which follows represents the author's attempt to distill and interpret the wealth of information derived from these discussions and reviews. He alone is responsible for any errors of interpretation or fact.

GENERATION MODELS FOR NON-RESIDENTIAL TRIPS

If one is willing to emphasize (perhaps overemphasize) certain distinctive features, it is possible to identify several major approaches among the wide variety of methods

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used in urban transportation studies to estimate non-residential travel. As a basis for discussion, we have separated trip attraction models into three broad categories: Land-Use Based Models; Activity-Purpose Models; and an assortment of procedures gathered under the rubric of Other Methods. It should be clear from the discussion which follows that these distinctions are based more upon expository convenience than on fundamental differences among the three groups.

Land-Use Based Models

In one way or another, land use forms the basis for almost all current approaches to the estimation of non-residential trip attractions. The primary distinction between land-use based models in this paper and other models lies principally in the nature and extent to which various measures of the intensity of land use are employed and in the relative importance of trip purpose as a measure of use.

The underlying rationale in all transportation planning models is the functional relationship between land use and urban travel. Travel patterns are recognized to be a function of the locational distribution of various kinds of land uses in the urban region. Land-use based models carry this functional relationship one step further by tying the rate at which trips are generated by various land uses to the intensity and type of land use activity. In these models, trip generation is assumed to be related to the kinds, amounts, intensities and locations of a limited set of generalized land-use classes.

In an attempt to determine the general utility of land use as a measure of trip attraction, reports of approximately 150 metropolitan transportation studies were examined to ascertain the degree of comparability among communities in the rates at which trips were generated by various land-use classes. Of these reports, only ten were of such a nature as to permit city-to-city comparisons. The results of this effort, as well as some of the difficulties which were encountered, are summarized in Table 1.

It was desired to present trip-generation rates for as many metropolitan areas and for as many land-use categories within these areas as possible. Furthermore, we wished to present person trips as well as vehicle trips. It is obvious from Table 1 that these objectives were not completely fulfilled. If comparability of trip-generation rates from city to city is a worthy objective, then more highly coordinated efforts towards this goal will be required.

Problems of Summarization. — Each metropolitan area transportation study tends to prefer its own land-use breakdown; in all, trip generation rates were reported for 40 different categories of land use. Definitions of the various land-use categories were very often missing from the reports (although they may be available from the consultants or state highway departments who performed the studies). The consequence of such a conglomeration is a grouping of overlapping land uses whose generation rates are not comparable. For example, the category "public buildings" includes hospitals and schools in the Chicago Transportation Study but does not in the San Diego study. Even if the bases for categorization could be determined, most studies would not have generation rates for each of the smaller categories, and averages for the larger classes would not serve to differentiate among smaller classes.

This dilemma is related to the more general problem of categorizing land uses for purposes of trip generation analysis. Preliminary studies based upon data from the 1956 Chicago study indicate that even in a single urban area, variations in trip rates within generalized land use classes are far too large to permit what is essentially a definitional convenience to be effectively used as a measure of trip generation (1).

A second problem which hinders the comparability of transportation studies with respect to generation rates is the variety of ways in which rates are expressed. For example, trips are reported as person trips or vehicle trips, and often there is no way to convert one into the other. Furthermore, the bases on which generation rates are calculated vary from study to study and often within a given study. For example, trips per acre and trips per 1,000 square feet of floor area are not comparable due to the wide range of building size (and thus floor areas) on any given acre of land, not to mention the fact that even the term "acre" is not the same from study to study—

TABLE 1

SUMMARY OF TRIP GENERATION RATES FOR TEN METROPOLITAN AREAS[a]

Metropolitan Area	Residential		Commercial		Industrial		Pub. & Quasi Pub.		Transportation		Pub. Bldg.		Pub. Open Space	
	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre
Tucson	18.2	13.0	134.3	112.6	3.9	4.3	14.3	8.8	–	–	–	–	–	–
Twin Cities	26.5	15.2	187.9	118.7	12.6	9.3	17.4	7.5	–	–	60.1	27.5	3.5	1.5
Corpus Christi	30.5	19.7	174.4	127.7	10.6	8.6	35.3	22.0	–	–	–	–	–	–
Pittsburgh	23.9	14.6	157.8	110.6	24.6	21.7	15.9	6.8	21.3	35.0	46.1	18.5	2.3	1.3
Chicago	48.5	26.1	181.4	144.6	22.0	16.0	12.4	6.0	8.6	10.2	52.8	24.2	4.2	3.1
Detroit	29.1	–	271.2	–	37.2	–	16.5	–	–	0.9[b]	32.8	–	3.4	–
Hutchinson	–	13.3	–	63.3	–	2.5	–	9.8	–	–	–	–	–	–
Ann Arbor	–	12.1	–	75.6	–	5.9	–	28.1	–	–	–	–	–	–
Flint	–	11.8	–	16.1[b]	–	20.1	–	1.6[b]	–	–	–	–	–	–
Baltimore	18.7	–	121.4	–	8.2	–	9.4	–	–	–	–	–	–	–
Range	18.2-48.5	11.8-26.1	121.4-271.2	63.3-144.6	3.9-37.2	2.5-21.7	9.4-35.3	6.0-28.1	8.6-21.3	10.2-35.0	32.8-60.1	18.5-27.5	2.3-4.2	1.3-3.1
Ratio, high/low	2.7	2.2	2.2	2.3	9.5	8.7	3.8	4.7	2.5	3.4	1.8	1.5	1.8	2.4

Sources: The Ann Arbor Metropolitan Area Traffic Study (1963), Baltimore Metropolitan Area Transportation Study (1964), Chicago Area Transportation Study (1959-62), Corpus Christi Transportation Study (1961), Report on the Detroit Metropolitan Area Traffic Study (1955), The Flint Metropolitan Area Traffic Study (1959), Hutchinson [Kansas] Transportation Study (1962), Pittsburgh Area Transportation Study (1961), Tucson Area Transportation Study (1960), Twin Cities Area Transportation Study (1962).

[a] Tp = person trips; Tv = vehicle trips.
[b] Not used in computation of range or ratio.

some using gross acre and some net acre as their base. Even the trip itself is defined differently for different studies. A trip may be a one-way or a two-way journey; it may involve several modes of transportation or only one. Some studies include trucks in their vehicle calculations, and others consider them separately. Still others weight truck trips and add them to auto trips on the basis that the larger vehicles cause a proportionately larger capacity requirement on the future road system. The difficulties involved in comparison of rates calculated on varying definitional bases are obvious.

Finally, and perhaps most important as far as prediction of future trips is concerned, there is the inevitability of change. All present rates are not fixed and immutable. Rather, they are based on a certain structure of land uses and land-use competition which is constantly changing. Agglomeration, competition, and new transportation all affect the generation of a given attractor. For example, the gathering of stores into shopping centers as opposed to dispersed locations seems to be producing fewer trips per store due to exclusion of walking trips in the analysis. No models to our knowledge have been constructed to account for this, and certainly it is impossible to depict such an occurrence as a constant generation rate. The rates reported in the various studies represent only one point in time, and since none of the studies were performed concurrently, that point is different for each study.

Floor Area as a Measure of Trip Attraction.—As an alternative to gross acreage, a number of studies have attempted to express trip attractions in terms of the number of square feet of floor space devoted to various land uses. A sought-for advantage in this approach is that floor area provides a measure of the intensity of use. For example, an acre of outlying single-story office buildings would be expected to generate far fewer trips than an acre of multi-story office buildings in the central area. The number of trips per square foot of floor area would be much more comparable in the two instances.

Despite its obvious appeal, floor area has not been used extensively, mainly because of the difficulty and expense of obtaining measures of floor area. Limited tests of the utility of floor area as an estimator of trip attraction have generally been inconclusive. In one such study, the relative effectiveness of floor area, land area, and employment (as determined from first work trips) was measured for approximately 40 non-CBD districts in the Chicago area. In each case, rate of generation was related to net residential density in each district. The following conclusions were made:

> No one of the three types of trip rates appears to be consistently superior. As measured by the variation coefficients, land area rates are best for two land uses, floor area rates for one, and first work trip rates for two. In three cases the land area rate has the highest correlation; in two cases, the floor area rate. (2).

Land-Use Activity—Trip Purpose Models

In the discussion of land-use based models it was stated that the primary distinction between the land-use and activity based models rests mainly on the nature and extent to which various indicators of the intensity of land use are employed, and in the role which trip purpose plays in the model. In evaluating the relative applicability of either of these two models, cognizance must be taken of the characteristics of the trip distribution model to be used in the analysis. For example, the opportunity model used in the CATS study required the separation of trips into three categories: (a) short trips; (b) home-based long trips; and (c) non-home-based long trips. The trip generation model used in the CATS study provided the basis for differentiating trips into these three groups.

In contrast to the CATS opportunity model, most gravity distribution models require separation of trips into three to six trip purpose categories depending upon the size of the study area and the degree of detail desired. In these cases, a trip generation model which provides generation by trip purpose is called for. Once trip making is differentiated on a trip purpose basis, relatively less reliance is placed upon land use per se as the basis for trip generation and more use is made of employment, retail sales and other measures of land-use activity which are more directly related to trip purpose. It should not be assumed, however, that the particular distribution model selected is the only basis upon which to choose a generation model or that the land-use and activity-purpose generation models represent pure forms of completely different approaches to estimating trip generation. The distribution model is only one factor in the selection of generation models, and the two generation models referred to here (in fact, all generation models in common use) represent different emphases, not essentially different bases, for trip generation. It should also be understood that there is a strong and logical relationship between the proportion of trips made for different purposes and the proportion of trips made to different land-use types.

Table 2 summarizes the land-use activity factors employed in estimating trip generation by several purposes for cities ranging in size from 55,000 to 2,900,000. The number of trip purposes used in these studies ranges from three to six (including commercial vehicle trips as a separate category) with the more elaborate models generally being limited to the larger studies. The various factors used to estimate trip attractions for the several purposes are shown in abbreviated form (Table 2).

Grouping of Trip Purposes. — Data obtained from the standard BPR-type of home interview survey permit identification of all sampled trips according to the purpose of each trip at both the origin and destination ends. Given these data, trip purpose types are then generally combined on the basis of the similarity of the land use at the non-home end and the trip length characteristic evidenced by each trip type (this method of grouping is similar to the CATS opportunity model grouping on the basis of "1" values). In most instances, an initial split is made between home-based trips, that is, trips with either origin or destination at home, and trips which are non-home-based. The following indicates the grouping of trip purposes used in the 1964 Fort Worth study (3).

TABLE 2

FACTORS USED TO ESTIMATE TRIP ATTRACTIONS

Study Year-Pop.	Trip Purpose Category: Home-Based						
	Work	Shop	Soc.-Rec.	Other	Special	Non-Home Based	Trucks
Washington, D.C. 1963-2,900,000	E	S_R	S_R, DU	E, S_R, DU	[1]A_{SC}, DU	E, S_RDU	
New Orleans 1960-645,000	NRD, DU, S_R E, A_C, I, DRD	NRD, DU, C S_R, DRD	DU, P, C P_5, S_R	[2]C, E DRD	[3]NRD, P/C, S_R E, I, H, DRD	NRD, DU, C S_R, E, A_C, SC	DU, D, E A_C, SC
Kansas City, Kan.-Mo. 1959-643,000	[4]E, D	[4]S_R, D	[5]P, DU		[5,6]P	[5]D	
Ft. Worth, Tex. 1964-540,000	E	[7,8]E_C		P, E_C E_M, E_O		P, E_C E_M, E_O	P, E_C E_M, E_O
Charleston, W. Va. 1965-250,000	[9]E, E_V	E_R, S_C, S_P		[9]S_V, E_V, DU A_R, SC_V, I	[10]SC_V	[9]E, E_V, SC_V S_C, DU, A_R, I	[9]E_V, T S_V, I
Nashville, Tenn. 1961-250,000	[11]E, E_W, E_B	[11]A_C, D	[11,12]P, I	[13]A_C	[14]SC, I	A_C, D	
Chattanooga, Tenn. 1962-240,000	E	[15]A_C	[15,16]P, I	[15,17]A_C	[15,18]SC, I	A_C	
Waterbury, Conn. 1963-190,000	E	E_R		P, E_C E_M, E_O		P, E_C E_M, E_O	P, E_C E_M, E_O
Erie, Pa. 1963-140,000	E	[19]E_R	P, E_R, E_O			P, E_R E_M, E_O	[20]P, E_R E_M, E_O
Greensboro, N.C. 1964-130,000	E	E_R		P, E_C E_M, E_O		P, E_C E_M, E_O	P, E_C E_M, E_O
Fargo, N.D. 1965-70,000	E, E_R	[21]P, E_R, E_O		P, DU C, E	[22]DU, E_R, E_O	DU, E, E_R	C, E, E_R
Appleton, Wis. 1965-55,000	[23]E, D A_{PU}, A_I			[23]DU, A_{PU}, A_I A_C, E		D, E, A_C A_I, A_{PU}, DU	DU, E A_C, A_I

Comments

[1]School trips
[2]Personal business
[3]School trips
[4]Different procedures used for stable and unstable zones
[5]Different procedures used depending on type of zone
[6]School trips
[7]Includes related business, eat, and convenience and shopping goods
[8]Gross sales and floor area suggested as possible alternatives
[9]Different factors used to estimate AM and PM peaks
[10]School trips
[11]Different procedures used for stable and unstable zones
[12]Recreation trips computed by uniform factor expansion
[13]Business trips
[14]School trips
[15]Different procedures used for stable and unstable zones
[16]Recreation trips distributed in proportion to surveyed recreation trips.
[17]Business trips
[18]School trips
[19]Special adjustments made for shopping centers
[20]Special adjustments made for areas adjacent to major railroads
[21]Retail employment alone used for CBD and outlying areas
[22]Personal business trips
[23]Different factors used to estimate origins and destinations

Key to Entries

Employment: E = Total employment; E_R = Retail employment; E_M = Manufacturing employment; E_C = Commercial employment; E_O = Employment other than retail and manufacturing; E_W = White collar employment; E_B = Blue collar employment; E_V = Various specialized employment.

Sales: S_R = Retail sales; S_C = Convenience goods retail sales; S_P = Personal service sales; S_V = Retail sales by various specialized categories.

Area: A_{PU} = Acres of public and semipublic land; A_I = Acres of industrial land; A_C = Acres of commercial land; A_R = Acres of residential land; A_{SC} = Acres of school land.

School Enrollment: SC = Total school enrollment; SC_V = School enrollment by various grade levels.

Household Characteristics: P = Population; P_5 = Persons five years of age or older; H = Persons per dwelling unit; DU = Number of dwelling units; NRD = Persons per net residential acre; DRD = Dwelling units per net residential acre; I = Income; C = Number of automobiles.

Miscellaneous: D = Distance from CBD; T = Truck ownership.

General Purpose (Used in Distribution Model)		Specific Purpose (From O-D Study)	
Home-Based Work Trips	Home to -	Work	- to Home
Home-Based Commercial Trips	Home to -	Related Business Eat Meal Shop (Convenience Goods) Shop (Shopping Goods)	- to Home
Home-Based Other Trips	Home to -	Personal Medical and Dental Education Civic and Religious Recreation Other	- to Home
Non-Home-Based Trips	All trips with neither origin nor destination at the home.		
Truck Trips	All truck trips.		

The specific number of general purpose categories used in the analysis will depend on the size and type of community being studied, the size of the home interview sample, budget, and other factors. Considering their distinct characteristics, home-based work, home-based non-work, and non-home-based trips should probably be analyzed separately in all but perhaps the very smallest communities.

Trip Attraction Factors.—The selection of trip attraction factors appears to be based on three broad criteria:

1. Logical relationship between a given variable, either singly or in combination with other variables, and attraction of trips for the particular purpose or purposes being considered;
2. The degree of association evidenced through statistical analysis of a given variable, either singly or in combination with other variables, with attraction of trips for the particular purpose or purposes being considered;
3. The availability, accuracy and expense of obtaining data regarding a given variable for both the study year and for the design year.

Generally, it is not possible to satisfy completely all three requirements simultaneously, and some compromise is necessary. Data availability appears to be the controlling factor in the selection of generation variables, with statistical association being used to select among the set of available data types.

Recent studies have relied heavily upon employment in different categories as a basis for estimation of trip attractions to non-residential land (Table 2). Zonal population is also used as an estimator of trip attractions as evidenced in the following equations from the 1964 Erie study (4).

Zonal Trips by Purpose	Zonal Estimates of Relative Attractiveness
Work trips	Total employment
Shop trips	Retail employment
Social-recreational trips	Population + 2.2 (retail emp. + other emp.)
Other home-based-trips	Population + 2.6 (retail emp. + other emp.)
Non-home-based trips	Population + 7.1 (retail emp. + other emp.) + 0.9 (manufacturing emp.)
Truck trips	Population + 2.4 (retail emp. + other emp.) + 1.5 (manufacturing emp.)

These data are shown as an indication of the various factors which may be used to estimate trip attractions to non-residential land. The exact form of the equation and the coefficients used will vary from study to study.

Other Methods

The land-use and activity purpose models previously described are representative of the basic approach taken by almost all current transportation studies to the estimation of non-residential trip attraction. There are, however, a number of significant variations to these basic models, both conceptual and computational, which warrant review in their own right.

Step-Wise Multiple Regression Analysis. —The advent of large capacity, high-speed computers has made feasible the application of a number of sophisticated statistical techniques to the analysis of wide varieties of factors potentially related to trip attraction. Of most direct use is multiple regression analysis, particularly a current variation which automatically reviews each potential factor, selects those which are most closely associated with trip attraction, and computes an estimating equation relating trips to the selected independent variables. The computer is programmed to proceed step-by-step through the several variables, determining the degree of correlation of each variable with trip attraction while accounting for the interrelated effects of all other variables which were reviewed previously. Variables are permitted to enter and remain in the regression only if they contribute beyond a preselected level of significance to the explanatory power of the equation.

The number of variables used and the complexity of the estimating equations which are derived are practically unlimited, since powers and combinations of variables can be handled in the analysis. However, it is generally found that a relatively few variables are most useful in any given equation, with little or no increase in accuracy being obtained through the introduction of additional variables.

Sample equations from two recent transportation studies will illustrate the nature of the regression equations developed by the step-wise program.

In the first example, 27 independent variables were reviewed in the development of peak hour generation equations for 332 zones in the city of Charleston and Kanawha County, W. Va. (5). The following equation for home-based social, recreational and miscellaneous trips is a somewhat extreme example of the relationships which were derived. (A particularly complex equation has been selected in order to illustrate clearly the point in question.)

$$Y = 0.5 + 1.173\sqrt{S_P} + 12.175\sqrt{E_R} + 0.031\,A_S + 0.050\,A_E$$
$$+ 0.811\sqrt{S_S} + 1.662\sqrt{A_C} + 0.011\,S_C m + 0.232\sqrt{ID/10}$$

where for each zone

Y = Total P.M. peak home-based school, visiting, social, religious, recreational and miscellaneous trip attractions.

S_P = Dollar volume of personal service sales.

E_R = Number of employees in recreation.

A_S = Senior high school attendance.

A_E = Elementary school attendance.

S_S = Dollar volume of shopping goods retail sales.

A_C = Attendance at colleges, adult education programs and business schools.

S_C = Dollar volume of convenience goods retail sales.

ID = Total income.

Presumably the order in which the variables appear in the equation is representative of their relative association with Y. The multiple coefficient of determination (R^2) is 0.78, and the standard error of estimate as a percent of the mean, $(S_Y / \bar{Y}) \times 100$ percent, is 78 percent.

In a recent study for the Fargo metropolitan area, the following equation for home-based miscellaneous trip attractions was developed (6).

$$Y = 47.19883 + 2.00901\ DU - 0.30248\ C - 0.30790\ P + 0.44575\ E$$

where for each zone

Y = total home-based auto driver trip attractions for purposes other than work, shop, and personal business;
DU = dwelling units;
C = cars;
P = population; and
E = total employment.

The multiple coefficient of determination is 0.531, and the standard error of estimate is 104.3 percent of the mean.

The major strengths and weaknesses of the step-wise multiple regression technique are indicated by these examples. The procedure permits an objective and efficient review of a large number of variables, and the incorporation of those which are most highly correlated with trip attraction into an estimating equation. These features, when properly used, represent the primary advantages of the multiple regression approach. However, when misused, these same features can lead to apparently precise, but misleading or even meaningless equations of relationship.

This caveat applies to all regression analysis, but most strongly to its use in the formulation of complex, multiple factor equations, particularly where the computer is interposed between the researcher and the raw data. In these instances it is essential that careful attention be paid to the reasonableness and theoretical validity of the equations and to the extent to which the several variables in the equation are subject to prediction for application of the equation to the design year.

Further, the researcher should not rely solely upon F ratios and the coefficient of determination as measures of the statistical validity of derived relationships. It is entirely possible (and is often the case) that the statistical significance of several of the regression coefficients may be very low, although the coefficient of multiple determination is beguilingly high. Computation and reporting of standard errors of the regression coefficients is essential to guard against unwarranted reliance on essentially uncertain relationships. The rounding off of equation parameters to two or three significant figures to be more in keeping with the quality of the input data would also serve to avoid the appearance of excessively precise regression equations.

Analogy Expansions.—In direct contrast to regression analyses which attempt to isolate the contributory effects of a relatively large number of explanatory variables to trip generation, the analogy technique is based upon a much more pragmatic and expedient view of the world. Essentially, this procedure uses observed trip rates which reflect all causative factors without seeking to identify them. Separate rates by trip purpose are computed for each traffic zone on the basis of survey data. If little change is anticipated in zonal activity during the projection period, the observed rates for that zone are used for the design year. If significant changes in any use are forecasted, land use or activity factors are employed to estimate trip attractions. An example of the analogy technique as applied to work and shopping trips in the Nashville transportation study is as follows (7):

Work Trips

$$T_W^{1960} = T_W^{1959} \times \frac{E^{1960}}{E^{1959}} \quad \text{(for zones where } E^{1959} \geq 100\text{)}$$

$$T_W^{1960} = 1.53\, E_{WC}^{1960} + 1.73\, E_{BC}^{1960} \quad \text{(for zones where } E^{1959} < 100\text{)}$$

Shopping Trips

$$T_S^{1960} = T_S^{1959} \times \frac{A_C^{1960}}{A_C^{1959}} \quad \text{(for "stable" zones)}$$

$$\left.\begin{array}{l} T_{SG}^{1960} = 6.3 \times A_C^{1960} \\ T_{SC}^{1960} = f\text{ (CBD Distance)} \end{array}\right\} \text{(for zones with "considerable new commercial development")}$$

where for each zone

T_W = home-based work trip attractions;
T_S = home-based shopping trip attractions;
T_{SG} = home-based shopping goods trip attractions;
T_{SC} = home-based convenience goods trip attractions;
E = total number of employees;
E_{WC} = white collar employees;
E_{BC} = blue collar employees; and
A_C = acreage of commercial land.

The strengths and weaknesses of the analogy technique are, perhaps, best expressed in the words of F.H. Wynn, one of its most astute proponents:

> This is an expedient, and should be recognized as such, while constant effort is made to get at the underlying reasons [for trip generation]. Nevertheless, this approach will produce good short-term results—much better than many of the most sophisticated formulae. (8).

Competitive Models. —The use of competitive distribution models of the gravity type leads naturally to the introduction of interzonal competition into estimates of trip attraction. Rather than estimate the number of trips of a given type attracted to a zone, the model uses indices of attraction which apportion to each zone the total number of trips of that type which were derived from estimates of household trip production. Such a model would appear to be most suited for estimating strongly competitive trips, such as shopping goods trips, but its greatest use has been for estimating miscellaneous trips for which no single set of measures of attraction is available. Table 3 illustrates the set of attraction indices derived for the Fort Worth study (9).

The indices in Table 3 are weights which assign to each land-use factor its relative importance in the trip attraction model. Consider the "Other Home-Based" trip purpose category, for example:

Let

Y_i = the "basic attractiveness" of zone i for other home-based trips relative to all other zones—basic attractiveness is used here to designate the attractiveness of zone i without regard to its location or accessibility relative to all other zones;

TABLE 3

TRIP ATTRACTION INDICES

Land Use Factor at Zone of Attraction	Trip Purpose		
	Other Home-Based	Non-Homed-Based	Trucks
Population	0.115	0.013	0.002
Commercial employment	0.048	0.290	0.246
Industrial employment	0.025	0.080	0.088
Other employment	0.150	0.100	0.009

P_i = population in zone i.

C_i = commercial employment in zone i.

I_i = industrial employment in zone i.

O_i = other employment in zone i.

Then

$$Y_i = 0.115 (P_i) + 0.048 (C_i) + 0.025 (I_i) + 0.150 (O_i).$$

The Yi's are then combined with appropriate friction factors to distribute the total number of other home-based trips among the various zones by means of the gravity model.

Extensive use was made of the relative attractiveness concept by the Southeast Connecticut Area Transportation Study (SEATS) in developing attraction indices for all purposes but home-based work (10). The procedure may be described as follows. For each of eight non-residential land uses (industrial, personal service, business service, institutional, recreational, commercial amusements, retail, other) a single variable, employment in that particular use, was assumed to represent the level of activity. Thus, for example, in any zone, industrial employment was taken as the measure of industrial activity in that zone, retail employment as the measure of retail activity, etc. This measure is called the destination zone factor. The frequency of trips to the various land uses was then grouped into three classes, home-based long, home-based short and non-home-based. Trip type factors for each class of trips to each land use activity were then computed as the ratio of the total number of trips of a given class to a given land use divided by the total employment in that activity. The final step was to develop an attraction index for each zone for each class of trip as a function of the trip type factors and the destination zone factors.

The procedure is shown in more detail for a single class of trip in the following.

Let

k designate a particular land use activity, k = 1, . . . , 8,

and

i designate a particular zone, i = 1, . . . , 100.

A_{ki} = destination zone factor for k^{th} land use activity in i^{th} zone. For example, the amount of industrial employment in zone 5.

L_k = total number of long trips to k^{th} land use in all zones.

F_{Lk} = trip type factor for k^{th} land use, where

$$F_{Lk} = \frac{L_k}{\sum_{i=1}^{100} A_{ki}}$$

I_{Li} = attraction index for long trips to zone i, where

$$I_{Li} = \sum_{k=1}^{8} F_{Lk} A_{ki}$$

The attraction index so computed is used to distribute home-based long trips among the various zones. A basic assumption in the model is that a single rate of attractiveness for a given trip purpose exists for all zones.

The relative attractiveness of each traffic zone may also be related directly to system variables of several types. Two such variables, a transit service index and an accessibility index, were used in estimating trip attraction by mode in the Baltimore study (11). The transit service index for a given zone is related to the frequency of transit service to that zone. The accessibility index for a given zone is a function of the reciprocal of highway travel times from that zone to all other zones.

An example of the use of these indices for estimating trips by all modes to CBD and non-CBD zones follows (derived by step-wise regression technique).

$$T_C = 222.856 + 0.354\ TSI + 2.346\ HS + 1.969\ TE + 3.684\ RE$$

$$T_N = 3{,}300.635 + 1.394\ PS + 1.255\ HS + 4.426\ CS + 1.616\ E + 8.051\ RE - 367.120\ AI$$

where

T_C = CBD trip attractions, all modes;
T_N = non-CBD trip attractions, all modes;
TSI = transit service index;
AI = accessibility index;
PS = primary school students;
HS = high school students;
CS = college students;
TE = total employment; and
RE = retail employment.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations must be evaluated within the full context of the restrictions of this study. Based as they are upon a limited review of essentially secondary sources, these recommendations should be treated as hypotheses to be tested, rather than as prescriptions or standards to be followed.

Role of Land Use in Trip Generation

Land use plays a pervasive and often ambiguous role in trip generation analysis. It can never be ignored as an element in traffic and transportation planning, yet its uncritical use may often obscure rather than reveal functional relationships between patterns of travel and urban activity. In the language of the mathematician, land use is necessary—but not sufficient.

As in most cases of this type, the problem is essentially one of definition—both of terms and of objectives. The results of our limited analyses, as well as the experience of almost all transportation studies, give ample evidence that, with few exceptions, generalized land use by itself is usually inadequate as a basis for estimating trip attraction. As we begin to subdivide these very broad categories into groups that are more identifiable with the nature of the activities which are performed in each group, a more rational and useful basis for trip estimation is created. It is not only that the major categories of land use are too general and include too many unrelated uses, but it is also that these broad designations are too far removed from the activities which take place upon them and which are the reasons for which trips to a given use are made. As finer groupings of land use are made, we move closer and closer to an identity with specific activity designations and farther away from the traditional concept of "land use." (Since our ability to predict the future location and level of land use activities tends to diminish rapidly as the detail of classification increases, there is an upper limit to the degree of detail which can be usefully employed.) Thus, the problem of definition of terms.

The problems of definition of objectives arise chiefly out of the extremely complex nature of the transportation planning process and its interrelation with land use planning and regulation. Trip generation is only one aspect of transportation planning. To be useful, it must relate on one hand with urban growth models or more traditional techniques of land-use projection, and on the other with the relatively precise demands of current techniques of trip distribution and traffic assignment. Standing, as it does, between land use and transportation planning, trip generation analysis has suffered with respect to each in trying to meet the requirements of the other. The recent collaboration of the Urban Renewal Administration and the Bureau of Public Roads in developing a multi-dimensional system of land-use coding based upon activities compatible with the Standard Industrial Classification should be of material help in resolving this dilemma (12).

Viewed from the perspective of transportation planning, land use must be considered essentially as a means for understanding travel characteristics, not as a device for estimating or forecasting trip attraction rates. This is not to say that land use, particularly as defined on the basis of travel-rated activities, can or should be completely laid aside in favor of more direct activity measures such as employment or retail sales. After all, urban travel is spatially as well as activity oriented, and the definition and physical location of activities on the land is essential for the planning of transportation systems and facilities. Clearly, the future distribution of spatially separated but functionally related activities will create the trips for which these facilities are to be built.

Without attempting to specify the exact form which land-use specification and classification should take in order to be useful for trip generation analysis, the following general principles have been suggested (13):

1. Land-use classes should relate to the purposes for which trips are made. More specifically, (a) activities which produce significantly different proportions of work trips, non-work trips, and non-home-based trips should be classified separately; (b) activities which produce significantly different proportions of trips by mode should be kept distinct; (c) activities which produce relatively large proportions of goods trips should be classified separately from those that produce predominantly person trips.
2. Land-use classes should be understandable to household survey respondents.
3. Land-use classes should be relatable to land-use models and economic theory.

Variables Used in Generation Analysis

Whatever the classification of land uses employed as a basis for interpreting and projecting travel at the spatial level, current practice tends to favor activity measures rather than area or space measures as a basis for analyzing and forecasting trip attraction. Measures of activity should be selected which have as many of the following characteristics as possible:

1. They should be functionally related to the purpose or purposes for which trips to a designated land use class are made. For example, employment is the primary (but not necessarily the only) factor attracting trips to industrial land, while school enrollment is the principal agent in the generation of trips to schools. Table 2 lists a number of activity measures which have been used in recent studies to estimate trips for various purposes.
2. They should be as directly and universally descriptive of the conditions in which the activity operates as is possible, so that relationships established in one community can be readily translated to other communities. For example, density would be preferable to distance from CBD as a predictive variable.
3. They should be subject to prediction or projection within the desired planning horizon. This applies not only to the location and level of the variable, but also to the relationship between it and trip generation. In this regard, employment in various major categories appears to be a particularly desirable measure since it forms an integral part of economic and regional growth models as well as being sensitive in a relatively predictable manner to the effects of automation and other technological and social changes.
4. They should be sensitive to the competition for trips among similar or related land uses. Retail sales, as a measure of the level of competitive activity of various commercial areas, would seem to satisfy this requirement best.
5. They should show a strong and direct statistical association with trip making. Logic and experience should not be disregarded, however, in the search for good statistical fits. Overly complex multi-dimensional, multi-factor equations are rarely justified, considering the lack of underlying theory and the questionable accuracy of some of the input data.
6. The complexity and degree of refinement of the measures used should be in keeping with the intensity of trip attraction to a particular land use and the relative importance of these trips in the total daily travel pattern. The analysis of work trips, for example, would warrant the development and use of highly specific measures of employment. In contrast, estimation of trips to parks and other urban open space might better be based upon gross acres or other fairly simple measures.
7. They should be relatively inexpensive to obtain in a uniform manner for the entire study area. Data which are collected, analyzed, and forecasted by other agencies as a regular part of their activities can be particularly valuable in this regard. Net or gross acres, broad categories of employment, school enrollment, and sales tax receipts are examples of measures which often meet these requirements. Floor space, particularly outside the central area, is, perhaps, the one single measure of trip-related activity which is generally not obtainable within these constraints.

Clearly, a number of the above requirements tend to be mutually exclusive, and it is unlikely that any single variable or set of variables will satisfy all of these conditions. The exact nature of the compromises with reality that will have to be made will depend strongly on the circumstances relevant to each study and the experience of those who are responsible for obtaining, analyzing, and using the data.

Methodological Approach

We have found a wide variety of approaches used in the determination and forecasting of trip attractions to non-residential land. There is no one best way, although any particular technique can be made better by careful attention to the primary objectives of the analysis and to the basic principles of sound engineering practice. In this respect, the following points appear to be particularly relevant:

1. Trip generation is a manifestation of human activity. A high degree of variability is to be expected, particularly in those activities (such as recreation, social interaction, and shopping) which generally lie outside of formal social or economic systems.

2. Most, if not all, of the basic data used in trip generation analysis are subject to a greater or lesser degree of error. At best, such errors add to the variability of generation forecasts. More often they may lead to biased and unreliable forecasts.

3. A clear distinction must be made between trip generation analysis for systems planning on one hand and for traffic planning or project design on the other. The collection and forecasting of data for trip generation analysis within the context of urban transportation studies is directed toward the planning of areawide transportation systems. Estimates of trip attractions to particular generators or sites is not feasible from these data. Not only is the variability in generic estimates ordinarily far too great to permit meaningful application to a single generator, but also the precise location of a large generator will usually be of overwhelming importance with respect to the impact upon any given facility. Analysis at this scale requires data and knowledge not commonly available or needed at the systems planning level.

4. Estimates of generation using one source of data or one analytical technique should be cross-checked against as many other sources as budget and time permit. Of particular importance in this regard is the establishment of control totals and subtotals from household trip production and other independent sources.

5. Given the present state of the art, relatively simple methods which derive from a synthesis of logic and experience may often yield better results than complex, mechanistic analyses, particularly where data are poor or where change in the zone of analysis is expected to be slight. In any event, estimates obtained through statistical abstractions such as regression equations should be carefully checked for reasonableness against perhaps less precise, but more stable models.

6. Statistical analysis should be used as an aid in testing hypotheses and specifying numerical values for generation models based upon rational or logical relationships, and not as an end in itself. Regression models should be based more on the criteria of simplicity and validity and less on attempts to wring the last degree of variance from the data. Regression coefficients should be expressed to as many significant figures as are warranted by the precision of the source data and no more. Coefficients carried out to the fifth decimal place lend an air of precision to the equations of relationship which is unwarranted and may be misleading.

Further Study

In an exploratory study such as this, each finding raises its own host of new questions. Within our limited means of time, money and knowledge, we have tried to answer some of these questions, but most have had to be set aside as fit topics for future research. In selecting among the many topics for which understanding is presently lacking, we have tried to view trip generation in the general context of transportation planning. Those questions which appear to us to be most germane in this regard are considered in the following:

1. Although most workers in this field would agree that the precision with which we can estimate trip attractions to many types of non-residential land uses is too low, we have no objective measures of what an acceptable level of precision would be. There is an urgent need throughout the urban transportation planning process for measures of the sensitivity of one stage of the process to errors transmitted to it from other stages. Not only are measures of this type unavailable, but the methodology by which they might be obtained has not been formulated. With specific regard to trip generation, research should be initiated to determine: (a) the probable effects which errors in the forecasting of various types of trip ends have upon the nature and volumes of trips derived from models of trip distribution and assignment; and (b) the probable errors in forecasting the independent variables used in trip generation equations and the effects which such errors have upon forecasted trip ends.

2. Many of the land-use classification systems in current use were not derived with the needs of generation analysis and other phases of transportation planning in mind. Sets of land-use groupings based upon the highly flexible multi-dimensioned activity coding system developed by the Urban Renewal Administration and the Bureau of Public Roads should be derived and tested for applicability in the analyzing and forecasting of urban travel generation and trip structure.

3. Linkages between land uses should be more deeply explored, particularly those that occur on multipurpose trips and daily trip sets. The effect of walking trips, especially in the CBD, needs careful study. Also of importance in this regard is the effect of separation and contiguity of activities upon trip attractions and trip length characteristics.

4. The volume and nature of goods movements generated by commercial and industrial uses should be given more attention than they are at present.

5. A comparative analysis of existing techniques for forecasting non-residential attraction should be undertaken on a continuing basis to provide objective measures of cost and reliability over time. A moderate-sized urban area rather than a very large metropolitan area would appear to be more suitable for such a study.

6. The relative utility of floor space, sales and employment in forecasting trips to commercial land and other high-intensity urban uses, particularly in central areas, should be more fully studied. Consideration should be given to the predictability of the several measures for the design year as well as to their observed association with trip attraction.

7. Improved techniques are needed to estimate traffic impacts of large generators for use in traffic planning and facility design. As it now exists, generation analysis is directed toward the planning of transportation systems and is generally not appropriate for studies of specific sites or facilities. Current work under NCHRP Project 7-1, "The Influence of Land Use on Urban Travel Patterns," which is directed toward improving our capability to estimate the amount of traffic produced by major facilities such as large factories, shopping centers, and airports, is an example of the type of research needed.

8. Studies at selected non-residential sites should be conducted concurrently with home-interview surveys to attempt to establish the nature and extent of errors in estimating trip ends on non-residential land from residential interviews.

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