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Developing Transportation Plans

6 Reports

Subject Area

55 Traffic Measurements

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Foreword

This RECORD is concerned with the problems involved in developing transportation plans for rural and urban areas. The vast amount of money spent for transportation data gathering and analysis has produced much research that is ultimately geared to the provision of better planning, although taken singly much of it is procedural in nature, permitting the data from transportation studies to be more easily assimilated into planning practice.

Transportation planners will find much in this RECORD to encourage them in their planning. Developments presented tend to be subtle rather than obvious in their impact, but the problems are of such immensity that all possible effort must be brought to bear upon them. The proper utilization of the vast amounts of data generated is evident in many of the studies presented here.

In the first paper, Kuhn deals with traffic generation at rural highway service areas. In explaining how traffic generation occurs, the paper indicates that visibility, accessibility, type of facility, interchange location, class of interchange, and brand availability are all prime factors. The development of a mathematical model for estimating service area traffic generation is indicated as a project for additional research.

Fleet and Robertson discuss the importance of efficient data utilization in the trip generation phase of the transportation planning process. The authors argue for the logic of disaggregate travel analysis of trip generation relationships, and three trip generation analysis procedures are suggested for use in the continuing planning phase.

Shunk, Grecco, and Anderson, using data on work trips only, present an approach to travel surveys that would satisfactorily define the same highway system using trips of all purposes. They suggest the use of a survey, conducted at major generators, to replace the traditional home-interview survey.

Deutschman and Jaschik report that household income is a determinant in transportation and land-use planning. Simplified procedures are presented to measure the sensitivity of household income with such variables as auto ownership, transit-trip ridership, auto and total trip-making, and home ownership. The researchers indicate the need for revisions of data collecting procedures pertaining to household income as well as a continued development of procedures to systematically measure household income for its effects on transportation and land-use planning.

Small urban areas could perhaps use simplified techniques to develop their transportation plans. Jefferies and Carter investigate such techniques. Using data from six small urban areas, their investigation indicates that simplified techniques are feasible using the gravity model, but also indicate that determination of trip generation is the key to accurate application of the gravity model in smaller urban areas.

The last paper, by Walker, describes a procedure for forecasting future trip ends using a grouping of generation zones. Changes in forecasting of variables related to trip production and trip attraction can shift a particular zone from its original grouping to another grouping of higher or lower trip generation rates.

Contents

Factors Influencing Traffic Generation at Rural Highway Service Areas

HERMAN A. J. KUHN, University of Wisconsin

•ANY ATTEMPT at sound interchange area planning or the control of development at interchanges requires an understanding of certain factors, such as a knowledge of the types of development most likely to occur and the traffic generating capabilities of each.

Numerous investigations have shown that development adjacent to rural freeway interchanges is largely highway-service oriented. One researcher, for example, noted that two-thirds of all development along rural routes in Pennsylvania was highway-service oriented with service stations, restaurants, and motels occurring in a 6:4:3 relationship (9). Michigan studies showed a similar tendency, although the ratios were not the same (7). Table 1 gives the extent of commercial activity along I-94 between Ann Arbor and New Buffalo. Development activity along I-90 in Wisconsin between Beloit and Tomah shows similar characteristics.

Much of the on-going research in the area of interchange development has attempted to define the extent of development in terms of (a) actual development by type, (b) changes in land values, and (c) zone of interchange influence. As Horwood [cited by Lehr (6)] notes, "There is virtually no information available which gives a clue as to the trip generating characteristics of most uses associated with highway user needs, such as motels, service stations and eating places." If the factors which most influence generation were to be defined and quantified, trip generation models could be developed as explainers of actual generation. Such models would provide a valuable tool which could be used to analyze traffic flows in an interchange area.

TABLE 1

QUANTITY OF COMMERCIAL DEVELOPMENT AT FULL INTERCHANGES[a]

Interchange Classification	No. of Interchanges	Service Stations (avg. per interchange)	Restaurants (avg. per interchange)	Motels (avg. per interchange)	Shopping Centers (avg. per interchange)
Major city[b]	8	3.38[d]	2.38	1.25	.38
Secondary city[c]	13	1.38	0.46	0.15	.08
Small town[d]	13	1.23	0.54	—	—
Rural[e]	18	0.44	0.28	—	—
Avg.	52	1.33	0.71	0.31	.08

[a]Within 1,000 ft of interchanges 3½ years after opening to traffic; IH 94—Ann Arbor to New Buffalo, Mich.
[b]Major city—located on the most direct route into a city of over 10,000 population. A state or U.S. highway which made a reasonably direct penetration was automatically included.
[c]Secondary city—for cities of over 10,000 population, all interchanges not classified as major city.
[d]Small town—adjoining a city or town of under 10,000 persons and within 1 mile of the city limits or 2 miles of the city center.
[e]Rural—interchanges not associated with a city or a town.
Source: Michigan State Highway Department (7).

Paper sponsored by Committee on Parking and presented at the 47th Annual Meeting.

FACTORS INFLUENCING DEVELOPMENT

It would be well to understand where development is likely to occur and to what extent (amount and type). This requires an understanding of the factors influencing development—an area that has concerned many researchers. Other studies have been on similar or related questions, among them the factors which can be used to delineate an interchange's zone of influence (1) or which influence rises in value (8). While the latter two relate to somewhat different aspects of the problem, they help provide an insight

TABLE 2

FACTORS INFLUENCING DEVELOPMENT AT INTERCHANGES[a]

Factor	Reference						
	(1)[b]	(3)	(8)[c]	(6)	(9)	(5)[d]	(2)
Visibility						1	8
Accessibility			1			2	9
Access controls	3						
Interchange type							
Traffic							
Volume			3	1		3	4
Mainline		5					
Crossroad		8			1		
Composition			4			3	
Mainline							
Crossroad							
Relational characteristics						4	
Position in interchange area "first-off position"							
Major urban centers							
Distance to	2	2		2	3		
Population of							12
Availability of backup business							
Existing development in interchange area		9					11
City or town served							
Distance to							2
Relation to direction of growth							
Population of				4			3
Cities connected			5				
Location of adjacent interchanges	4	3					
Proximity of other highways	5						
Site characteristics							
Topography	1	1			2		10
Soils							
Availability of utilities		7					
Population at interchange		6		3			
Area characteristics							
Rural/urban							
Population—composition of—growth rate					4		
Economy of area							
Economic considerations							
Site cost							5
Development cost							
Development controls							6
Marketing factors							
Competition between companies							7
Brand coverage							
Oil company policy on facility spacing							13
Return on investment							
Miscellaneous							
Years open to traffic (age of interchange)		4					1
Type of crossroad—federal, state, etc.			2				
Trip lengths of motorists							

[a]The numbers in each column refer to the numerical order in which the original source listed them and do not necessarily indicate their relative importance.

[b]This source evaluated factors that can be used to delineate an interchange's zone of influence rather than those which directly influence development. Since the two are related, however, these factors are included.

[c]This source evaluated factors that can be related to a rise in property values rather than those directly influencing development.

[d]Factors derived from the author's study and from discussions with high-level management of several major oil companies. Although many other factors are also considered in the site development process, they are often of only minor significance, given good visibility and accessibility, which are probably the primary factors.

into the factors which influence development. Table 2 has been developed from several sources in an attempt to draw some uniformity from them. The factors have been itemized numerically in the order presented by the authors. The numbering does not imply a ranking by the author, although it would seem that their order of presentation should be somewhat related to their relative importance. However, based on this author's research into development factors two facts were readily apparent: (a) the lack of agreement on the relative importance of the various factors (Table 2), and (b) the surprising lack of emphasis on the importance of visibility and accessibility as prime characteristics.

This lack of agreement on the relative importance of the various factors may be explained partly by study timing. Most studies are made at a specific point in time, i.e., x years after completion of a facility, and they sometimes assume that development stability has occurred. As a result, certain conclusions are drawn. However, development at interchanges is a fluid phenomenon; it does not occur and then cease. There is often a surge of development activity on the best sites and then a leveling off. Stability does not necessarily occur for many years, if at all, and development continues on properties which were bought early and held until an appropriate later date. It is an established fact that developers buy early and sometimes hold their land for a number of years before developing.

As for what developers buy or attempt to buy, a recent article in Petroleum News (4) notes that, with luck, they buy "a large sized tract in a prime position, with good visibility and accessibility." That statement fairly well sums up the major considerations for developers. They are included as the first four major headings of Table 2. The remaining factors are less important. Cost is a far less important consideration than one would expect. This is because the oil companies and other developers all realize that someone will pay the "going price" for a prime parcel, exorbitant as it may seem. Prices as high as $150,000 per acre have been recorded for filling station sites (6).

As part of a study of the land use and traffic generation characteristics of rural highway interchanges the author interviewed top level management of several major oil companies. They emphasized the same factors as site selection and development criteria. Although they indicated that no specific formulas or models existed for determining the best locations, and that their decisions were based, partly at least, on "seat-of-the-pants" judgment, they were unanimous in their agreement that visibility from the freeway, easy access,[1] and the site's relationship to the use of the crossroad were the most important factors. The latter is important because oil companies want to locate not only in the "first-off position" but also at a site where local or "neighborhood backup" business is available. This is especially important on such highways as the Interstate System where traffic volumes can undergo severe seasonal fluctuations.[2] Backup business is particularly crucial to restaurant operation and can mean the difference between success and failure. It is also important, to a lesser degree, to individual service station operation.

FACTORS INFLUENCING GENERATION

Of course, the primary reason that oil companies develop is to sell gasoline; as one petroleum industry source noted: "big gallonage benefits have made the Interstate a good place to be" (4). Development is made in response to the prospect for doing business and this is directly related to a facility's ability to attract business from the highway; in other words, to its generation capability.

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[1]This does not necessarily mean the absence of access controls. The sound application of access controls should work to the advantage of both the motorist and the potential developer. It would appear that here is an opportunity for developers and the state to work together in their mututal interest.

[2]Seasonal fluctuations along Wisconsin I-90 at the Mauston permanent traffic recorder station ranged from a low of 51 percent of AADT for an average day in January 1966, to a high of 193 percent of AADT for an average day in July 1966 (5).

INTERSTATE SERVICE AREA STUDY — State Highway Commission of Wisconsin

MOTORIST/TRUCKER QUESTIONNAIRE

Station Identification [IC 1 2 | # 3] Serial Number [4 5 6]

Date [MO. 7 8 | DAY 9 10] Hour Period Beginning (24 hr basis) [11 12]

Vehicle Type [13] Vehicle Occupancy: Adults [14] Children [15]

TRIP DATA

Origin (To Day) ______ [16 … 23]

Destination (To Day) ______ [24 … 31]

Purpose of Trip CAR [32] TRUCK [33]

Route Traveled: 1. I-I 2. CROSS-I 3. I-CROSS 4. CROSS-CROSS [34] Travel Direction 1. NB 2. SB 3. EB 4. WB [35] To 1. NB 2. SB 3. EB 4. WB [36]

EXTENDED TRIP

Origin ______ CITY (COUNTY) STATE [37 … 40]

Destination ______ CITY (COUNTY) STATE [41 … 44]

SERVICE AREA STOP

Stop Purpose ______ [45]

Why did you decide to stop at this particular station [46]

Length of stop (nearest 5 minutes) [47 48]

~~Did you use a credit card~~ 1 YES 2 NO [49] ~~How many credit cards do you carry~~ [50]

PURCHASES

Fuel: 1. REG 2. ETH 3. DIESEL #1 4. DIESEL #2 5. PROPANE TYPE [51] GALLONS [52 … 54] COST [55 … 58]

Food: COST [59 … 62] Other (Specify) [63] COST [64 65]

Previous Stop Location ______ CITY (COUNTY) STATE [66 … 69] Purpose [70]

Next Service/Rest Stop: Location (if known) ______ CITY (COUNTY) STATE [71 … 74]

How often do you stop? Time (hours) [75 76] Miles (hundreds) [77 78]

Truckers Only: Does your firm have contractual stops 1. YES 2. NO [79]

VEHICLE TYPE

1. PASSENGER CAR-WISCONSIN WISCONSIN LICENSE
2. PASSENGER CAR-NOT WISCONSIN
3. PICK-UP, PANEL OR SINGLE UNIT SINGLE REAR TIRE
4. SINGLE UNIT-DUAL REAR TIRE
5. SINGLE UNIT-THREE OR MORE AXLES
6. COMBINATIONS
7. BUS
8. TAXI

TRIP PURPOSES

PASSENGER CARS

0. HOME
1. WORK
2. PERSONAL BUSINESS
3. MEDICAL-DENTAL
4. VACATION TRAVEL
5. SOCIAL & EAT MEAL
6. CHANGE TRAVEL MODE
7. SERVE PASSENGER
8. SHOPPING
9. RECREATION

TRUCKS & BUSES

1. PICK UP GOODS
2. DELIVER GOODS
3. PICK UP & DELIVER GOODS
4. OTHER WORK-CONNECTED BUSINESS
5. TO BASE OF OPERATION
6. PERSONAL BUSINESS
7. SERVICE CALL
8. VACATION

STOP PURPOSE

6. NEED GAS
7. MECHANICAL
8. EAT MEAL
9. REST STOP
0. OTHER

Reason for stopping at particular station

1. VISIBILITY
2. TO USE CREDIT CARD
3. ADVANCE HIGHWAY SIGNING
4. FAMILIARITY
5. REPEAT TRANSIENT
6. NEED GAS
7. MECHANICAL DIFFICULTY
8. EAT
9. REST STOP
0. OTHER ______

FORM P-L-38-66

Figure 1.

Reason for Choosing a Particular Facility as an Indicator

One indicator of the ability to attract or generate traffic could be obtained, it was felt, by asking service area patrons why they chose to stop at a particular facility, i.e., why they selected a particular facility (as opposed to why they stopped). This information provides some clue as to generation capability as well as explaining the sometimes large differences in generation between different stations at the same interchange. In developing a predictive traffic generation model, this information would be a useful first step.

Specific information on why motorists chose a particular facility was obtained as one phase of a survey of highway service area users. The study was conducted weekdays in July and August 1966, on I-90 between Beloit and Tomah, Wis. Slightly more than 3,000 interviews (Fig. 1) were obtained at 17 service areas located at 11 different interchanges. The data were grouped into 4 different service area categories separately for Wisconsin and non-Wisconsin autos.

The categories, or groups, were defined as follows: (a) auto services only, (b) auto services only plus restaurant, (c) modified oasis, and (d) oasis.

Group A provides the usual gasoline station facilities, offering only auto fuel and, to some extent, mechanical services, restrooms, and usually vending facilities for hot and cold drinks, candies, cigarettes, and, in some cases, sandwiches and desserts.

Group B has all of the above (although some of the food-vending facilities may be eliminated) plus a separate restaurant on the premises, offering snacks to full course meals.

Group C provides the facilities of Group B and, in addition, fuel for trucks, but no truck mechanical services or trucker-motel facilities. It may, however, be so elaborate as to include a gift shop, cheese shop, and the like.

Group D includes auto fuel and mechanical services, although the latter is apt to be minimal or even nonexistent because of the deference shown to truckers. It provides restaurant facilities; truck services, including fuels, scales, icing facilities, and mechanical services; as well as rooms, showers, etc.

"Reason for choosing" proved to be difficult to define positively in each case. Only 7 of the 10 reasons used are given in Table 3, since together they account for over 89 percent and 95 percent of the reasons why Wisconsin and non-Wisconsin auto drivers, respectively, said they selected a particular facility. The motorist is often motivated by more than one reason, interacting with another or others with varying degrees of importance.

Visibility

Visibility included visibility of the site or on-premises signing from the Interstate highway sufficiently in advance of the ramp to permit a turnoff, as well as the closest station to the interstate on the crossroad ("first station off"). An extreme example of the latter would be where a facility had essentially no visibility from the Interstate. In this case the motorist might have been motivated to get off by the "Gas, Food, Lodging" official signing or by oil company lead-in signing. After exiting, his choice may have been dictated by the "first-off station." This most certainly could have been the case, for instance, for some of the non-Wisconsin autos stopping at Station 216; 55.9 percent of them indicated visibility as their reason at a station which has virtually no visibility from the highway. Of the non-Wisconsin cars stopping at this facility 66.7 percent were through Interstate travelers. On the other hand, Station 199, with poor visibility, particularly in the northbound direction, indicated a low (as expected) 3.8 percent of non-Wisconsin cars stopping because of visibility.

On the whole, visibility played a greater part with the non-Wisconsin driver than with the Wisconsin driver, with few exceptions. Very often the ratio was 2 to 1 or better, with twice as many non-Wisconsin autos indicating visibility as Wisconsin autos. This is particularly significant in a number of cases where the bulk of generation was out-of-state.

Brand Distribution and Credit Card Use

The question on credit cards was intended to determine the percentage of motorists who stopped because they wanted to use a credit card. "All-station" values indicating

TABLE 3

PERCENTAGE DISTRIBUTION BY REASON FOR SELECTING A SERVICE FACILITY

Service Area		Reason for Choosing						
Group	Number	Visibility	Credit Card	Advance Signing	Familiarity[a]	Repeat[b]	Need Gas	Other
(a) Wisconsin Autos								
	019	7.7	16.9	–	75.4	–	–	–
	024	16.7	–	10.4	58.3	10.4	2.1	2.1
	043	32.3	16.1	–	35.5	3.2	12.9	–
	059	6.3	43.8	–	31.3	6.3	6.3	6.3
	103	30.9	16.4	–	45.5	–	3.6	3.6
A	130	18.2	30.3	–	48.5	–	3.0	–
	152	4.1	16.3	2.0	71.4	–	2.0	4.1
	157	62.5	20.8	–	12.5	4.2	–	–
	159	23.6	36.4	3.6	32.7	–	–	3.6
	199	18.5	22.2	–	55.6	3.7	–	–
B	187	50.0	–	–	21.4	–	7.1	21.4
	055	21.2	1.9	1.9	50.0	3.8	3.8	17.3
C	056	12.6	3.7	–	61.6	4.2	0.5	17.3
	216	25.3	4.2	2.1	50.5	3.2	–	14.7
	131	34.4	1.0	2.1	38.5	2.1	–	21.9
D	138	20.8	–	4.2	58.3	4.2	–	12.5
	265	32.5	1.1	–	49.4	1.1	–	16.0
All stations		22.4	9.9	1.5	51.3	2.7	1.5	10.8
(b) Non-Wisconsin Autos								
	019	39.0	32.7	11.3	12.6	–	4.4	–
	024	35.9	4.3	33.7	7.6	–	9.8	8.7
	043	69.8	16.3	2.3	4.7	–	4.7	2.3
	059	17.5	61.4	–	15.8	–	–	5.3
	103	57.3	12.6	6.8	16.5	–	4.9	2.0
A	130	26.2	42.9	2.4	16.7	–	11.9	–
	152	52.7	16.4	9.1	12.7	–	5.5	3.6
	157	64.5	25.8	–	9.7	–	–	–
	159	34.5	40.7	6.9	12.4	–	2.8	2.8
	199	3.8	67.6	15.2	13.3	–	–	–
B	187	67.1	7.1	10.6	4.7	–	9.4	1.2
	055	40.3	2.6	1.3	31.2	2.6	–	22.1
C	056	58.3	8.0	2.0	22.1	3.0	2.5	4.0
	216	55.9	2.4	3.1	29.1	1.6	4.7	3.1
	131	65.4	7.5	10.3	8.4	–	1.9	6.5
D	138	26.9	–	23.1	42.3	3.8	3.8	–
	265	52.7	7.5	4.3	19.4	1.1	6.5	8.6
All stations		46.2	20.7	8.1	16.1	0.8	4.0	4.2

[a]The customer who stops only occasionally because he stopped there on a previous trip.
[b]The habitual customer who stops once or twice a week.

9.9 percent of Wisconsin drivers and 20.7 percent of non-Wisconsin autos stopped for that reason were lower than expected, probably because of interplay between it and other reasons. Among two of the leading brands the percentages were much higher. A field survey of available facilities conducted in Spring 1966, just before the interview phase of the study, showed that Texaco and Standard Oil operated 13 of the 37 highway service developments (or 35 percent) along the facility between Beloit and Tomah. Credit card purchases showed that their credit sales for fuel varied from a low of almost 50 percent to a high of over 80 percent for non-Wisconsin autos. Wisconsin auto figures were somewhat less, ranging between about 40 percent and 60 percent. These figures indicate that brand coverage, along the Interstate and, more importantly, throughout an area, plus the outstanding credit cards that a company has, may play a significant role not only in credit card use but also in generation. Actual credit sales compared to the percentage of motorists who indicated a desire to use a credit card are given in Table 4.

TABLE 4

GASOLINE CREDIT PURCHASES

Service Area		Wisconsin Auto		Non-Wisconsin Auto	
Group	Number	Indicated Credit Card as Reason	Actually Used Credit Card	Indicated Credit Card as Reason	Actually Used Credit Card
	019	16.9	42.9	32.7	47.7
	024	—	20.0	4.3	21.4
	043	16.1	26.1	16.3	25.6
	059	43.8	57.1	61.4	82.4
	103	16.4	36.7	12.6	27.5
A	130	30.3	48.4	42.9	55.0
	152	16.3	28.9	16.4	37.3
	157	20.8	19.0	25.8	26.7
	159	36.4	61.7	40.7	62.5
	199	22.2	48.0	67.6	65.7
B	187	—	7.7	7.1	17.1
	055	1.9	11.1	2.6	21.7
C	056	3.7	35.3	8.0	43.5
	216	4.2	25.9	2.4	12.7
	131	1.0	5.9	7.5	20.4
D	138	—	—	—	—
	265	1.1	16.0	7.5	16.3
All stations		9.9	34.4	20.7	39.3

Familiarity

While familiarity was indicated as the reason for choosing by 51.3 percent of the Wisconsin motorists and 16.1 percent of the out-of-state motorists, it is a difficult parameter to define. How does one say, for instance, that a certain interchange has this much or that much familiarity? While it may be definable in terms of the interchange's age, it appears that it may also be the result of a combination of the other factors which originally introduced the motorist to the particular facility.

Advance Signing

Advance signing was indicated by 8.1 percent of out-of-state motorists and only 1.5 percent of Wisconsin motorists. Apparently, its only significance as an indicator of generation was whether or not advisory or lead-in signing was present.

Generation Study as an Indicator of Generation Factors

A study of the actual volumes of traffic generated by each facility during the 16-hr interview period (Table 5) and an analysis of some of the differences from station to station yields further information on factors influencing generation. Although no specific relationships have been developed showing how the volumes relate to such things as crossroad volume, proximity to major cities, visibility, brand availability, type of facility, relative placement within the interchange, and numerous other factors, some general influences can be pointed out.

Visibility plays a major role. However, it is difficult to define what it consists of and how it can best be measured. Some of its elements are visibility in terms of distance (time) before the ramp departure point (gore), location of the site or sign with relation to the driver's cone of vision, and the attention it commands because of size, color, contrast with surroundings, etc. One station operator noted that foggy nights were accompanied by a considerable drop in business compared to nights when visibility was good.

The influence of visibility is perhaps best demonstrated by the impact it has on non-Wisconsin autos driving solely on the Interstate. Wisconsin autos are somewhat less influenced by visibility alone, partly because of greater familiarity with the area and the greater influence of the other factors.

TABLE 5

16-HOUR GENERATION

Sta. No.	Individual Stations				Interchange			
	Facility Type	Total Vehicles	Auto	Combos	Total Vehicles	Auto	Combos	Visibility from Interstate[a]
019	A	241	227	2	241	227	2	VG
024	A	178	159	1	178	159	1	VG
043	A	83	80	1	83	80	1	F
052	A	32	32	–				P
055	C	320	290	9	1378	1153	105	G
056	C	947	759	96				E
059	A	79	73	–				G
103	A	180	168	1	180	168	1	F
130	A	93	79	1				G
131	D	326	234	57	1444	810	484	G
135	D	639	316	258				G
138	D	386	181	135				G
152	A	110	104	–				VG
157	A	94	87	–	426	401	–	P
159	A	222	210	1				E
187	B	100	99	–	100	99	–	F
199	A	142	142	–	142	142	–	P
216	C	530	365	95	530	365	95	P
265	D	494	267	151	494	267	151	E

[a]Subjective evaluation based on distance, cone of vision, and the attention that the service and/or its signing commands. Ranked as poor (P), fair (F), good (G), very good (VG), and excellent (E).

At one large oasis, for instance, 38.2 percent of the business was derived from non-Wisconsin autos, of which 93 percent were Interstate-only travelers. Of that number, 82.2 percent were southbound travelers. This facility is one of the largest, most visible complexes on the Interstate particularly for the southbound direction of travel. It is in the right-hand off quadrant on the city side of the interchange and has an attractive restaurant and gift shop. Beside it, in the same quadrant, but dwarfed and partly hidden by the larger oasis, is a major brand gasoline-only station (although with limited distribution in Wisconsin) which does hardly any business. Directly across the street is a major brand station with excellent coverage statewide. Although it has about the same visibility as the oasis, it is not nearly so commanding a facility. About 72 percent of its business was non-Wisconsin auto and of that, 78.9 percent was Interstate-only, 77.7 percent southbound and 22.3 percent northbound. For both the oasis and the latter station the overwhelming number of trips were from the direction with the best visibility. A complicating factor, of course, was the difficulty with which the northbound off-movement could be made. It is axiomatic, however, that facilities with the greatest visibility, sometimes aided by other factors, do the best business and hence generate the greatest volumes of traffic.

At another interchange with three gas-only facilities, the one with the commanding visibility—probably the best visibility for any single gas-only station on the system—generated more than twice the traffic of either of the other two facilities; in fact, more than the other two combined. Other factors contributed, the most important being brand availability and market coverage; the brand carried was one of the market leaders. Also, for the northbound movement it was in the right-hand quadrant, "first-station off."

At this same interchange the importance of being in the right-hand quadrant was demonstrated at another facility. Most of this station's business (91.5 percent) came from the Interstate; of its non-Wisconsin auto business, 95.2 percent was southbound Interstate only. Since this station has poor visibility from both the northbound and the southbound direction the importance of its being in the right-hand quadrant (although not the off quadrant) is readily apparent. The station is visible at the southbound off-ramp crossroad terminal, which is undoubtedly why so many southbound drivers stopped there. One of the other stations along the east edge of the Interstate did the same volume of southbound non-Wisconsin auto business (58 vehicles for the station on the east side as opposed to 59 for the west-side station), but this is due largely to its exceptional visibility from the southbound direction; it has even better visibility from the northbound direction.

In general, the stations with the best visibility did the best business, other factors notwithstanding. One station had a good business for a single auto-only facility; however, a rough check indicated that about 45 percent of its business came from a large motel in the same quadrant. Were it not for the influence of such a large volume-generator immediately adjacent, its business would have been marginal, at best.

The volume of business of the four services at the US 51 interchange north of Madison was largely influenced by the major route entering the city, motorist familiarity, and the relatively large volume of repeat trucker business. Truck combinations accounted for 484 out of a total 1444 trips generated at the interchange.

Another facility, the oasis at Lake Delton, did a good business with no visibility at all. However, it is near the Wisconsin Dells resort area, a major summer generator, and has also built up a repeat business because of motorist familiarity. That a large number of non-Wisconsin autos also indicated visibility as their reason for stopping (55.9 percent) would indicate that the "first-station off" the Interstate (also coded as visibility) was another significant factor.

SUMMARY

There are a number of factors influencing the volume of traffic a highway service facility generates. A better understanding, not only of the degree of influence but also of how various influences interact with one another may allow the development of a predictive generation model for highway services. Since highway service facilities are the predominant use at rural interchanges, such a model would be a useful interchange area planning tool and an aid to better interchange design.

The factors that appear to be the best explainers of generation are as follows:

1. Visibility from the freeway—either of the site or on-site signing.
2. Accessibility—within ¼ mile.
3. Facility type: (a) auto service only; (b) auto service plus restaurant; (c) auto service, restaurant, plus truck fuel (modified oasis); and (d) full truck stop (oasis).
4. Location: (a) with respect to interchange—first-off; and (b) with respect to major city—city side and size of city.
5. Interchange class.
6. Brand availability.
7. Other.

Crossroad volume has not been included as an explainer of generation because it appears to the writer that interchange type, perhaps as defined by Michigan, and city size and proximity may be better explainers of the same basic causative factors, which are certainly interrelated. For example, a major city interchange would be expected to carry reasonably high volume of traffic, whereas a rural interchange could be expected to have a low volume. The same applies to the influence of proximity to major cities.

Average generation volumes for all stations combined was not discussed because they are meaningless in terms of the many interacting influences on generation. Each station should best be viewed as an entity with its own peculiarities.

In general, individual gas-only stations on average or below average rural sites in Wisconsin can be expected to generate about 100 vehicles per 16 hr of operation, whereas the single stations on excellent sites can be expected to generate up to 200 to 250 vehicles on a 16-hr summer weekday. Oases can be expected to generate between 400 to 700 vehicles per 16-hr summer weekday for the average or better than average facility and up to 1000 per day for something like the Shell oasis at Janesville.

How many trips a motel added to such a facility would add is difficult to say. As an example, however, the Holiday Inn at US 12-18 generated nearly 1100 two-way trips during the 16 hr of interviewing at the adjacent service station. It had about 325 rooms at the time; based on a parking lot occupancy at 6 a.m. of 170 cars, against about 220 spaces allocated in the parking lot, its occupancy was about 77.4 percent. Using these figures, the 16-hr two-way generation would be about 4.4 trips per occupied unit or a 1430 vehicle generation for full occupancy.

The importance of being able to define fairly precisely the traffic generating capability of a facility is readily apparent. As an aid in interchange area planning and design, it would be an invaluable tool.

Although insufficient data were available at the time of investigation to allow the development of an explainer model for service area generation, it appears that the above factors are the most likely explainers. Additional research and counting is planned in an attempt to develop a generation model for rural highway service facilities.

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Trip Generation in the Transportation Planning Process

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This paper attempts to serve two purposes with respect to trip generation analysis. Research findings concerning data variations and aggregative effects are outlined. Also, the implications of the continuing phase of transportation planning for trip generation methodology are discussed.

Trip generation estimating procedures have generally relied heavily on statistical methodology. Such procedures require a sound knowledge of the structural relationships contained in the basic data set. Several suggestions are offered for the operational transportation planner concerning trip generation methods. By utilizing standard statistical techniques, it is possible to identify the sampling variations associated with zonal aggregate data and to illustrate the realistic level of accuracy to be expected from zonal estimating procedures. Other simple statistical procedures make explicit the effects of aggregating trip-making relationships which are, in actuality, most meaningful at the individual household level. It is concluded that the typical "fine tuning" of a multiple regression trip generation analysis with aggregate data may be of marginal value. The compelling logic of a disaggregate analysis of trip generation relationships is indicated.

Trip generation estimating relationships are derived from cross-sectional data and are subject to change with time. These relationships must be evaluated for stability periodically. Little has been written concerning the trip generation phase of the continuing urban transportation planning process. Several of the existing and proposed procedures are particularly valuable as a basis for an efficient monitoring and reevaluation program. Three trip generation analysis procedures are suggested for use in the continuing planning phase. Rather than implementing an extensive resurvey, well-designed small sample cross-sections and on-site surveys appear to hold promise for periodic reevaluation of basic trip generation estimating procedures.

•A NUMBER of papers have appeared concerning the methodology of what has been generally called trip generation analysis [see summary of literature (1) and discussion (2)]. The bulk of this work has been directed toward the improvement of estimating procedures relating observed travel to household characteristics and land use activities. Major interest and effort have been in the direction of statistical efficiency and selection of optimum relationships. Little effort has been devoted to understanding the inferences concerning travel behavior that are implicit in these procedures.

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The first section of this paper explores the structure of several simple travel relationships and household characteristics, using standard statistical procedures, in order to make explicit the consequences of typical trip generation study assumptions. Two general aspects are treated: data variations and the effects of areal aggregation. The sampling variations of zonal aggregate data are identified and related to a level of accuracy that can be realistically expected from zonal estimating procedures. Partitions of variance are utilized to illustrate the effects of areal aggregations (zones, districts, etc.) of what are, in actuality, trip-making relationships meaningful at the individual household level.

These notions are by no means new. For example, the problems attendant to areal aggregations of behavioral data have been discussed in the literature of sociology (3) and of geography (4). An excellent discussion of the important aggregation considerations in the construction of a behavioral system simulation model can be found in Orcutt, et al (5). A recent project suggests the importance of this problem in the trip generation study (1). The purpose here is to illustrate, with a typical transportation study data set, the magnitude of the problem and to offer some suggestion as to the implications of these findings for the typical trip generation analysis.

A second, and somewhat different, problem is the role of trip generation in the continuing study. Trip generation estimating relationships are derived from cross-sectional data and are subject to change with time. These relationships must be periodically evaluated for stability. Though other transportation study models require equal consideration, trip generation supplies the most direct link to the vital changes in the land use pattern and deserves particular attention.

Little has been written concerning the methodology for continuing reevaluation of the derived estimating procedures. The second portion of this paper is intended to evaluate some of the current methods, plus some newer and less widely known procedures, to determine if they can be adapted to provide an efficient monitoring and reevaluation program in the continuing phase.

The trip generation phase is of interest due to its relative sensitivity to the quality and adequacy of the data used in the estimating procedures. Previous studies in which comprehensive travel models have been developed have noted that results are particularly dependent upon the adequacy of the data available for the trip generation estimates (6, 7, 8, 9, 10, 11). The justification for the collection of several of the detailed household travel data items is primarily the trip generation study. Other technical phases of the transportation study require significantly fewer data and less detail in those data. With this premise in mind, this discussion will delineate some of the problems that the analyst faces in using the standard home interview survey data (12). Suggestions will be made, both for traditional studies and continuing analysis, concerning both the use of these data and the efficacy of alternative methods of using these data.

The findings reported here are from research conducted by the Urban Planning Division involving a number of aspects of the typical trip generation study. This research has also formed the basis for a publication which documents more fully the state of the art of trip generation methodology (2).

TRIP GENERATION IN THE TRANSPORTATION STUDY

Decisions concerning expenditures for transportation facilities and services in urban areas have become particularly important. Each choice has complex implications for the entire urban community. To aid in making these decisions, effective and accurate forecasts of travel demand are necessary. Given the impetus of the 1962 Federal-Aid Highway Act, these forecasts are generally derived within the framework of the urban transportation study.

These studies are characterized by a systematized process which, when carried through, serves as a basis on which to plan, design, and evaluate transportation systems. This process is generally considered to be comprised of the following key technical phases: population and economic studies, land use allocation, trip generation, trip distribution, modal split, and traffic assignment. Though necessarily oversimplified, the essential elements are illustrated. Of these, only trip generation will be treated in this paper.

The trip generation phase is intended to prepare forecasts of travel demand by small geographic area. Travel demand is used here in the restrictive sense of trip-making frequency. The result is, in essence, a spatial distribution of travel demand, or simply a frequency of trip-making, defined at one end of the trip and stratified by the type of trip being made. This is the stage of the travel forecasting process where the traditional linkage between land use and travel is introduced.

This paper deals primarily with a restricted subpopulation of generated travel—those trips beginning and ending at the household. These trips are of primary interest because of their direct relationship to the characteristics of the household. More information concerning travel motivation is available in this situation. The nonhome end of the trip presents other problems which would cloud the issues—a discussion of some of these problems can be found in two recent reports (13, 14).

Various approaches to trip generation estimation have evolved within the last two decades. In almost all cases, however, the analyses are similar. Typically, the total number of trips generated in a given areal unit is related to either average measures of the characteristics of the households in that unit or aggregated characteristics of the unit itself. The geographic unit is generally characterized by land use activity or intensity measures, while households are identified by certain "socioeconomic" data. Using this information, estimating procedures are normally derived by statistical methodology. The derived relationships are then presumed to remain stable over time, and trip forecasts are obtained by introducing changes in the socioeconomic and land use characteristics. This process uses vast amounts of descriptive data. The data set concerned with household travel habits is both extensive and costly. In many cases, the travel inventories comprise over one-half of the urban transportation study budget. It is important, then, that efficient use be made of these data.

The transportation study typically works with traffic analysis zones. This need for relatively fine geographic detail pushes the typical household travel survey data set to the limits of its usefulness. An examination of the sampling variations that are associated with this small area use of data will offer insight into data efficiency. Relatively little has been done to actually examine the nature and effect of these variations and to indicate what level of accuracy one should expect from these data. The areal aggregation introduced by using traffic zones requires relatively restrictive assumptions concerning the spatial distribution of variation in the derived travel parameters. Rarely are these assumptions actually evaluated. This situation also has major implications for efficient data utilization.

AGGREGATION EFFECTS AND DATA VARIATIONS

Most current methods of trip generation analysis rely on areally aggregated data. The level of aggregation is generally the traffic zone and occasionally the traffic district. This level of analysis has primarily evolved out of the procedures used in the traffic assignment process. The extent of aggregation is usually limited, on the upper side, by the point-loading concept of traffic assignment (that all trips emanating from an areal unit are loaded on the network at a common point, usually the center of activity within the unit). The lower limit of aggregation is a function of statistical estimating efficiency.

Aggregation Effects

The underlying assumption of areal aggregations is that contiguous households exhibit some similarity in family and travel characteristics, thereby allowing them to be grouped or aggregated with mean parameter values used for each group. Statistically this implies that the mean value of any particular parameter is reasonably representative of all households within the specific areal unit. It also implies that differences between areal unit mean values are more expressive of the spatial distribution of the parameter than are the extremes to be found in a single areal unit. Obviously, if there are major differences within single areal units, this assumption of homogeneity is inappropriate.

Strict homogeneity is practically impossible to obtain, particularly with the complex combinations of urban land uses. If all areal units are fully homogeneous, complete use is made of the disaggregate dwelling unit information. The degree to which these units are not homogeneous results in a loss of disaggregate detail. If sufficient detail is lost, then full value is not obtained for the survey dollar and changes in sample design or use should be considered. As an example of information loss, consider the commonly used car ownership variable. The number of cars owned by a particular family has direct implications for the family's frequency of trip-making. When this variable is aggregated by areal unit and any degree of heterogeneity exists, the relationship between travel and vehicle ownership at the family level is clouded. The net result is that the significance of a vital estimating relationship is reduced.

Aggregation effects are dramatically illustrated by looking at changes in the simple correlation coefficient during the process of aggregation. The simple correlation coefficient (r) is a measure of the degree of association between two variables (15). In Table 1, the lower correlation at the dwelling unit level implies that a differentiation between family size and car ownership exists at this level. The correlation between equivalent zonal aggregates is significantly higher. This implies that most of the distinction between car ownership and family size is lost in the process of aggregation. This illustrates the inherent danger in making statistical inferences from aggregate data concerning disaggregate relationships (3).

To make these problems of aggregate explicit, it is necessary to examine them in terms of measures of variation. A one-way analysis of variance (ANOVA) computer program (16) was used to partition the total variation into that attributable to the differences between groups and that associated within each group. Unexpanded dwelling unit data were used. Data variation was expressed in terms of summed squared deviations about a mean value. Mathematically, this is the total sum of squares (TSS) and is expressed by:

$$\sum_{j=1}^{k} \sum_{i=1}^{n_j} (X_{ij} - \overline{X})^2 \qquad (1)$$

where

X_{ij} = the i th observation on some variable (X) taken in the j th group (areal unit);

$\overline{X}$ = the grand mean of variable X = $\dfrac{\sum_{j=1}^{k} \sum_{i=1}^{n_j} X_{ij}}{N}$;

N = the grand total number of observations = $\sum_{j=1}^{k} n_j$;

n_j = the total number of observations in the j th group; and

k = the number of groups.

If the data are grouped, then the TSS can be partitioned into two components. The first is the sum of the squared deviations between the group means and the grand mean, weighted by the number of observations in each group. This is the between sum of squares (BSS). The within sum of squares (WSS) is computed by summing the squared

TABLE 1

SIMPLE CORRELATIONS BETWEEN FAMILY SIZE AND CAR OWNERSHIP AT THE ZONAL AND DWELLING UNIT LEVELS

Relationship	Observation Unit	r
Family size vs cars owned	Households	0.400
Total persons vs cars owned	Households summed by zone	0.955

deviations of each observation within the group from the group mean. Mathematically, the two components of the TSS may be stated as:

$$TSS = \sum_{j=1}^{k} n_j (\overline{X}_j - \overline{X})^2 + \sum_{j=1}^{k} \sum_{i=1}^{n_j} (X_{ij} - \overline{X}_j)^2 \quad (2)$$

where $\overline{X}_j$ is the j th group mean of variable X.

The two components in the equation (BSS and WSS) can be interpreted as measures of the variation between the groups and within the groups, respectively. Typical multiple regression trip generation estimates are developed utilizing the variations between groups. Variations between the groups are attributed to the differences between them. The amount of this component (BSS) that is actually "explained," however, is a function of the degree of homogeneity within the groups. Homogeneity, in this case, implies a small (or zero) within-group sum of squares. By computing the WSS for various typical areal units, the homogeneity assumption can be evaluated. At the same time, effects of increasing levels of aggregation on the BSS and WSS can be seen. This information is summarized in Table 2. The results indicate that, by far, the greatest portion of the total variation is within areal units and is lost, insofar as its usefulness to trip generation analysis is concerned. In particular, a zonal level regression analysis applied to the data of Table 2 would deal with only a little over 20 percent of the total variation of trip-making by dwelling units. At the district and sector level, the proportions are progressively less.

As the degree of aggregation increases, the amount of variation between groups decreases. This is of particular importance in a regression analysis (1, 2, 13). As the variation between groups decreases, it becomes less difficult to obtain a good data fit, as there is less variation to deal with. Much of the meaningful variation has been eliminated. It is this deceptive "increase" in statistical reliability that has led some analysts to work at higher levels of aggregation (districts, for example). "Increased" statistical efficiency, however, is not meaningful unless the comparison is being made on a common base. Measures of accuracy derived at different levels of variation are not comparable. An example will illustrate both the problems involved and the manner in

TABLE 2

BSS AND WSS OF TOTAL TRIPS PER DWELLING UNIT, GROUPED BY THREE AREAL UNITS

Areal Unit (Number)	WSS	% of TSS	BSS	% of TSS
Dwelling units (5,255)	0	0.0	213,936[a]	100.0
Zones (247)	170,270	79.6	43,666	20.4
Districts (57)	184,864	86.4	29,072	13.6
Sectors (10)	192,895	90.2	21,041	9.8

[a]This is also the total sum of squares in all three groupings.

which estimating procedures derived at differing areal levels can be compared as to efficiency.

To determine the effect of this spurious accuracy, multiple regression trip generation analyses were conducted on the same trip and socioeconomic data at two levels of aggregation, zones and districts. The final estimating equations are given in Table 3. Typically, estimates are required at the zone level and the district equations are adjusted to this level. The statistical tests used to evaluate the district equations say nothing about the adequacy of these equations at the zonal level of application. Moreover, it is statistically incorrect to attempt to "explain" the between-zone variation of the dependent variable with an equation that was developed using data aggregated by districts.

If the adjusted district level equations are utilized to derive zonal trip end estimates, and then these estimates are compared, by zone, to the actual values from the expanded survey, a comparison with the zonal regression results at a comparable level is possible. This was accomplished by deriving two squared correlation coefficients (15). One expresses the degree of fit between the zonal regression estimates and the base data (actually the multiple R^2 yielded by the regression program). The other expresses the fit between the zonal estimates from the district equation and the base data. The latter is the square of the simple correlation (r^2) between the zonal estimates from the district equation and the base data. This value (0.77) is given in Table 3. The comparison is enlightening. The security of the high r^2 at the district level (0.95) has vanished when the equation is applied at the zone level.

The aggregation problem has many facets, and perhaps the most important point of this discussion relates to the utilization of the basic household travel survey. The travel survey is costly and obviously should be used efficiently. In practice, this does not seem to be the case. Detailed data concerning household travel and characteristics are obtained, but the richness of this detail is washed out by aggregation. This becomes a difficulty when the analyst attempts to make inferences concerning the disaggregate behavior of households from these aggregate data. Many of the real reasons for trip-making are hopelessly concealed. If disaggregate inferences are to be made, Stowers and Kanwit conclude that it is logical for analysis to precede, rather than succeed, aggregation (17). Several other authors have noted the problems of utilizing the travel survey for trip generation analysis. Of particular interest are the comments by Shuldiner (18, 19). This discussion is not intended to suggest that the O-D survey be abandoned or in large part modified. Rather, it is hoped that more efficient use can be made of the data. Stowers and Kanwit suggest a possible alternate approach (17). They argue for the household as the basic unit of analysis, citing the compelling logic of such an analysis. Meaningful relationships are first developed at the household level and then aggregated to give zonal estimates. The important point is that full use can then be made of the household level information prior to aggregation. Details are left to a later section of the paper. If this method is to be useful, it must offer reliability at the same level (at least) as existing methods. A comparison was made by deriving zonal estimates using both aggregate and disaggregate data and determining the efficiency of both estimating procedures at this level.

TABLE 3

RESULTS OF REGRESSION ANALYSES CONDUCTED AT TWO LEVELS OF AGGREGATION

Level	Equation	Number of Observations	r^2	$\bar{Y}$
Zones	WP = 18.2 + 1.68 CO	283	0.80	315
Districts	WP = 143.0 + 2.12 CO	57	0.95	1,708
Zonal estimates with district equation		—	0.77	—

WP = home based work trip productions; CO = total cars owned; $\bar{Y}$ = mean of dependent variable.

Table 4 gives two regression equations for estimating total home-based trips. The first equation was developed using trip and socioeconomic data expanded and aggregated to zones prior to analysis. These data were dwelling unit samples from a home interview survey. Trips were expressed as total home-based trips per zone. The second equation was derived from the raw dwelling unit data. The data were taken as a group and were left unexpanded. Here, the data represented a cross-section of all households in the study area. Trips were expressed as total home-based trips by each dwelling unit.

The immediate conclusion (Table 4) based on the standard errors ($S_{y.x}$) and coefficients of determination (R^2), is that the zonal equation is superior (15). These results are misleading. As noted before, differing definitions of variation are associated with different levels of aggregation. These two statistics should be recomputed after the dwelling unit equation is applied at the zone level.

Using the number of households in each zone, zonal trip end estimates were derived from the dwelling unit equations. In the same manner as before, a squared correlation coefficient (r^2) was calculated comparing these zonal estimates to the base data. The percent standard error was also calculated. These adjusted values are shown in Table 4. The adjusted proportion of the variance explained (r^2) was 0.94, and the adjusted percent standard error was 19.4. This reveals that the dwelling unit equation, applied at the zonal level, can "explain" 94 percent of the zonal variation in trip-making. This, taken with the percent standard error, shows that either method yields practically the same accuracy at the zonal level.

This discussion implies that the typical "fine tuning" of zonal regression equations may be of questionable value. In comparison with the information losses due to aggregation, whether the derived zonal equation has a coefficient of determination of 0.75 or 0.90 is relatively unimportant. Considering that much of the meaningful variation has been washed out, whether 75 percent or 90 percent is explained may not be worth the effort commonly devoted to improvement.

The more logical behavioral base of dwelling unit analysis, given that it is comparable to zonal analysis, supplies a compelling argument for the use of this type of analysis. The dwelling unit relationships, because they have not lost their meaning to aggregation, are more likely to be stable over forecast intervals. These relationships are most accurately measured at the level of the greatest detail, the household. In transportation planning, the interest lies in household travel patterns, not in aggregate zonal changes. Thus, logic would suggest that the analysis should be conducted at the household level. The main point of this entire section on aggregation is that these problems are important and that their recognition is of importance to any transportation study. Such an analysis will permit a more efficient trip generation study.

Household Variations and Homogeneity

One of the major considerations in the efficiency of aggregation is the degree of homogeneity in the areal units. Ideally, aggregated households should exhibit almost ex-

TABLE 4

RESULTS OF REGRESSION ANALYSES CONDUCTED AT THE ZONE AND DWELLING UNIT LEVEL

Level	Equation	Number of Observations	R^2	$S_{y.x}$	$\bar{Y}$	% $S_{y.x}$
Zones	TT = -36.03 + 5.09 CO	143	0.95	296.07	1,679	17.6
Dwelling units	TT = -0.69 + 1.39 NP +1.94 CO	5,255	0.36	3.89	5.20	74.9
Dwelling units at the zone level		—	0.94	—	—	19.4

TT = Total home based trips
CO = Total cars owned
NP = Number of persons 5 years of age or older
R^2 = Coefficient of determination
$\bar{Y}$ = Mean of the dependent variable
$S_{y.x}$ = Standard error of estimate
$\%S_{y.x}$ = Standard error divided by the mean of the dependent variable

TABLE 5

STATISTICS ON CARS OWNED PER DWELLING UNIT FOR EIGHT ARBITRARILY SELECTED ZONES

Zone No.	Mean	Standard Deviation	Standard Error of the Mean	Percent Standard Error	Maximum	Minimum	Number of Observations
20	0.7143	0.6437	0.1405	19.7	2	0	21
35	0.9861	0.3137	0.0370	3.8	2	0	72
52	0.9583	0.6829	0.0986	10.3	3	0	48
65	1.1000	0.6074	0.1109	10.1	3	0	30
136	1.2373	0.5177	0.0477	3.9	3	0	118
140	0.8889	0.5774	0.1111	12.5	2	0	27
168	1.3881	0.7579	0.0926	6.7	3	0	67
216	1.3667	0.5813	0.0750	5.5	2	0	60
Total area	1.0558	0.7264	0.0100	0.9	5	0	5,255

actly the same characteristics. Differences should primarily occur between areal units. The results reported above point to the conclusion that zones are not homogeneous. This can be tested directly by studying the distribution of characteristics within a single zone. The standard deviation (s) can be used to represent the extent that a range of values of a characteristic can be found in a single zone (15). Comparing this statistic to the standard deviation computed for the entire study area yields a relative index of homogeneity.

Table 5 presents several statistics for dwelling unit car ownership calculated by zone. The zones were arbitrarily selected. Note that in most of the zones s is nearly as large as the value of s is for all of the sampled dwelling units in the area. The hypothesis of zonal homogeneity, in the case of car ownership, is not supported. The range of dwelling unit car ownership is nearly as extensive within each zone as within the entire area. If all zones are considered, this conclusion is reinforced. A crude index of homogeneity was calculated for each zone by dividing the value of s for the zone by the value of s for all dwelling units in the study area (Table 6). Again, the characteristic is household car ownership. In general, there are large variations in dwelling unit car ownership within each individual zone. Of the 207 zones, 18 percent have as large or larger variations than the total area, and 72 percent have at least three-fourths of that for the total area. Similar calculations were made for typical household characteristics (family size, for example) and for various trip types, yield-

TABLE 6

FREQUENCY DISTRIBUTION OF THE HOMOGENEITY INDEX FOR CAR OWNERSHIP OF ALL ZONES

Homogeneity Index $= \frac{s_{\text{d.u.'s in zone i}}}{s_{\text{all d.u.'s}}}$	Number of Zones	Percent of Total Zones	Cumulative Percent
1.55 & over	5	2	2
1.28 to 1.54	5	3	5
1.14 to 1.27	11	5	10
1.00 to 1.13	16	8	18
0.86 to 0.99	52	25	43
0.72 to 0.85	60	29	72
0.59 to 0.71	49	24	96
0.31 to 0.58	9	4	100
Totals	207[a]	100	

[a]Excludes zones with no dwelling units.

ing similar results. For the sake of brevity, these results will not be repeated here. It seems safe to conclude that, for the purposes of trip generation analysis, zones are heterogeneous.

Sampling Variations

In a zonal regression trip generation analysis, aggregate trip and socioeconomic characteristics are utilized to develop estimating equations to forecast future trips. For each zone, either average or total values of each characteristic are taken to be representative. Both average and total values rely upon the adequacy of the zonal mean as an estimate. In the first case, the average is used directly. Zonal total values can be thought of as being the zonal average multiplied by the number of dwelling units in the zone.

Depending on the number of samples (dwelling units) in each zone, the mean value of each zonal characteristic will not be known exactly, but as within some range. As the number of samples within a zone decreases, the range of likely values for the mean expands, and we become less confident of the mean as being representative. The variance of the characteristic also affects the magnitude of this range. These consequences are well known from elementary sampling theory.

Rarely is any consideration given to the magnitude of the variations introduced, because of sampling, into the inputs to zonal regression trip generation analysis. As the estimating equations are directly developed from these inputs, some consideration is essential. The degree to which the regression analyses can be reasonably expected to fit these data is dependent upon the amount of variation in the data. A degree of "fit" to closer tolerance limits than those associated with the input data due to sampling is spurious.

The effects of sampling variation on the sample mean of each zone can be represented by the standard error of the mean (15):

$$S_{\bar{x}} = \frac{s_x}{\sqrt{n}} \tag{3}$$

where

$S_{\bar{x}}$ = standard error of the mean;

s_x = standard deviation of X; and

n = sample size.

The standard error of the estimate ($S_{y.x}$) from the zonal regression equation indicates the variation to be expected in the estimates of the dependent variable derived from Eq. 3. For each of these statistics, it is more meaningful to standarize them by expressing each as a percent of the mean value to be estimated. They are expressed as the percent standard error of the mean and the percent standard error of the estimate, respectively.

An analysis of the distribution of the zonal percent standard errors of the mean ($S_{\bar{x}}$) compared with the regression standard error of the estimate ($S_{y.x}$) can provide an indication of the extent to which the analyst should attempt to improve $S_{y.x}$. Regression standard errors that are pushed to greater accuracy than the majority of the zonal standard errors result in false precision. Estimates from such an equation have less variation than that known to exist due to sampling. The accuracy of the estimating procedure can only be expected to approach or equal the accuracy of the data being "fitted" and further "fine tuning" is meaningless. Thus, zonal percent standard errors of the mean can be used to indicate the point at which, in terms of $S_{y.x}$, the regression analysis can be terminated. A suggested graphic representation is shown in Figure 1. Because a value of the percent $S_{\bar{x}}$ is derived for each zone, a frequency distribution of these values is convenient. The distribution illustrates the pattern of zonal sampling variation.

In Figure 1, the regression dependent variable is home-based work trip productions per zone. The mean of the distribution of the work trip zonal percent standard errors ($S_{\bar{x}}$) is represented by the vertical dashed line. The solid line represents the regression percent standard error for a zonal work trip estimating equation developed using these same data. If the mean value (23.3) is selected as a cutoff criterion, then a similar value of $S_{y.x}$ should be an indication that the equation needs little further improvement. The equation in Figure 1 has, perhaps, been carried far enough. In this case, regression is the limiting factor. If the regression analysis had been carried further, such that the percent standard error became 15.0 (vertical dotted line, Fig. 1), this would be a good example of unfounded "fine tuning."

If such an analysis is included as an integral part of the trip generation study, the analyst is provided with considerable information regarding the nature and quality of the available data. In addition, it is possible to decide the extent to which the accuracy of regression trip generation equations can be improved without overextending the accuracy of the input data.

TRIP GENERATION IN THE CONTINUING TRANSPORTATION PLANNING PROCESS

When the necessary steps have been taken to prepare the first target year forecasts, the transportation planning process is by no means complete. These forecasts must be responsive to changes occurring in the urban area, and particularly to changes in the basic forecasting relationships. The continuing transportation planning phase supplies the framework for this monitoring and reevaluation function. This continuing process necessarily requires that current information on the basic parameters of travel be available in order to make comprehensive evaluations and revisions of the original forecasts. Two types of information are required, current estimates of the inputs to the forecasting procedures and data describing the changes (or stability) in the estimating relationships.

In the continuing phase, trip generation relationships are of particular interest. They deserve attention because of the direct link that is provided to the vital changes in the land use pattern. Any major changes in household travel behavior are reflected here. Trip generation estimating relationships are derived from cross-sectional data and are subject to change with time (20). These relationships must be evaluated periodi-

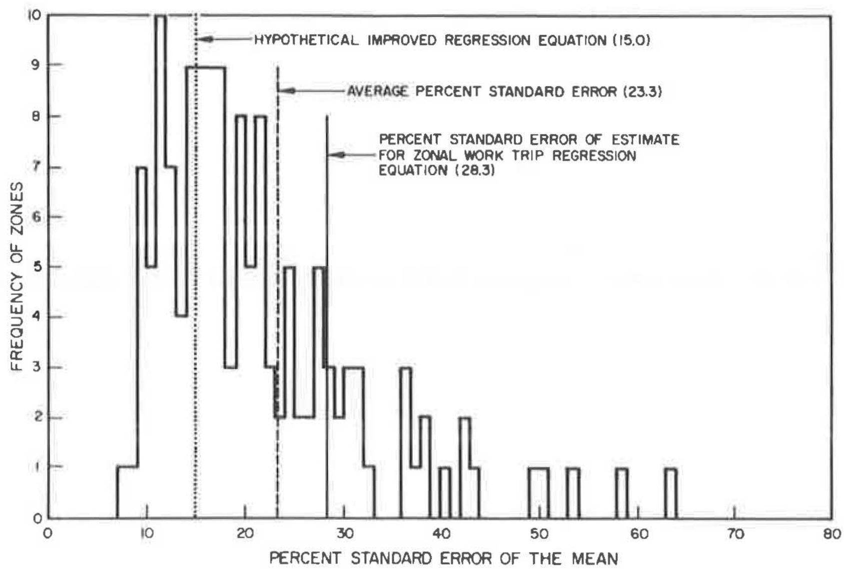

Figure 1. Frequency distribution, by zone, of the percent standard error of the mean for work trips.

cally for stability. This continuing reevaluation of trip generation estimating procedures is a vital element of the continuing process. Little has been written concerning this element.

The second major consideration in providing for adequate continuing trip generation is the availability of pertinent recent data to allow the preparation of current estimates. One way to assure this availability would be periodic full-scale surveys. Cost rules this alternative out except at relatively long time intervals. Between surveys, other methods must be used.

The extent of and procedures for continuing trip generation analysis will be different in each study. It is not possible to offer any detailed procedures for any part of the continuing phase. Much of what will be done in the continuing program will depend on what was done in the initial phases. For this reason, the procedures outlined should only be taken as illustrative of what might be accomplished. Each study must adapt the procedures as appropriate.

Several new approaches to trip generation analysis have recently emerged, although their applicaton has been somewhat limited. Of these, three are presented that have particular potential as efficient tools in the continuing process.

Dwelling Unit Analysis

Travel behavior is most efficiently studied at the household level. Vital trip-making relationships are most explicitly identified at this level of detail. Continuing monitoring and evaluation of the trip-making estimating procedures will require information on these relationships at this level of detail. Dwelling unit analyses can efficiently summarize these relationships for the entire area, allowing important changes to be quickly identified. This information can then be used to revise the basic trip generation procedures.

Previous discussion has emphasized the mechanical and statistical aspects of "data fitting." There is a more important argument for the use of a disaggregate, dwelling unit analysis. It is generally felt that a family's travel behavior is, in part, a product of the unique characteristics of that family. These relationships lose their meaning if they are aggregated. Monitoring of the aggregate relationships, however, gives little information on the components of change. If the subtle changes in household travel behavior are to be understood, it will be at the disaggregate level and not at the aggregate level. Aggregate measures of change are only the external manifestation of numerous possible combinations of travel behavior shifts.

Several more practical reasons suggest the use of a dwelling unit level analysis in the continuing phase. The costs of monitoring changes are particularly important. Small sample surveys are easily and effectively used with dwelling unit analyses, particularly where the intent is to determine the changes which have taken place in the basic relationships. Though some effort will be necessary to obtain a well-designed sample, the appropriate monitoring information can be obtained at a small fraction of the cost of a full survey. The linearity assumptions of aggregate regression analyses also present some difficulty. If, for example, there is a nonlinear relationship at the dwelling unit level, bias is introduced by an aggregate regression analysis. It is possible to avoid this problem by working at the disaggregate level and employing a different method of variable definition.

Often, the areal units of an aggregate trip generation analysis change, making the base year work incompatible with subsequent work. Most aggregate analyses use variables which directly reflect the size of the areal units. If these units change, the analysis must often be redone. The application of a dwelling unit equation is not limited to established analysis units. Past experience indicates that the flexibility to adapt to changes in areal units is a valuable asset in the continuing process.

A further consideration is the expectation that there will be growing awareness of the need to study human behavior at a disaggregate level. This paper has argued for the logic of disaggregate travel analysis, as have others (1, 17). In the area of land use development models, these same arguments are appearing, e.g., Harris, Garrison, and Schlager (21). On the empirical level, there is the summary of the work done by the University of Michigan in studying household location choice and travel behavior (22).

Though these ideas have affected the analysis procedures of only a few transportation studies, it seems logical to expect that this will be a growing trend. If, as Schlager suggests, the household location decision is to be stratified by particular household types, then this same identification will be available for trip generation. This supplies one of the major inputs to a disaggregate trip generation analysis. It would appear that the state of the art of land use models is turning toward more disaggregate model development. It follows that trip generation studies, because of the intimate relationships of travel and land use, should begin moving in this direction.

The actual application of dwelling unit estimating procedures to the development of areal estimates is relatively efficient. While a single areawide small sample cross-section can be used to evaluate the magnitude and direction of changes, small samples for each area having identified changes will be required for updating. Means of the independent variables for each areal unit and the total number of households contained in the unit are also required. The sample would never actually be expanded, however. The following general equation could then be used to obtain trip estimates:

$$\hat{Y}_w = Na + Nb_1\overline{X}_1 + \ldots + Nb_i\overline{X}_i + \ldots + Nb_n\overline{X}_n \quad (4)$$

where

$\hat{Y}_w$ = the estimate of the dependent variable for area w;

N = total number of dwelling units in w;

$\overline{X}_i$ = the i th independent variable mean for the analysis area, based on the sample;

b_i = the regression coefficient of the i th independent variable; and

a = the regression constant.

Equation 4 presumes linear relationships. Many of the significant household characteristics are not easily scaled in this manner. Stage in the family life cycle, occupation of the head of the household, or structure type are typical examples (17). "Dummy variable" regression analysis allows such qualitative variables to be used and circumvents the restrictions usually associated with linearity.

Using this technique, household characteristics are stratified into meaningful categories. Household variation is then associated with the differences between the several categories of household types rather than by absolute scale ratios, as in the linear regression case. Thus, qualitative household groupings are used to explain the behavior of the households.

The application of the dummy variable technique is identical to the usual dwelling unit regression methods, except that now the number of households associated with each household type is required. The mean values of the linear regression parameters, by area, are also required and can be obtained by small sample surveys. Estimates can be used to obtain the count of households in each dummy variable category. If a residential location model with household type stratifications has been developed, household counts by type are readily available. The general utility of this method and its use of behavioral data make it an extremely useful tool.

Cross-Classification Analysis

Another recently introduced technique offers many of the same capabilities as dwelling unit analysis. This method, cross-classification analysis, has been largely limited to research applications (10, 11, and 18). It is becoming more widely used by operational transportation studies (23, 24).

Essentially, a multidimensional matrix is constructed, each dimension representing an independent variable (household characteristic). These characteristics are then stratified into meaningful categories. Each dwelling unit observation is allocated to a cell of the matrix based on the values (categories) of the independent variables. The

TABLE 7

RELATIONSHIP OF FAMILY SIZE AND AUTO OWNERSHIP TO AVERAGE TOTAL PERSON TRIPS PER DWELLING UNIT

Number of Persons per Dwelling Unit	Average total person trips per dwelling unit				
	Number of autos owned per dwelling unit				
	0	1	2	3 & Over	Weighted Average
1	1.03	2.68	4.37[a]	–	1.72
2	1.52	5.13	7.04	2.00[a]	4.38
3	3.08	7.16	9.26	10.47	7.46
4	3.16	7.98	11.56	12.75	9.10
5	3.46[a]	8.54	12.36	17.73[a]	10.16
6-7	7.11[a]	9.82	9.61	16.77[a]	11.00
8 & over	7.00[a]	9.65	6.18	11.00[a]	12.24
Weighted average	1.60	6.62	10.53	13.68	6.58

[a]Average based on fewer than 25 samples.

dependent variable (trips of some type) is accumulated by cell, and the average determined for each cell. A typical application (two-dimensional) is given in Table 7, and a graphic representation is shown in Figure 2.

Changes in a dependent variable are studied when two or more independent variables are varied. In this respect, the methodology is the same as regression analysis using only dummy variables. By holding one or more of the independent variables constant, the effect of varying a particular variable can be studied.

This technique makes particularly full use of the household travel survey data and, by its nature, offers the analyst the opportunity to work closely with the data. It is also not bound by the usual assumptions of linearity. For these reasons, the same positive comments made about the data efficiency associated with dwelling unit analysis apply here. Perhaps the greatest limitation is imposed by the amount of data required for adequate representation and statistical stability. Despite this, the technique is straightforward and efficient and offers none of the problems often encountered with curvilinearity and the treatment of qualitative variables.

Much of the early work with this technique as a tool in trip generation analysis was undertaken by the Puget Sound Regional

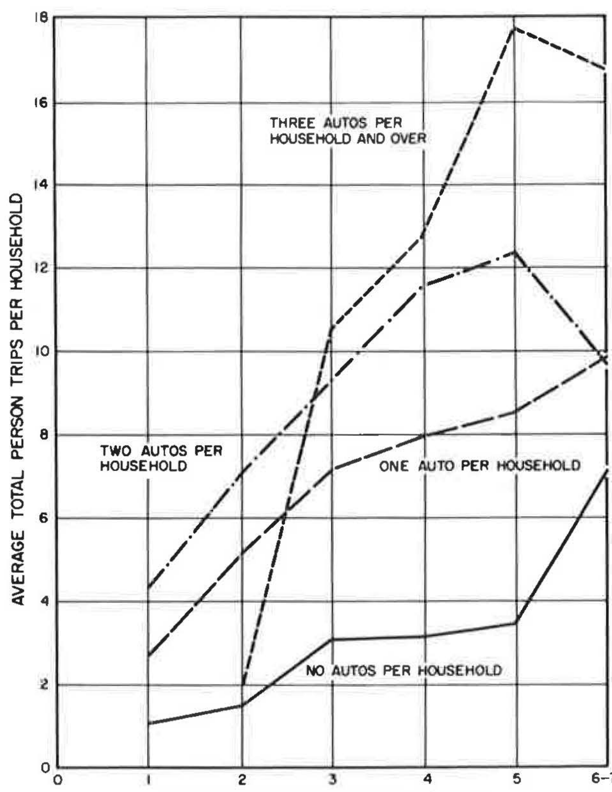

Figure 2. Average total person trips per household related to family size and car ownership.

Transportation Study (23, 24). The matrix of values was initially developed using the dwelling unit data and then applied at the zonal level. Household and density characteristics were used in a method that employed weighted zonal rankings based on zone averages of five independent variables: household size, cars per household, median income of the head of the household, population per acre, and population per net residential acre.

To evaluate the changes in basic estimating relationships, the use of the cross-classification and dwelling unit techniques are identical. In practice, this matrix method may be less complex and more efficient in the monitoring of change than a full dwelling unit analysis. The data, as before, need only be from an areawide small sample survey.

The preparation of new forecasting procedure inputs is also similar to that discussed in the previous section. Again, small sample estimates of zonal characteristics are required. In the case of the Puget Sound method, the new ranking of each zone must be determined. The more general case requires an estimate of the number of dwelling units, by analysis area, that are expected to fall into each matrix cell.

Site Analysis

Most current methods of analyzing nonresidential trip generation rates rely on trip information collected in the home interview survey, while the independent variables are usually obtained from other sources. Home-based work trip attractions, for example, are usually based on employment estimates at the nonhome end of the trip. This approach assumes, of course, that the characteristics of trips attracted to nonresidential land, obtained in the sample at the home end, are representative of similar trips by all other households that the sample represents.

A recent study has indicated the utility of using O-D data for estimating nonresidential trip generation (25). Another study has noted that O-D data are not adequate for this purpose (13). Both views are within the context of nonresidential trip generation analysis as a tool in project and facility planning, rather than in traditional transportation systems planning. In the development of base year relationships, the interest is in total systems planning rather than individual sites. This changes in the continuing phase when the impact of new major single site traffic generators is of particular importance. While steady growth will often be found throughout the region, evaluating the transportation consequences of new major generators will be a large task in the continuing phase. Examples of such generators would be shopping centers, airports, and hospitals.

In these cases, better information on the generation of travel can be obtained by collecting data at the site rather than relying on home interview data. This is not as prodigious a task as it seems. These major generators are relatively few in number, even in an entire area. One study found, for example, that a large percentage of the nonhome trip ends (70 percent) were actually attracted to a relatively small proportion (15 percent) of the parcels in the study area (14). Concentrating on these relatively few important attractors would provide more accurate estimates than spreading the same effort thinly over all areas. This does not suggest that home interview trip end data should be replaced. Rather, it is intended that the basic data be supplemented with more information for the few sites which contribute large amounts of traffic. In combination, on-site data and home interview data can place nonresidential (and some residential) trip generation analyses on a much more stable base.

In the base year procedural development, site analyses will be useful to improve the accuracy of nonresidential trip generation estimates. Here the use of this technique is supplementary. In the continuing phase, on-site data collection at new major generators can supply much of the necessary update information. These data, in combination with small sample updates of the nonresidential trip generation rates for the entire area, can provide the framework for a continuing trip generation program.

Site analyses have been little used by transportation studies except for one-shot single site studies. A good example of a comprehensive program is that reported by the California Division of Highways (26, 27). Traffic entering and leaving selected sites was related to characteristics of the particular facility to obtain trip rates. Such rates as trips per employee, trips per square foot of floor area, and trips per hospital bed were obtained. Counts were obtained on an hourly basis over a period of from two or three days to a week.

The Chicago Area Transportation Study has recently employed these methods to develop trip end estimates for a high rise apartment, for O'Hare International Airport, and for walking trips in the Loop (28). Here, both interview techniques and traffic counts were used.

It seems reasonalbe to conclude that on-site surveys for major generators should play an increasing role in both the initial and continuing phases of transportation planning. Such methods should make trip end estimates more reliable and allow the home interview data to be used more appropriately.

SUMMARY

The intent of this paper has been to bring trip generation analysis into perspective in light of recent practice and developments. Major emphasis has been placed on illustrating the consequences of the typical assumptions inherent in the derivation of generation forecasting procedures. Much of this has been based on standard statistical methodology. Though it is hoped that transportation studies will find these procedures useful, the primary motive has been one of understanding. A major failing of most trip generation forecasting procedures has been the lack of effort devoted to understanding the inferences concerning travel behavior that are implicit in these procedures.

The second purpose of the paper has been to offer a beginning framework for continuing trip generation analysis. Two major elements, monitoring and updating, are associated with a continuing trip generation program. Trip generation forecasting procedures are subject to change with time. The monitoring function supplies the information necessary to indicate significant change in the derived forecasting relationships. In addition, inputs to these forecasting procedures are periodically required to develop new estimates. This is the updating function. In the discussion of continuing procedures, the intent has been to outline efficient procedures to accomplish the two continuing generation elements. Adaptations of three procedures are suggested. Major data collection costs are reduced by utilizing small sample cross-sections and on-site surveys.

Perhaps the primary point of the first section of this paper is that trip generation analyses are too often conducted by rote. An inordinate amount of faith is typically placed in the traditional approaches to analysis. This particular phase of transportation planning is frequently too product oriented. Each of the points made in the first section refer to a method of dissecting these procedures to make explicit the assumptions made. It is this disassembly which is vital to understanding.

Much of what has been discussed relates to the basic travel data. Here two points are important. The high cost of these data requires efficient use. Several of the comments made above indicate that more efficient use could be made of the data by employing different procedures. In particular, disaggregate dwelling unit level analyses are strongly supported, based both on data utilization and compelling logic. The second point is that existing methodologies tend to impute more validity to statistically derived forecasting procedures than is warranted. The false security of superficial accuracy tends to hide the real value of each procedure and to allow the selection of the wrong one.

The problems of aggregation are paramount in trip generation analysis. It is not realistic to infer disaggregate (household) travel relationships from aggregated data. It is vital that the trip generation analyst understand the problems attendant to aggregated data, as almost all studies are performed at an aggregate level. The procedures suggested in the paper can be used by any analyst for this purpose. Perhaps the problems of aggregation are best summarized by the general comment that aggregation should follow analysis, rather than the reverse.

The arguments for disaggregate analysis can be carried over into the continuing phase. The same advantages, plus the benefit of an effective and efficient method for periodic evaluations and updates of trip end estimates apply. The large costs of data collection are circumvented because of the ready adaptability of dwelling unit and cross-classification analysis to small sample survey methods. In addition, the analyses are not limited to established methodologies. Innovations, such as dummy variable regression techniques, allow more flexible analysis.

Nonresidential trip generation estimates have generally been a problem. In both the initial and continuing phases, on-site surveys can supply the information necessary to develop estimates at major sites. This is of particular value in the continuing phase where major efforts must be devoted to evaluating the impacts of new major generators. Site analyses also are a valuable supplement to the basic household travel surveys.

As trip generation estimates provide a basic ingredient for transportation planning, it is important that these estimates have as great a degree of reliability and validity as possible. Additional data collection or improvements in statistical precision do not necessarily result in increased forecasting capability. The real objective should be the design and utilization of techniques that both recognize data limitations and are structured in a sound and logical manner. This type of care, rather than statistical complexity, will yield usable forecasting procedures.

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Discussion

R. D. WORRALL, Northwestern University—Fleet and Robertson are to be complimented on an interesting and useful paper. Their comments on the statistical hazards associated with the conventional trip-generation study are very well taken; they should be examined carefully by anyone likely to engage in such analysis.

My remarks here are directed to four points raised by the authors, two relating to statistical analysis and two to the more general theme of trip generation and its place within the total transportation planning process.

First, however, a minor quibble. The authors suggest that the study of trip generation and the analysis of travel demand may, in the sense that both deal with the frequency of trip-making, be considered as one and the same thing. The two however are very definitely not the same. They are very different, with different objectives, different output, and substantially different analytic rationale. In the one case the analyst is concerned simply with developing an efficient estimate of zonal trip-ends for subsequent distribution and assignment. In the other he is concerned with the much more complex question of the relationship between travel demand, travel "price," and the urban resident's basic demand for goods and services. There are obvious similarities between the two—one may argue that the first is an inelastic subset of the second—but they are certainly not the same thing and it is somewhat misleading to suggest, even in passing, that they are equivalent. I will return to this point later.

I like the authors' discussion of the problems of spatial aggregation, particularly the sections dealing with variance partitioning and the use of disaggregate models. The former illustrates clearly the seductive nature of aggregation bias, while the latter provides the analyst with a convenient mechanism, not only for circumventing problems of spatial aggregation, but also for extending the scope of a conventional linear regression model to include categorical and nonlinear relationships. Recent empirical work at Northwestern University supports the authors' comment that the disaggregate household model used in their example yields zonal trip-end estimates as accurate as those obtained from a standard aggregate model, with the added advantage of a sharper, more coherent model structure. Obviously the method is equally applicable to the study of nonresidential trip generation, or to any situation in which the analyst wishes to avoid aggregation of a heterogeneous data set. It should be noted, however, that its use does involve a number of statistical problems which the authors do not discuss—most notably those involving the limitations on the use of dummy variables. Several excellent discussions of the topic are available (2, 29).

Disaggregation for its own sake is of little value—it merely increases the variance of the basic data set. Its virtue lies mainly in the flexibility which it affords the analyst to develop alternate aggregative structures, each appropriate to a specific phase of his analysis and each yielding a sharper, more meaningful model format. The criterion for the aggregation in each case is, of course, the clustering of trip-making units which are homogeneous with respect to their trip-making characteristics. In the case of trip generation analysis it has the particular virtue of releasing him from an initial, arbitrary aggregative structure, frequently based upon a fortuitous spatial proximity rather than any logical relationship.

I am somewhat less happy with the authors' discussion of sampling errors. I am also a little unhappy with some of their empirical examples. In Table 1, for example, the variables "family size" and "total persons" are not disaggregate and aggregate equivalents, and the difference between the two values of r is indicative not of a reduction in the "significance of a vital estimating relationship," but simply of a reduction in variance due to the process of aggregation. Similarly, in Table 4, the differential composition of the two equations (the zonal equation contains an extra variable) suggests that specification bias may have influenced the result. The points are minor, but they suggest that a different selection of examples may perhaps make the authors' points more clearly.

Certainly one should avoid "overtuning" a regression equation (presumably the authors are thinking here of overindulgence in variable transformations or interactance terms). Certainly, also, one should strive for the simplest possible model structure. Their suggested cut-off criterion based on the comparison of percent standard errors, however, is somewhat arbitrary. Their point concerning the danger of overtuning could be made much more clearly, and with greater validity, in terms of the partitioning of variance discussed earlier in the paper. The whole question of sampling error and sampling design in travel surveys is extremely complex. It deserves more attention than it has received in the past, particularly from the cost-conscious.

Relatively little research has been directed toward the important question of the temporal stability of travel forecasts. Again there are compelling arguments in favor of disaggregate rather than aggregate modeling. Predictions of future trip-rates based purely on zonal aggregates, for example, will inevitably be in error if a significant change occurs in the composition of the zone over time. Equally, a prediction of household trip-making based upon estimates of residential density and car ownership is likely to yield erroneous forecasts if the relative importance of these parameters, i.e., the values of the β coefficients in the regression equations, changes over time. Such a change is not only possible but almost inevitable. For example, as car ownership levels tend towards a general saturation point it may be expected that differences in car ownership rates are likely to account for less and less of the variance in zonal trip production. Other factors—personal travel preferences, transportation systems improvements, substitution effects, etc.—will and do exert a more significant influence on the trip-making process, consequently the old proxy relationships will no longer hold.

All this is to argue in effect not only for a continuing monitoring of trip generation data, but rather for a continuous, microscopic analysis of travel behavior, set at the level of the individual decision unit (e.g., the household or the firm) and aimed at isolating the fundamental relationships between the decision unit's daily activity pattern on the one hand (i.e., the set of activities in which the members of unit regularly engage and which generate a demand for travel) and the characteristics of its travel demand on the other. Equally, it is to argue for a basic change in the analyst's orientation, away from the description of aggregate travel patterns and toward the specification of disaggregate travel demand relationships, sensitive to system and activity variables. Several interesting starts have been made in this direction (1, 34, 35).

Unfortunately, all this is likely to be rather expensive. The cost of a possible longitudinal monitoring scheme for Chicago, for example, based upon the surveillance of a panel of 2000 households has been estimated at approximately $200,000 per year. Alternate sample designs, based on a combination of randomized cross-sectional samples and partial overlap designs reduce the cost somewhat but not significantly (1).

The question of cost brings me to my final point. Any statement concerning the efficacy of current expenditures for the collection and analysis of travel data should, logically, be set in the context of the objectives of the total transportation planning process. More specifically, it should take account of the importance of these expenditures to the achievement of these objectives. To make such a statement we require at least five pieces of information: a statement of the desired accuracy of the final travel forecast, a statement of the cost (or penalty) of failing to meet this accuracy (e.g., a misinvestment of construction funds), a statement of the sensitivity of the forecast to errors in specific phases of the planning process (e.g., errors incurred in the process of generation, distribution or assignment, etc.), a statement of the sampling distribution for each phase, and a statement of the cost of achieving a particular degree of accuracy in each phase. This, in effect, is to ask for a combined sensitivity/cost-effectiveness analysis of the transportation planning process, in both its initial and continuing phase—a pretty tall order, but probably the most critical single requirement in current urban transportation planning. A start has been made on such a project by CONSAD Research Corporation under a contract sponsored by the Federal Department of Transportation.

Finally let me once again compliment the authors on an interesting and extremely useful paper. Coupled with the recent "Guidelines for Trip Generation Analysis" published by the Federal Department of Transportation, their discussion should be of considerable assistance to any agency involved in the analysis of trip generation data.

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HAROLD D. DEUTSCHMAN, Tri-State Transportation Commission—Multiple linear regression equations, utilizing an arbitrary zonal scheme for observational units of independent and dependent variables, have become a common method for trip generation analyses. The authors are to be commended for indicating some of the frequently overlooked pitfalls inherent in the trip generation process. The primary message of the paper concerns the statistics of regression and cautions the analyst on the statistical paradoxes in measuring the accuracy of a regression equation when zonal data are used. It is emphasized that the conventional coefficient of correlation only explains the variation between the zonal units and not between the original data set. If the zones are in fact not chosen specifically as homogeneous units, then the actual variation in the trip-making characteristics may be as little as 20 percent as explained by the aggregated zones, even when the variance in the regression analyses indicates a figure of 95 percent. The authors point out that "aggregation will tend to cloud much of the variation and also many of the relationships that may explain this variation." They address themselves to the problem of how fine the regression equations should be tuned to—what are the best results that may be obtained, considering the relative homogeneity of the zones? By analyzing the standard error of the mean for each zone, an excellent measure of reliability may be inferred from the data set being utilized by regression. The illustration that the percent standard error of the estimating (regression) equation may not be smaller than the average standard error of the mean of the dependent variable (by zone) provides a significant measure of the limits of efficiency for the regression equation. There is much merit in this portion of the paper, in relating the accuracy inherent in the trip generation equations with that of the data set.

The authors then turn to alternate approaches of trip generation, including dwelling unit analysis and cross-classifications. These approaches are broached, but an in-depth analysis of the applicability and effectiveness of the processes is not undertaken. It is indicated that a dwelling unit analysis could use the dwelling unit as the basic observational unit instead of zones, thus eliminating the aggregation effect. In lieu of average zonal figures such as median income and average auto ownership, dummy variables may be employed to describe the socioeconomic and density characteristics. While data aggregation is avoided, basic limitations arise such as (a) there is a significant increase in the number of independent variables, using the distribution of variables instead of means; (b) some variables are only amenable to a zonal description, such as gross residential density, and could not be effectively utilized in a dwelling unit analysis; (c) the variables used in the basic regression equation must be projected to a future year. Since the number of variables is greater, this task is more formidable. In addition, since the number of zones effectively equals the number of households, a complex methodology must evolve to estimate a number of characteristics for each household for the forecast year.

Much research is needed in the trip generation phase of travel analyses. I take a pragmatic view of the analytical techniques that may be used. The one to be chosen should be most efficient from the standpoint of not only reproducing the survey data, but must also include the efficiency of (a) estimating the independent variables and (b) relative stability of the estimating equation over time (forecasting capability).

It was pointed out that the regression technique of trip generation using aggregated data has basic limitations; it must also be noted that the alternate methods posed have their limitations as well. Since the number of variables, equations, and techniques used in trip generation analyses are many in number, it is strongly suggested that once an enriched data set becomes available over two periods in time (detailing the full spectrum of socioeconomic data with the travel data), all of the suggested methods of trip generation be analyzed on a common basis. It is only through this analysis that the various procedures may be systematically evaluated.

CHRISTOPHER R. FLEET and SYDNEY R. ROBERTSON, Closure—In preparing this paper, the authors chose to narrow the perspective somewhat by dealing primarily with the existing state of the art. The discussants have ably contributed the appropriate and, perhaps, essential extension of the authors' comments into a broader context.

Worrall's concern over our equation of travel demand and trip-making frequency is understandable. Though it would perhaps be easier to pass over this point as an argument in semantics, we are sympathetic. Too few of the ideas concerning the demand of persons for transportation services have penetrated the methodology of transportation planning. Particularly lacking is the interaction between travel demand and the transportation system variables. At this point in time, only the most subtle interaction between trip generation and the transportation system is present.

Worrall suggests that the argument for disaggregate analysis must be carried further, to allow a "microscopic analysis of travel behavior," relating daily activity to travel demand. Though this is certainly theoretically attractive, we do not think that the required tools are yet available. Also, as he notes, the costs are prohibitive. And, even if it were to be possible to develop this type of analysis, is the transportation planning process capable of using the resulting information effectively?

This brings us to Worrall's final point, with which the authors completely agree. It is difficult to seek the efficient use of the travel survey data when we have no real notion of how effectively the data are used in the transportation planning process. At present, we have little or no knowledge concerning the balance of the technical phases in terms of accuracy. And, even if we could identify where the imbalances occur, no rational basis exists for allocating resources to remove them.

Regarding our discussion of sampling errors, it appears that Worrall was expecting more than the authors intended. Certainly a comprehensive sampling error analysis was not done. The intent was to illustrate the kinds of variation associated with the zonal regression input data due to sampling. Our interest was in the regression dependent variable—trip-making. It seemed reasonable to conclude that the degree of precision in estimating the dependent variables using regression should be no greater than the precision associated with that dependent variable due to sampling. Carefully fitting an optimum equation to data where the numerical values are known to vary over a wide range does not seem appropriate. It was this that was considered to be "overtuning."

Deutschman suggests that disaggregate trip generation analysis is a two-way street and that there are basic limitations, some of which he enumerates. Perhaps we did not devote sufficient time to this. However, the paper was intended to be suggestive in this area, rather than definitive. Of the limitations noted, those concerning forecasting bother us most. Though we disagree that "the number of zones effectively equals the number of households," the identification of stable (particularly over time) household types is difficult. The estimation of the future number of households of each type also presents a significant problem. As noted in the paper, however, many of the disaggregate household location models can supply this information.

The authors completely agree that the next step must be the evaluation, with time series data, of the notion that disaggregate trip generation models are more likely to remain stable over forecast intervals. We also can find no argument with Deutschman's pragmatic criteria for an efficient trip generation procedure.

The Journey to Work: A Singular Basis for Travel Pattern Surveys

G. A. SHUNK, W. L. GRECCO, and V. L. ANDERSON, Purdue University

This study investigated the feasibility of using the patterns of travel for the work purpose and the peak hour to define the same highway system as would be determined using trips of all purposes and total day travel. The objective was to justify an approach to travel pattern surveys wherein the traditional home-interview survey would be replaced by a survey, conducted at major generators.

The study used data from a conventional home-interview study. Trips for work and shop purposes were selected from the all-purpose, total-day file, as were trips for an afternoon peak hour. Sixteen different time-mode-purpose combinations, including the all purpose base condition, were assigned to the major street network. A link-by-link comparison of the loadings, under specific conditions, was made using the multiple regression technique.

Results indicated that the peak hour and work trips yielded excellent prediction of the links used by total day and all-purpose travel. The precision was good, both from the standpoint of variation explained (R^2) and standard error of the estimates. The precision was retained for several purpose-mode combinations representing more feasible survey procedures. The results indicated that a test of the revised survey procedures would be worthwhile.

•THE SIGNIFICANCE of travel to and from the place of employment is readily accepted by practitioners of urban transportation planning. In most urban areas, such travel represents the single most frequent and regular utilization of the transportation system. For various reasons, most jobs start and end at the same time, placing a high volume demand on the transportation system over a short time period. Further, by the very nature of specialized labor and inadequate communications, workers must concentrate in space, as well as time. The high volume demand, already concentrated in a small time period, then concentrates in space at each employment center, many of which are closely grouped. These situations should be an important focus of urban transportation planning activity.

This research was conducted to determine the feasibility of using only work trips, and alternatively, only peak-hour work trips to reproduce the demand on a highway system exhibited by trips for all purposes and occurring during the entire day. The hypothesis thus proposed implies that the system capacity demanded by work travel during the peak periods is available for and is, indeed, used by trips for nonwork purposes, which occur during nonpeak periods. Therefore, a highway system which serves work travel will properly serve other travel as well. This situation, of course, is not absolutely true, but the proposal contends its applicability on the major street and highway system that is generally included in an urban transportation study.

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The importance of the work and peak-hour portions of total urban travel is underscored by the extent to which they have been subjected to previous analyses. Their regularity and stability are characteristics important in consideration of predictive parameters. It would seem that they might well serve as sufficient singular bases for prediction of a highway system to serve all urban travel. Indeed, this relationship has previously been accepted by some and has even been employed occasionally. But the literature is devoid of what the authors consider adequate quantitative substantiation of the relationship.

The application of the thesis proposed here concerns elimination of the traditional home-interview O-D survey in favor of a travel pattern survey at the destination (employment) place. In this regard, it is important to emphasize that the approach taken in this research did not utilize such a technique. Rather, its purpose was to establish a firm basis for future development of an employment place survey procedure by demonstrating that work travel is indeed an adequate representation of total urban travel on the major highway system. The extension of feasibility to the peak hour would provide a direct hourly volume for design purposes.

The approach used developed travel patterns for all purposes and the total day as a basis against which to test patterns developed using work and peak hour travel. The travel patterns were examined over the system of major streets and highways. Zone-to-zone travel patterns were not used as the basis for testing, since they are strictly dominated by the functions of respective zones. Since the desired results of the prediction procedure concern the major street system, loads on the links of the network representing this system were the basis for comparison. Travel of the respective purpose groups was assigned to the network, and a test of the representivity was made on a link-by-link basis. In this manner, the same centroid influence was virtually eliminated in favor of testing the conditions on the major street network.

DATA PREPARATION

The data were obtained from the Indianapolis Regional Transportation and Development Study (IRTADS). The specific information selected from the IRTADS data file was the travel data from the home-interview survey, as coded and punched on No. 2 cards.

No use was made of either the truck-taxi or the external survey data since the principal objective was to replace the home-interview study. The inventory of the 1964 street network as punched in standard (BELMN) format was also obtained. Transit network information was not used because the proposed work was highway oriented. Transit trips were included in one phase of the analysis where no network information was required.

The complete file of home-interview travel data was preprocessed to put it in a suitable form for subsequent manipulation. Dwelling unit (No. 1) cards were not used at all. All trips with an origin or destination outside the study area were eliminated. Without a home-interview survey, such trips could still be tabulated at external cordon interview stations in the same manner as presently used. The remaining trip cards were grouped according to home orientation. Home-based trips were placed in one file and sorted on zone of residence. Non-home-based trips were placed in a second file and sorted on zone of origin. These files were input for the travel data processing programs for the total day condition.

In order to select a representative peak period, the combined home- and non-home-based files with externals deleted were processed by a computer program which scanned the trip survey cards for trip purpose, mode, and times of start and arrival, and computed the number of trips entering and leaving the transportation system, by mode and purpose and in tenth-of-an-hour increments throughout the day. The program then aggregated the incremental periods into successive one-hour blocks and produced the number of trips in progress, by mode and purpose, for contiguous one-hour periods, successively by tenth-of-an-hour increments through the day. The peak hour selected was that defined for all auto driver trips as the condition considered to place the most stress on the highway system. A single hour was selected because the objective in the peak hour phase of this study was to obtain a single hour volume on which to base design recommendations. The peak hour selected was from 16.4 to 17.4 hours (4:24 to 5:24 p.m.).

Processing of the travel and network data involved extensive use and total reliance on the BELMN package disseminated by the Bureau of Public Roads for use in operational transportation planning studies (4, 5). Three specific purpose groups were obtained in addition to the all-purpose group: home-based work, home-based shop, and non-home-based work. A non-home-based work trip was one having a work purpose at either end of the trip. The three purpose categories also included serve-passenger trips with passenger purpose the same as the group in which it was included, because IRTADS interviewers "linked" trips at the time of interview. The modes selected for analysis (Phase II) were auto driver and highway person, reflecting the decision to maintain a highway orientation. The former represented vehicle trips and was indicative of traffic volume. Highway person trips included auto driver trips as well as passengers in automobiles, trucks, and taxis. No transit or school bus trips were included in Phase II because of the lack of knowledge of a network for either group. Two periods, total day and the single afternoon peak hour, defined the time conditions.

Program PR-6 processed the street network inventory cards. Program PR-1 built "trees," the link-by-link description of the path taken in moving from one zone to another. The minimum travel-time path was used. Program PR-130 further processed the binary tree information by summing the time to traverse the links in each tree, producing skim trees.

The major utilization of the BELMN programs was concerned with processing the travel data. Input to program PR-133 was in two phases, home-based and non-home-based trip cards; the results were combined at a later stage. PR-133 accumulated the trips from each origin to each destination zone according to groups, based on the trip purposes and travel modes specified. Output from PR-133 was trip tables. The normal PR-133 expansion of trip data was not used, in order to retain the capability of check-summing at subsequent steps in the processing. Because of the nature of PR-133, all final trip tables are complementary, i.e., do not overlap. Program PR-152 was used to merge certain tables in an additive manner to obtain the purpose combinations specified for analysis.

Since trips on links of the network had been selected as the decision variable, the trip tables had to be assigned to the street system. The traffic assignment program uses a factoring procedure to conserve space in core storage and on tape. It divides the actual trip volume by 4 in order to store the number in a field width of two less positions (binary digits). Such a procedure is not critical for high volumes, but proves extremely damaging in cases where there are many low volumes. Since the trip data had not been expanded as would normally have been the case, the discrepancies were serious. As a means of overcoming the problem, it was proposed to multiply the volumes by 20 prior to assignment. This permitted retention of the exact count of the sample and eliminated the loss of critical volumes. It also yielded figures of a magnitude similar to observed traffic volumes. Program PR-151 was used to expand the recombined results from PR-152 by a factor of 20. The trip processing and assignment procedure was executed separately for the total day and the peak hour situations.

The traffic assignment process, using program PR-2, assigned to each link of the minimum time path tree the zone-to-zone movements given in the trip table. No attempt was made to apply capacity restraint to the loaded networks, since the differences in absolute volumes would have yielded inconsistent results. The objective was to match the control loading condition, and then restraint procedures would be applied to the synthesized loadings. There were 16 separate network loadings, made up by the 12 specified purpose situations and 4 totals.

Since the principal interest of the hypothesis was in the major street system, it was necessary to select the links in this group. In order to provide an objective basis for the selection, the functional street classifications developed by IRTADS were used to group the links. The IRTADS system was composed of five groups: local, collector, arterial, expressway, and freeway. Because of the small number in their groups, expressway and freeway links were combined under the latter title. The resulting collector, arterial, and freeway groups were considered the major street system. All local links, centroid and external node connectors, were removed because of domination of travel on them by the zone represented by the centroid. Links connecting between different groups were considered collectors.

Examination of the volume distributions in the respective groups indicated certain conditions for which modifications were appropriate. The link volumes for the auto driver, total day, all-purpose condition were chosen as the criteria since they were the best available representation of actual traffic volumes. Based on the estimated standard error of the group, all links with volumes less than 140 were deleted. This was because the true volumes on these links in the average situation might be reasonably considered not different from zero. Links that were the only connection between the system and local links were deleted for the same reason as the local links. Links previously classified as arterial or freeway but having volumes less than 1000 were merged with collectors. Collectors with volumes greater than 5000 but less than 12,000 were merged with arterials, those with volumes over 12,000 were merged with freeways.

The rationale for these modifications was based on the fact that no capacity restraint was used in the assignment process. As a result, trips were assigned to the absolute minimum time path without consideration for the capacity of the links used. Such a situation would explain the failure of links to carry volumes commensurate with their functional classification. In order to correct the situation, links having arterial level volumes were defined as arterials, etc. This was the reasoning behind volume considerations when reorganizing the groups. The volume criteria for each group were established by a generalized capacity analysis of the respective street classes.

The system used in the final analyses was composed of the following: (a) freeways—218 links, (b) arterials—529 links, and (c) collectors—1793 links.

ANALYSIS PHASE I—DEFINING THE BASIC EFFECTS

The procedures employed to test the proposed hypotheses fell into two distinct phases—the first directed toward establishing a basis for consideration of the second, which was directly concerned with testing the principal hypotheses regarding work and peak hour travel.

Phase one undertook examination of the hypothesis that the several factors of trip purpose, mode of travel, and time of trip do significantly influence the character of person-movement in an urban area. The objective was to obtain a quantitative definition, in probabilistic terms, of that interrelationship, which most practitioners have come to accept in a qualitative sense. The variables chosen for examination were travel volume and length of trip.

Travel volume was defined as the number of trips made, where each survey card represents a trip. Trip length was the time required to complete a given trip on the minimum time path from the zone of origin to the destination zone. The purpose of a trip was that indicated on the survey card at the point of destination. Purpose was considered in six groups: work, shopping, social-recreational/eat meal, personal business/medical-dental, school, and other. Mode of travel was defined in three groups: auto driver, nontransit passenger, and transit passenger. The definition of transit includes school buses as well as other buses; there is no other form of transit in Indianapolis. The nontransit passenger group includes passengers in private automobiles, taxis, and trucks. Time was defined in 24 one-hour groups. The mean of the start and arrive times reported for the trip-maker was used to place the trip in its time group.

The length (in time) of travel from each zone to every other zone was computed from the minimum time path tree by PR-130, part of the BELMN package. The appropriate skimmed tree time was appended to the individual record of each trip by a computer program and was made an additional permanent part of each trip record.

The nature of the hypothesis to be tested was appropriate for investigation by the analysis of variance technique (ANOVA). For the present investigation, it was decided to select four random subsamples from the basic trip file. These four complete subsamples provided the replications which are necessary to estimate experimental error. In order to simplify the sample selection procedure, the observation selected for testing was the mean trip length value over all trips in each cell.

The equation representing the analyses, commonly called analysis of variance model, was

$$X_{ijkl} = \mu + P_i + M_j + T_k + PM_{ij} + PT_{ik} + MT_{jk} + PMT_{ijk} + \epsilon_{(ijk)l}$$

where

X_{ijkl} represents trip volume or trip length, depending on the analysis, for the i th purpose, by the j th mode, in time period k, for the l th subsample;

μ = respective overall mean;

P_i = effect of the i th purpose, i = 1, ..., 6;

M_j = effect of the j th mode, j = 1, ..., 3;

T_k = effect of the k th time period (hour), k = 1, ..., 24;

PM_{ij} = effect of the purpose-mode interaction;

MT_{jk} = effect of the mode-time interaction;

PT_{ik} = effect of the purpose-time interaction;

PMT_{ijk} = effect of the purpose-mode-time interaction;

$\epsilon_{(ijk)l}$ = experimental error;

l = index for the subsample, l = 1, ..., 4.

All effects are fixed, i.e., they are not random samples from an infinite population of such values but the subsamples are considered random samples from infinite populations in the 432 purpose-mode-time combinations. The inference can, therefore, only be considered applicable for those levels of the respective factors included in this analysis over all the populations from which the subsamples were drawn. The analysis described is known as a complete three-factor factorial analysis with four observations per factor-level combination. The assumptions required for use of the ANOVA were considered sufficiently satisfied. The complete factorial analysis of variance computations were executed by program BMD-2V (21).

All main effects and interactions were significant (α = 0.01). The high significance of the main effects had been expected. It implied that the volume and length of trips differed significantly with the purpose of trip, the mode of travel, and the time of observation. The significance of the interactions was not anticipated. It implied, for example, that the relationships between volume or trip length and the single factors (e.g., purpose) were inconsistent if any other factor was not held constant. The results of this analysis emphasized that the factors examined in regard to travel pattern development were worthy of further consideration. They also indicated that further analyses would have to account for the interactions.

ANALYSIS PHASE II—DEFINING SPECIFIC EFFECTS

Phase two of the analysis involved testing the principal hypotheses, concerned with the use of work and peak hour trips to represent the important total daily travel. The objective of the analysis was to determine whether trips of a single purpose or a particular time period could be expected to define the transportation system used by all travel. Travel volume on individual links of the highway network was the decision variable selected. Reflection on the objective of the research pointed up the necessity of retaining the all-purpose loading as the control condition, against which the hypothesized revisions would be tested. The nature of the situation, with the variable to be predicted containing the variable used to predict, indicated that a regression approach would be appropriate.

The extent of the regression analysis required was investigated by a modification and extension of the analysis of variance performed in phase one. The objectives of this second ANOVA were to determine which factors should be included in the regression models and what different models were necessary. This analysis was tested for the effect of change in purpose, mode, and time on individual link volumes.

Definitions of the factors and variable for this analysis were modified from those applied in the first investigation. In this analysis, purpose was considered at three levels: home-based work, non-home-based work, and non-work. This reflected a split of the previous P_1 (work) and combination of P_2 to P_5. Mode was included at only two levels, transit trips having been deleted. The time levels were redefined as peak hour, one particular hour, against non-peak hour, the remaining 23 hours combined. The observed variable was relative assigned traffic volume. This variable was obtained by assigning trips (variable in the first analysis) to the links of the highway network and dividing each resulting link volume by the link-trip total over all links for its particular factor level combination. This manipulation eliminated between-cell differences attributable only to differences in absolute total volumes of trips observed for respective purposes. The effect of the absolute totals had been examined in the first analysis; the second analysis was to examine the degree to which selected observed effects extended to the highway system. The resulting variable, termed link-relative-importance (LRI), was indicative of the status the particular link assumed regarding movement of traffic in the area.

Of particular interest in this ANOVA was whether the significance of interactions carried through from the first analysis. An interaction implies that the results of varying one factor under the constant level of another factor might not match the results of identical variations of the first factor under different conditions of the second factor. Thus, a significantly different relationship might be found between volume and purpose for auto-driver trips than for passenger trips. Interaction significance would imply a need for different regression models at each level combination of the interacting factors. This analysis would yield a rational basis for the form of the regression equations and contribute to the understanding of underlying relationships.

The ANOVA procedure bases its tests of significance on properties of the normal distribution and requires that the experimental error within the classification groups or cells be normally and independently distributed. Tests of this condition utilizing the Kolmogorov-Smirnov (K-S) test for goodness of fit (15), indicated that the raw LRI values were not normally distributed. It was found, however, that after a square root transformation of the raw data was carried out, the K-S test showed significant (0.05 level) departures from normality in only a very few cases for the arterial and freeway classes. The collector class was discarded from further consideration in the ANOVA examination because the observed departures from normality could not be considered insignificant.

Another ANOVA assumption tested concerned homogeneity of variance between cells. The common test for this condition is that attributed to Bartlett (1). The square root transformed data were used for this test. It was apparent that cell variances of the design were quite nonhomogeneous. Box (3) considered the variance problem and indicated that the robust nature of the ANOVA on means was capable of withstanding quite a degree of heteroscedasticity.

In spite of the lack of variance homogeneity and the minor variations from normality, it was decided to continue with the ANOVA as proposed. The analysis was run separately for the two street classes with no attempt made to examine between-class effects. This decision was based principally on the variation in the number of observations between the classes. The ANOVA models took a similar form of the equation previously given except that the dependent variable is the square root of the link-relative-importance. The main effects and the interactions are similar to those defined for the first ANOVA. Computations for this analysis were also performed by program BMD-2V.

The significance level chosen for testing the F ratios was 0.25, based on the fact that probability of type II or β error (accepting a false hypothesis) was of importance. Increasing the α or probability of type I error (rejecting a true hypothesis) to the level of 0.25 reduces the probability of β error. The low β error was considered necessary because the objective of the test was to determine which effects were not significant and could thereby be eliminated from consideration in model development. The hypothesis proposed for this test was that the purpose, mode, and time factors described here have no significant effect on relative link volume. The ANOVAs for these tests are given in Table 1. All significance tests were made using an F ratio with only the error mean square, since the model was composed completely of fixed effects.

The tests on the freeway links indicated significant results due to the main effects of time, purpose, and mode. No effect on LRI was noted due to interaction. It can be concluded that LRI does vary between the peak and nonpeak periods, due to change in consideration of the work or the nonwork purpose, and due to travel mode. The implications are that, for freeways, separate regression models describing peak and nonpeak traffic would yield better results than a single model. Further, there is sufficient effect due to the work purpose and mode that models describing travel must include recognition of the work purpose and means of travel. The extension of these results is valid and consistent only over the factors and levels considered here.

The tests in the ANOVA for arterials indicated the same effects observed for freeways as well as a significant mode-purpose interaction. This additional effect may reflect the change in orientation of traffic from movement to land service as street class decreases. The variability in the influence on volume exerted by work purposes cannot be considered the same for all modes, and conversely, as was the case for freeways. This implies a need for more models to account for interaction.

REGRESSION ANALYSES

The models for the regression analysis were developed in accordance with the results of the ANOVAs and included factors representing purpose, mode, and time. The definitions of the variables and factors for regression were further modified from those used previously. The dependent regression variable (Y), in accordance with the control condition, was the number of trips for all purposes that were assigned to the individual links of the highway network. This represented a combination of the three purpose levels tested in the second ANOVA. The independent regression variables (X's) were similarly assigned volumes, but represented trips for a specific purpose: home-based work, non-home-based work, and home-based shop. The first two were identical to classifications in the second ANOVA; the third was an additional factor in-

TABLE 1

ANALYSIS OF VARIANCE FOR FREEWAY AND ARTERIAL LRI

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
(a) Freeway LRI				
Time	1	28.37	28.37	3.31*
Mode	1	17.67	17.67	2.06*
Purpose	2	511.07	225.54	26.7*
Time-mode	1	2.31	2.31	0.27
Time-purpose	2	3.23	1.61	0.19
Mode-purpose	2	0.41	0.20	0.23
Time-mode-purpose	2	15.90	7.95	0.93
Error	2,604	22,318.74	8.57	—
Total	2,615	22,897.68		
(b) Arterial LRI				
Time	1	39.28	39.28	4.95*
Mode	1	253.22	253.22	31.8*
Purpose	2	1,783.42	891.71	112.2*
Time-mode	1	3.84	3.84	0.48
Time-purpose	2	8.01	4.00	0.50
Mode-purpose	2	67.98	33.99	4.38*
Time-mode-purpose	2	18.23	9.11	1.15
Error	6,336	50,380.69	7.95	—
Total	6,347	52,554.68		

*Significant at α = 0.25.

cluded because of the general interest and availability of the data. The shop level was not included separately in the purpose factor of the second ANOVA because the objective at that point was to define the effect of work relative to all other purposes combined. Levels of the mode factor were auto driver, identical to M_1 in both previous analyses, and highway person, a combination of the M_1 and M_2 levels of the second ANOVA. Time was treated in a similar manner: peak hour corresponded to P_1 and total day was the combined P_1 and P_2 levels. The definition of the regression factors closely approached the definitions of the original principal hypotheses. The only variation occurred in the second level of purpose; P_2 was defined as non-home-based rather than all work because of the build-up approach. Adding non-home-based work to an equation including home-based work implied the desired effect of total work. The factor definitions for the second ANOVA and the regression analysis are listed below together with the nomenclature for the principal hypotheses.

	HYPOTHESES	ANOVA	REGRESSION
Purpose:	HBW	HBW	HBW
	ALL WORK	NHBW	NHBW
	ALL PURPOSES	NW	ALL PURPOSES
Mode:	DRIVER	DRIVER	DRIVER
	PERSON	PASSENGER	PERSON
Time:	PEAK HOUR	PEAK HOUR	PEAK HOUR
	TOTAL DAY	NON-PEAK HOUR	TOTAL DAY

(H—home, B—based, W—work, N—non)

The factor level combinations for the regression variables are listed below.

Independent Variables

1. HBW, auto driver, total day;
2. NHBW, auto driver, total day;
3. HBW, highway person, total day;
4. NHBW, highway person, total day;
5. HBW, auto driver, peak hour;
6. NHBW, auto driver, peak hour;
7. HBW, highway person, peak hour;
8. NHBW, highway person, peak hour;
9. HB shop, auto driver, total day;
10. HB shop, highway person, total day;
11. HB shop, auto driver, peak hour;
12. HB shop, highway person, peak hour.

Dependent Variables

1. All-purpose trips, auto driver, total day;
2. All-purpose trips, highway person, total day;
3. All-purpose trips, auto driver, peak hour;
4. All-purpose trips, highway person, peak hour.

The technique used was to build up a multiple linear (in the coefficients) regression equation in steps, adding one independent variable at each step. This technique follows the logic of the proposals for modifications in survey procedures, i.e., one variable represents one type of survey, an additional one represents a more extensive survey, etc. Thus, it is shown just how much precision (increase in determination) is gained by augmenting basic survey data. The computations for the analysis were performed by computer program BMD-2R (22).

The initial run of the program permitted free selection of that independent variable which caused the greatest increase in the total dependent variation explained. This run eventually included all independent variables. Subsequently, a program option was exercised which selected independent variables in the logical order of the proposed build-up survey procedure.

Nine sets of equations were developed. Four of these had dependent and independent variables of the same mode-time combination. The mode-time combination varied between sets. The remaining five sets were developed with dependent variables common for planning and design purposes, but with independent variables of a type more easily surveyed. The latter five sets did not have similar mode-time combinations for dependent and independent variables. Within each set the dependent variable did not change. The nine equations in each set represented different combinations of the basic street classes. The first three of these treated freeways, arterials, and collectors, respectively. Two more were developed by combining freeways and arterials for one (FA) and freeways, arterials, and collectors for the other (FAC). The remainder included all freeway and arterial links as well as subsets of the collector group based on volume: collectors with day vehicular volume not less than 4000 (T4), 3000 (T3), 2000 (T2), and 1000 (T1).

The regression equations represent the relations within the condition groups or cells of the ANOVA. The feasibility of the development approach employed was checked by comparing the order of entry of variables in the free situation to that observed when the entry order was specified. It should be emphasized that the following analysis was not oriented to developing predictive relationships, but rather to determining the degree to which variation in the all-purpose group was explained by variations in specific purpose groups. It is not implied that the equations shown are applicable elsewhere, but rather that variation explained (R^2) may be universal and that the respective expansion ratios (slopes) are typical.

The first regression analysis developed simple, linear relationships between peak hour and total day volumes. The equations given in Table 2 predict total day volume based on peak hour volume. Only the all-purpose condition is presented because the objective was to demonstrate the representivity of all traffic by the peak hour. Results are shown for both modes and for three separate street classes: freeways (F), arterials (A), and collectors (C). The prediction of total traffic based on peak hour traffic is quite reliable for all street classes. The prediction is better on higher-type facilities because they are the ones most utilized in the peak hour. These positive results give credence to a basic hypothesis of this research and form a basis for further study of peak hour travel by purpose.

The multiple linear regression analyses examined the three separate street classes and several combinations (FA, FAC) of these. The examination of several street groups was undertaken in order to determine the changes in predictivity for various single classes and combinations within the total street system. Within each street group several mode-time combinations for the variables were used. In four of these cases, the mode-time condition was the same for the dependent and independent variables. In the

TABLE 2

SIMPLE REGRESSION ANALYSIS

Total Day Volume Prediction	Explained Variation	Error Degrees of Freedom
	Auto Driver	
(F) $Y = 824 + 5.446X$	$R^2 = 0.969$	216
(A) $Y = 899 + 5.150X$	$R^2 = 0.905$	527
(C) $Y = 314 + 5.307X$	$R^2 = 0.875$	1791
	Highway Person	
(F) $Y = 1549 + 5.304X$	$R^2 = 0.961$	216
(A) $Y = 1410 + 5.090X$	$R^2 = 0.895$	527
(C) $Y = 493 + 5.383X$	$R^2 = 0.857$	1791

Y = total day trips; X = total peak hour trips.

remaining cases, the mode-time condition of the independent variable represented a more practicable survey procedure than did the mode-time combination of the predicted variable. All dependent variables represented mode-time combinations useful in planning and design.

The four homogeneous sets were concerned with predicting the total day (D) and peak hour (H) trips by highway-oriented persons (P) and vehicles (V). Selection of the proper relationship would be based on the mode and time prediction desired; that same mode-time combination would be surveyed. Three of the other five relationships predicted peak hour vehicle (HV) trips using total day person (DP), total day vehicle (DV), and peak hour person trips (HP). The results of these would be design hour traffic volumes, based on surveys of all employees, all those driving to work, and all those traveling in the peak hour respectively. The remaining two relationships used total day person trips (DP) to predict total day vehicle (DV) and peak hour person trips (HP). These represented a survey of all employees to predict daily vehicle traffic or a person trip design hour.

Tables 3 through 6 show results of the regressions for the free-entry situation. In this situation the variables (X) enter solution one at a time, in the order of the additional explained variation (R^2) that their inclusion will yield. The variable entering also causes the greatest reduction in the error sum of squares of all variables not in solution. The tables show the order of entry of the four most significant independent variables for each street class or combination for prediction of the four different mode-time conditions of all-purpose trips. Also given are the cumulative R^2, standard error of the estimate, and coefficient of variation at each step.

The R^2 values describe the proportion of variability in the predicted trips explained by the factors included in the equation at that step. Here the standard error of estimate provides the upper confidence limit on each prediction. It is indicative of the possible error that the prediction procedure may be expected to exhibit. Adding one standard error to a predicted volume assures 0.84 probability that the true volume is not greater than the result; two standard errors implies 0.97 probability of enclosing the true value. The standard error indicates the possible error in capacity due to use of a design hour volume obtained from the procedure described here. The coefficient

TABLE 3

SIGNIFICANCE ORDER AND RELATED PARAMETERS, MULTIPLE LINEAR REGRESSION PREDICTION OF TOTAL DAY VEHICLE TRIPS FOR ALL STREET CLASSES AND COMBINATIONS

F	A	C	FA	T4	T3	T2	T1	FAC
Variables Entered in Order (X)								
1	1	1	1	1	1	1	1	1
13	14	13	13	13	13	13	13	13
2	2	2	2	2	2	2	2	2
4	13	14	4	4	4	4	4	4
Cumulative Proportion Variation Explained (R^2)								
0.9730	0.8613	0.8108	0.9266	0.9168	0.9105	0.9116	0.9205	0.9307
0.9878	0.9364	0.8866	0.9659	0.9599	0.9533	0.9523	0.9571	0.9642
0.9943	0.9727	0.9631	0.9868	0.9840	0.9820	0.9821	0.9843	0.9875
0.9945	0.9769	0.9639	0.9874	0.9846	0.9826	0.9827	0.9849	0.9880
Cumulative Standard Error of Estimate (S.E.)								
799	951	656	919	900	866	824	769	717
537	645	437	627	625	626	605	565	516
368	423	250	391	395	389	371	341	304
363	397	247	381	388	382	365	336	299
Cumulative Coefficient of Variation (C.V.)								
0.137	0.178	0.317	0.167	0.169	0.175	0.186	0.208	0.249
0.092	0.120	0.245	0.114	0.118	0.126	0.136	0.153	0.179
0.063	0.079	0.140	0.071	0.074	0.079	0.084	0.092	0.106
0.062	0.074	0.138	0.069	0.073	0.077	0.082	0.091	0.104

TABLE 4

SIGNIFICANCE ORDER AND RELATED PARAMETERS, MULTIPLE LINEAR REGRESSION PREDICTION OF TOTAL DAY PERSON TRIPS FOR ALL STREET CLASSES AND COMBINATIONS

F	A	C	FA	T4	T3	T2	T1	FAC
Variables Entered in Order (X)								
4	4	4	4	4	4	4	4	4
13	14	13	14	14	14	14	14	14
5	5	5	5	5	5	5	5	5
1	1	10	1	1	1	13	13	13
Cumulative Proportion Variation Explained (R^2)								
0.9616	0.8610	0.7566	0.9043	0.8927	0.8840	0.8844	0.8946	0.9076
0.9857	0.9219	0.8674	0.9604	0.9539	0.9468	0.9449	0.9495	0.9570
0.9912	0.9600	0.9388	0.9789	0.9745	0.9713	0.9708	0.9733	0.9781
0.9916	0.9636	0.9396	0.9804	0.9758	0.9725	0.9721	0.9746	0.9793
Cumulative Standard Error of Estimate (S.E.)								
1370	1525	947	1492	1455	1403	1340	1262	1188
839	994	699	960	954	951	925	874	810
658	713	475	702	711	699	674	635	578
647	681	472	677	693	684	659	608	563
Cumulative Coefficient of Variation (C.V.)								
0.160	0.197	0.353	0.187	0.188	0.194	0.206	0.232	0.280
0.098	0.128	0.261	0.120	0.123	0.132	0.142	0.160	0.191
0.077	0.092	0.177	0.088	0.093	0.097	0.104	0.117	0.136
0.075	0.088	0.176	0.085	0.090	0.095	0.102	0.112	0.133

TABLE 5

SIGNIFICANCE ORDER AND RELATED PARAMETERS, MULTIPLE LINEAR REGRESSION PREDICTION OF PEAK HOUR VEHICLE TRIPS FOR ALL STREET CLASSES AND COMBINATIONS

F	A	C	FA	T4	T3	T2	T1	FAC
Variables Entered in Order (X)								
7	7	7	7	7	7	7	7	7
11	8	8	8	8	8	8	8	8
5	15	15	15	15	15	15	15	15
1	5	13	11	11	11	11	11	13
Cumulative Proportion Variation Explained (R^2)								
0.9869	0.9157	0.8546	0.9561	0.9493	0.9434	0.9412	0.9450	0.9510
0.9928	0.9625	0.9374	0.9799	0.9764	0.9738	0.9724	0.9750	0.9791
0.9960	0.9845	0.9744	0.9911	0.9895	0.9885	0.9882	0.9893	0.9911
0.9961	0.9850	0.9757	0.9914	0.9899	0.9889	0.9884	0.9895	0.9913
Cumulative Standard Error of Estimate (S.E.)								
101	137	87	129	128	126	121	114	105
75	92	57	88	87	84	83	77	69
56	59	37	58	58	57	54	50	45
55	58	36	58	57	56	54	50	44
Cumulative Coefficient of Variation (C.V.)								
0.110	0.158	0.314	0.146	0.150	0.159	0.170	0.194	0.231
0.082	0.106	0.206	0.100	0.102	0.106	0.117	0.131	0.152
0.061	0.068	0.134	0.066	0.068	0.072	0.076	0.085	0.099
0.060	0.067	0.130	0.066	0.067	0.070	0.076	0.085	0.097

of variation is the proportion of the mean that is the standard error. It is an indication of relative precision of the estimate. The increase in R^2 and decrease in the standard error and coefficient of variation must be balanced against the increased cost of survey necessary in order to attain these.

All independent (single purpose) variables were available for selection in the free-entry regressions. The entry order and parameters of fit were affected by the individ-

TABLE 6

SIGNIFICANCE ORDER AND RELATED PARAMETERS, MULTIPLE LINEAR REGRESSION PREDICTION OF PEAK HOUR PERSON TRIPS FOR ALL STREET CLASSES AND COMBINATIONS

F	A	C	FA	T4	T3	T2	T1	FAC
Variables Entered in Order (X)								
10	10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11	11
16	15	15	15	15	15	15	15	15
7	13	13	16	16	16	13	13	13
Cumulative Proportion Variation Explained (R^2)								
0.9859	0.9013	0.8305	0.9519	0.9444	0.9373	0.9344	0.9379	0.9442
0.9925	0.9448	0.9149	0.9737	0.9693	0.9664	0.9644	0.9671	0.9719
0.9955	0.9751	0.9610	0.9869	0.9847	0.9836	0.9832	0.9843	0.9866
0.9960	0.9761	0.9644	0.9875	0.9853	0.9841	0.9838	0.9850	0.9873
Cumulative Standard Error of Estimate (S.E.)								
154	207	136	195	194	190	184	174	161
112	155	96	145	144	139	136	126	114
87	105	65	102	102	97	94	87	79
82	102	62	100	100	96	92	85	77
Cumulative Coefficient of Variation (C.V.)								
0.116	0.166	0.334	0.154	0.158	0.166	0.180	0.204	0.244
0.084	0.125	0.236	0.114	0.117	0.121	0.133	0.148	0.173
0.066	0.084	0.160	0.080	0.083	0.085	0.092	0.102	0.120
0.062	0.082	0.152	0.079	0.081	0.084	0.090	0.100	0.117

ual street classes or combination of street classes considered. The entry order for a given dependent variable for the separate classes was somewhat erratic, but for the combinations it was fairly uniform. The home-based work trip that was consistent with the mode-time condition of the dependent variable was the first variable to enter in all regressions. Predictions of total day volume usually chose shopping trips second, followed by the respective non-home-based work group. The reverse was true for predicting peak hour trips. It is apparent that shopping travel is more important in total day than in peak hour travel. The fourth entry was generally too erratic to permit valid conclusions.

The R^2 values were better for peak hour prediction than for total day, and better for vehicle trips than for person trips. The R^2 decreased with mean volume of the street group considered. The R^2 values for the FA and FAC classes were very similar, and the FA class was slightly higher in all situations but one. As more of the collector class was included with FA, the R^2 decreased slightly, until at the T1 group it began to increase. The standard errors decreased with the mean volume of the analysis group. The comparison of coefficients of variation showed an increase as more links were included in the analysis group and the group mean volume decreased. The coefficients were consistently greater for person than for vehicle trips, and were larger for total day than for peak hour trips. These results indicated which variables were most important for predicting trips of various time-mode groups. They form a basis for comparison of the results of selected variable situations. It is significant that the basic element of the proposed revised survey procedure was always the most important predictive variable.

The destination place survey procedure previously proposed implied a logical order of variable entry into prediction equations. The most elemental survey would involve home-based work trips. Next would come, in addition, non-home-based work trips. The third step would involve home-based shopping trips as well. The results discussed henceforth are for regressions on these selected variables, indicating the cumulative results (fit) as each additional variable was selected for the equation.

The regressions were run for nine street class groups and nine prediction situations within each group. Since the trends were fairly consistent, only results for the two most important street class combinations are shown here. Tables 7, 8, 9, and 10 show detailed results for the FAC and FA groups. The R^2 and coefficient of variation values

TABLE 7

PARAMETERS AND COEFFICIENTS, MULTIPLE LINEAR REGRESSION FOR SELECTED PREDICTORS, ENTIRE STREET SYSTEM (FAC)—NORMAL DEPENDENT CONDITIONS

Y	X	Parameters				Coefficients			
		R^2	ΔR^2	S.E.	C.V.	B_0	B_1	B_2	B_3
	1	0.9307	—	717	0.249	620	1.488	—	—
DV	2	0.9573	0.0266	563	0.196	336	1.290	1.587	—
	13	0.9875	0.0302	304	0.106	123	1.140	1.489	1.615
	4	0.9076	—	1188	0.280	1083	1.601	—	—
DP	5	0.9337	0.0261	1007	0.237	682	1.379	1.986	—
	13	0.9792	0.0455	565	0.133	294	1.183	1.851	2.820
	7	0.9510	—	105	0.231	77	1.185	—	—
HV	8	0.9791	0.0281	69	0.152	31	1.133	1.271	—
	15	0.9911	0.0120	45	0.099	14	1.070	1.209	1.330
	10	0.9442	—	161	0.244	126	1.227	—	—
HP	11	0.9719	0.0277	114	0.173	59	1.172	1.486	—
	15	0.9866	0.0147	79	0.120	31	1.099	1.422	2.106

Note: ΔR^2, increase in explained variation; B_0, regression equation constant; B_1, regression coefficient of first variable; B_2, regression coefficient of second variable; B_3, regression coefficient of third variable.

TABLE 8

PARAMETERS AND COEFFICIENTS, MULTIPLE LINEAR REGRESSION FOR SELECTED PREDICTORS, ENTIRE STREET SYSTEM (FAC)—SPECIAL DEPENDENT CONDITIONS

Y	X	Parameters				Coefficients			
		R^2	ΔR^2	S.E.	C.V.	B_0	B_1	B_2	B_3
	4	0.9196	—	773	0.269	658	1.124	—	—
DV	DP 5	0.9408	0.0211	663	0.231	406	0.985	1.246	—
	13	0.9765	0.0357	418	0.145	167	0.864	1.163	1.742
	4	0.9287	—	182	0.276	103	0.282	—	—
HP	DP 5	0.9470	0.0183	157	0.238	44	0.250	0.290	—
	13	0.9577	0.0107	140	0.212	11	0.233	0.279	0.239
	4	0.9193	—	135	0.297	69	0.196	—	—
HV	DP 5	0.9327	0.0134	123	0.270	34	0.176	0.173	—
	13	0.9423	0.0096	114	0.251	13	0.165	0.165	0.157
	10	0.9353	—	121	0.266	85	0.850	—	—
HV	HP 11	0.9584	0.0231	97	0.213	42	0.815	0.943	—
	15	0.9737	0.0170	77	0.169	22	0.763	0.898	1.495
	1	0.9341	—	122	0.268	62	0.259	—	—
HV	DV 2	0.9520	0.0179	104	0.228	21	0.231	0.226	—
	13	0.9586	0.0066	96	0.211	4	0.219	0.218	0.132

TABLE 9

PARAMETERS AND COEFFICIENTS, MULTIPLE LINEAR REGRESSION FOR SELECTED PREDICTORS, FREEWAY AND ARTERIAL CLASSES (FA)—NORMAL PREDICTED SITUATIONS

Y	X	Parameters				Coefficients			
		R^2	ΔR^2	S.E.	C.V.	B_0	B_1	B_2	B_3
	1	0.9266	—	919	0.167	1183	1.382	—	—
DV	2	0.9524	0.0258	741	0.135	715	1.220	1.611	—
	13	0.9868	0.0344	391	0.071	314	1.215	1.456	1.513
	4	0.9043	—	1492	0.187	2047	1.465	—	—
DP	5	0.9305	0.0262	1273	0.159	1391	1.275	2.057	—
	13	0.9793	0.0488	695	0.087	689	1.158	1.827	2.555
	7	0.9561	—	129	0.146	147	1.131	—	—
HV	8	0.9799	0.0238	88	0.100	62	1.116	1.222	—
	15	0.9911	0.0112	58	0.066	36	1.064	1.140	1.248
	10	0.9519	—	195	0.154	231	1.167	—	—
HP	11	0.9737	0.0217	145	0.114	111	1.151	1.401	—
	15	0.9869	0.0132	102	0.080	67	1.092	1.321	1.955

TABLE 10

PARAMETERS AND COEFFICIENTS, MULTIPLE LINEAR REGRESSION FOR SELECTED PREDICTORS, FREEWAY AND ARTERIAL CLASSES (FA)—SPECIAL PREDICTED SITUATIONS

Y	X	Parameters				Coefficients			
		R^2	ΔR^2	S.E.	C.V.	B_0	B_1	B_2	B_3
	4	0.9119	—	1007	0.183	1299	1.035	—	—
DV	DP 5	0.9316	0.0197	888	0.162	898	0.918	1.257	—
	13	0.9705	0.0389	583	0.106	458	0.845	1.113	1.603
	4	0.9257	—	243	0.191	157	0.274	—	—
HP	DP 5	0.9438	0.0181	211	0.166	56	0.245	0.316	—
	13	0.9538	0.0100	192	0.151	- 2	0.235	0.297	0.214
	4	0.9084	—	187	0.212	118	0.118	—	—
HV	DP 5	0.9206	0.0122	174	0.197	61	0.171	0.180	—
	13	0.9288	0.0082	165	0.187	24	0.165	0.168	0.134
	10	0.9384	—	153	0.173	168	0.803	—	—
HV	HP 11	0.9557	0.0172	130	0.147	93	0.793	0.864	—
	15	0.9687	0.0130	110	0.125	63	0.753	0.809	1.342
	1	0.9314	—	162	0.184	94	0.252	—	—
HV	DV 2	0.9486	0.0172	140	0.159	24	0.228	0.240	—
	13	0.9545	0.0059	132	0.150	- 6	0.221	0.228	0.114

exhibited trends between street groups similar to those observed in the free-entry situation. Comparisons of the results using person shopping trips versus vehicle shopping trips indicated that the vehicle trips usually explained more variation than the person group. As a result the vehicle mode was used for all home-based shop variables included in the analysis. Use of the vehicle mode permits a license plate survey of shop trips.

When using the same mode-time condition for both dependent and independent variables, the FAC group (all street system links) was second in prediction (R^2) only to the freeway class. The two groups were very close in all cases. The difference in R^2 between separate street classes was greater than between progressive groups combining collectors with the FA group. The standard error of the estimates decreases as more of the collector links are included with those in the FA group. The FAC group exhibits the lowest standard errors in most situations. If precision is important, the FA group is better than the FAC, since the coefficients of variation are less. A good balance in this decision is desirable, but standard errors are more readily translatable into effects, i.e., design errors.

The regression coefficients shown in Tables 7 through 10 are related to the proportion that the several purpose groups are of total travel. The regression equation constants are indicative of the travel attributable to purposes not accounted for by the variables in the equation. The current research proposes no more than that these coefficients may be generally applicable, although their validity must be further tested.

The regressions involving dependent and independent variables of different mode-time groups exhibited less precision than the homogeneous cases. The differences were slight in all cases, however, and probably are easily rationalized in light of survey cost savings. The general trends of all parameters are similar to those observed in the homogeneous cases. Some discrepancies which are unexplainable may probably be best attributed to anomalies of the data or analysis. The important fact is that the generally excellent predictivity is exhibited in these situations which imply more feasible survey procedures.

The implications of these results are important to the selection of survey procedures. Based on the increase in R^2 and the decrease in standard error of estimate and coefficient of variation, the order of survey complexity follows directly. The same progression follows for all mode and time groups. A vehicle trip survey of home-based work trips requires employer records of those employees driving to work. A home-based work person trip survey requires tabulation of all employee records and a tabulation regarding mode. An all-work trip (home and non-home-based) survey requires interview of drivers or all employees, depending on the mode of interest. Extension to include shopping trips requires, in addition, a license plate survey at shopping districts. Decisions on the form of any revised survey procedure are best made according to costs and feasibility. This research has provided the study director with alternative procedures for replacing the costly home-interview survey. It must be his decision, in light of the community conditions, to select a feasible alternative which will provide valid travel patterns at the least possible cost.

CONCLUSIONS

Several conclusions can be drawn regarding the proposed hypotheses and related relationships:

1. The variance analyses were quite valuable in development of the regression relationships.
2. The travel patterns of home-based work trips represent an excellent approximation to the important travel patterns of trips of all purposes for peak hour or total daily travel.
3. Use of all-work trips improves the above relationship slightly.
4. Use of shopping trips in addition to work trips further improves the representivity slightly.
5. The relationships discussed above were appropriate for travel by all highway-oriented modes. Use of highway person trips showed marginally better results than auto-driver trips.
6. The improved results observed in moving from statement 2 to statement 5 are due to the increased information obtained from the survey. The marginal improvements must be weighed against the increased cost due to the more extensive survey procedure.
7. Travel for all purposes during a peak hour showed excellent results in representing travel for all purposes during the entire day.
8. Total day travel for the work purpose was a good representative of the peak-hour travel by all purposes.
9. Typical results of the regression analyses performed on IRTADS data are shown below:

   (a) Predicting all-purpose travel using all-work and home-based shopping trips for peak hour vehicle travel on the entire highway system:

   R^2 = 0.9911 S.E. = 45 C.V. = 0.099

   (b) Predicting all-purpose travel using all-work and home-based shopping trips for the total day vehicle travel on the entire highway system:

   R^2 = 0.9875 S.E. = 304 C.V. = 0.106

   (c) Predicting all-purpose peak hour vehicle travel using all work and home-based shopping person trips for the total day on the entire highway system:

   R^2 = 0.9423 S.E. = 114 C.V. = 0.250

   (d) Predicting total day vehicle travel for all purposes using total day person trips for all work and home-based shopping purposes on the freeway and arterial classes:

   R^2 = 0.9705 S.E. = 583 C.V. = 0.106

10. The data used in these analyses were samples from all-work trips. The proposed survey procedures would include only trips to major employment concentrations.

RECOMMENDATIONS

1. The regression coefficients of the prediction equations established for the IRTADS data should be tested on data from other urban areas. If no significant differences are found, the survey expansion procedure would be greatly simplified.

2. The representivity of the work trip for all-purpose travel should be examined in different size urban areas in order to define the effect of size on representivity.

3. The surveys proposed in this research should be executed simultaneously with a traditional travel survey in order to define the relative strengths of each approach and to eliminate the criticism noted earlier, that the work trips examined in this research were actually drawn from a home-interview survey.

4. Further investigations should be made of the effect of characteristics of the place and type of employment on the observed relationships in order to improve the estimates of work trip generation. This seems appropriate because of the importance that work travel will assume in prediction of total urban travel.

5. Study should be made of the effect the number of the employees in each work place has on the observed relationship in order to better define the extent of survey required.

6. More detailed investigation should be made of the implications of various types of industrial and residential land-use locations, since this will become highly important in planning based on the procedure proposed here.

7. A study should be made of the effect on prediction of total travel by using only those trips to major employment concentrations. These effects should be established for urban areas of varying size.

APPLICATION

The analyses discussed previously were directed at eliminating the need for a home-interview survey to establish the patterns of urban travel. The following discussion will suggest how the techniques proposed would be implemented in the urban transportation planning process.

The major revisions concern the home-interview survey. If an all-purpose, peak-hour analysis has been selected, the only revision will be elimination from the home-interview data of all but peak-hour trips. Use of a work-trip oriented approach would imply complete elimination of the home interview. Further decisions on procedure rest on the extent of analysis desired. A home-based work-oriented analysis requires only examination of employer records to obtain the employee's address. Additional information regarding salary and family characteristics might also be obtained to refine the analysis and to do special studies, providing necessary permission can be obtained. If the analysis is to consider trips during the entire day, all employees would be tabulated. A peak-hour orientation would require definition of the reporting (or leaving) time of the workers, selecting only those which would necessarily be traveling during the peak hour chosen. Use of vehicle trips only or a need to determine mode for all travelers would employ a procedure such as having employees place their time cards in different bins, according to their travel mode. An alternative approach would involve mode tabulation for each worker by either supervisors or survey personnel.

Decision to include all work trips in the analysis would require a more involved survey. In essence, each worker would have to be interviewed in some manner. The interviews could be conducted one at a time by either supervisors or study staff personnel. Alternatively, the workers could be surveyed by questionnaire. Direction in completion of the questionnaire could be given either locally by monitors or to the entire work force simultaneously by means of a public address system. The basic data sought would be the address of the origin and destination of all trips made to or from the employment place. A "contact" survey could also obtain such information as mode, time, and routing of the work trip as well as attitudes regarding work travel. Use of a questionnaire is less satisfactory than an interview, but it is also less expensive and time consuming. The balance in difficulty and cost would have to be weighed against utility. Further extension of the proposed procedures to include shopping travel would involve tabulation of arrivals at major shopping areas. Use of only home-based shopping trips by vehicles would merely require tabulation of license plates. This could include the usual parking study as an adjunct. Including all home-based shopping person trips would require tabulation of the number of persons arriving in each vehicle. Shopping trips by transit would be prohibitively difficult to survey.

TABLE 11

RELATIVE COST IN HOURS OF THREE ALTERNATIVE SURVEY PROCEDURES

Procedure	Lafayette	Indianapolis
Coding employee records (60 per hour)	353	5,627
Employee interviews (20 per hour)	1,059	16,880
Home interview (5 percent sample) (1.842 hours each)*	1,641	20,598

*Based on data from Austin Transportation Study, published by the Texas Highway Department.

A comparison of costs to obtain data would be of value at this point. Table 11 indicates the relative cost in hours of the three approaches. The figures are based on a coding procedure that would be an appropriate approach to handling employee records only (28). The rate for employment place interviews was estimated at 20 per hour. Another alternative to the proposed technique would be the use of a city directory providing similar information at a further cost reduction (19).

Depending on the survey procedure and approach selected, expansion of the survey results might be necessary to obtain true traffic volumes. The expansion could be made according to typical figures which have been shown to be stable and reliable (10, Chapter II). Alternatively the expansion could be based on figures from microsample home interviews or questionnaires sent home with workers interviewed in the principal survey. The regression coefficients developed in the previous analysis may provide at least a good first approximation to expansion factors. The results of the survey or the expansion, as applicable, would be assigned to the street network in the same manner as usual, followed by the appropriate capacity restraint iterations. Development of the distribution model would use work and residential trip ends developed from the survey in the same manner as usually employed. The model results would be expanded by the traffic volume factors discussed previously in order to perform screenline and cordon checks where appropriate.

Development of the future travel potential would, of course, be based on the economic base and population studies. These would be combined with the existing land use information to determine the future pattern of employment generating activities. After allocating employment and residential activities, the work trips would be distributed as before. The traffic expansion factors, modified to account for changes over time, would be used to obtain total volumes. Care would have to be given to incorporating changes where necessary in ratios implicitly assumed constant in this analysis, such as work travel as a proportion of total area travel.

The work described here is merely a demonstration of one feasible extension of the reported research. The authors do not imply that the results of this research do more than indicate the possible feasibility of revised survey procedures.

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Discussion

KEVIN E. HEANUE, Chief, Urban Development Branch, U.S. Bureau of Public Roads—The authors are to be commended for presenting a paper with such far-reaching implications. Professional analysts in the field will recognize that the recommendations could point toward a significant change in urban travel inventory procedures. Academicians will be pleased in that the development of the authors' ideas will provide innumerable research topics.

However, the authors have used a rather limited argument in their development of a rationale for such drastic changes in travel survey procedures, namely, reduction in inventory costs. I would like to present a somewhat expanded argument for a change in survey procedures, at the same time attempting to relate such changes to the current status of urban transportation planning.

All urban transportation studies in the country are currently entering their continuing phases. They have completed their base year inventories, developed land use and travel models, made forecasts, and completed a network evaluation. In the continuing phase they will be monitoring changes in land development and travel, and then reappraising their models and forecasts to determine if they remain valid.

The authors' recommendations tie in very well with the requirements of the continuing studies. Simplified procedures for developing ADT and peak-hour models should prove to be invaluable aids in validating existing forecasts. A second and equally important use is providing second estimates for critical facilities where the initial traffic estimate falls at or near design break points, such as between a 4-lane or a 6-lane facility. Structural engineers have long followed the practice of using a second estimating procedure when they are basing their designs on techniques that are approximations of structural theory. It might be said that they have safety to consider. Are not the safety problems of an overload facility an equally valid argument for backing up our highly approximate techniques with a second estimating procedure? In addition, one should not overlook the 1970 census plans when peak hour models are to be considered. It is to be hoped that the Census Bureau in 1970 will be collecting place of employment and coding it to small areas. The availability of such a significant national data base would almost require the development of peak hour work trip oriented forecasting procedures.

An intriguing and entirely different argument for the authors' suggestions can be found in a paper by Alonso, "Choosing and Building Models for Predictions," presented at the June 1967 Conference on Urban Development Models, jointly sponsored by the Highway Research Board, the Bureau of Public Roads, and the Department of Housing and Urban Development. Alonso, in effect, says that in conventional urban transportation planning, our model "chains" are too long. We string together a series of models for generation, distribution, and assignment, not to mention land use, each with its own contribution to the variance of the final assigned volumes. In generation and distribution, we have further stratified into three to six purposes. The designer then takes the planner's ADT and applies directional and peak hour factors to determine a design hourly volume.

With the peak hour composed to such a large degree of work trips (approximately 80 percent in morning peak), might it not be far more rational to go directly from work trips, which we can get a good grip on, to peak hour, rather than through this whole series of stratifications and mergings of the data that now constitute our modeling process? The authors are, in effect, suggesting just such a shortened model "chain." I might add that the CONSAD Research Corporation, under contract to the Bureau of Public Roads, is looking into the structure of the urban transportation planning process in an attempt to gain insight into the efficiency of the entire process with respect to compounding or dampening the variances introduced by the various data sources or in the model structure.

I am impressed with the accuracy of the models, particularly when they are compared to the capabilities of existing assignment techniques. Thomas Humphrey in his research paper, "A Report on the Accuracy of Traffic Assignment When Using Capacity Restraint," demonstrated that the overall standard errors in conventional assignment were above those shown for the authors' models. In other words, the error in conventional assignment techniques is greater than the standard errors of models, which were based on the authors' selected categories of trips.

I have one rather significant reservation as to the findings. I feel that the suggested procedures should be justified in terms of benefits to continuing studies rather than in terms of new forms of base year analysis. The continuing process is too expensive and complex to be founded on an initial phase which considers only a limited portion of daily travel. Detailed socioeconomic characteristics determined through home interviews are essential if valid behavioral models which respond to changes occurring during the forecast period are to be developed rather than the descriptive (and often time regression oriented) procedures we seem to be dependent upon. A further danger of total reliance on peak hour or work trip oriented models is the declining relative importance of the peak hour. Evening and weekend traffic in the vicinity of suburban shopping centers is the controlling factor in many designs.

MAX R. SPROLES, Planning and Research Engineer, North Carolina State Highway Commission—This paper investigating the feasibility of using patterns of travel for the work purpose and the peak hour for urban transportation planning is of great interest to those of us who have the responsibility for conducting and updating urban transportation planning studies. This job is a major one. The requirements of time, energy, and manpower are becoming so great that methods requiring less data collection and analysis time must be found.

The researchers have presented the statistical tests needed to ascertain that the data now gathered can be substantially reproduced by data collected in a different manner and for a much shorter time period. The authors have provided comprehensive coverage of the quantitative review of the work trip and the peak-hour travel data related to the average daily travel as normally used in urban transportation studies. This report can well be used as a guide for future work regarding peak-hour model studies, and studies of travel to various types of travel generators.

It appears feasible to use data collected at the place of work and at special shopping surveys to develop total travel patterns for urban areas. This type of survey will be increasingly more important as we begin updating urban studies where comprehensive O-D surveys have already been conducted, and it will provide enough data to make a valid check of trends and travel patterns in urbanized areas.

Substantial amounts of research are still needed in this area. This should be integrated with the research now being produced and applied, to provide more data as to various size urban areas and various sizes of traffic generators and to compare with data from various states to see how they may be used in travel pattern surveys.

I hope that in the near future we will have documentation of the practical uses of these new survey techniques.

Income and Related Transportation and Land-Use Planning Implications

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•HOUSEHOLD income measures are among the most significant determinants of urban life and growth. Income is intermeshed with the location, nature, and type of housing; employment; recreation; community service facilities; and transportation systems. Moreover, it is tied to manifestations such as civic pride, community and neighborhood identity, and individual self-consciousness. Low income areas are often characterized by excessive living densities, poor social and economic conditions, and a high proportion of physical blight, while the more affluent areas commonly are associated with a higher degree of amenities and more attractive life styles.

Along with projections of such variables as population and employment, the planner must study the projection and distributional shifts of household income in order to consider the land-use and transportation plans to best serve the population. In addition, an obviously important consideration for municipal or regional planning is the economic status of the household, which is significant in financing improvements or innovations through direct costs and taxes, and more subtly, for the desire to spend public funds for a proposed plan.

Simple procedures are presented to measure the effect of income on such variables as (a) housing market, (b) auto ownership, (c) auto and transit-trip generation, and (d) time and distance separation of residence and worksite. The data source for this study was the home interview survey results from the Tri-State Transportation Commission, describing the New York metropolitan area. Methodology is presented to indicate the sensitivity of household income to these variables. Three different assumptions of the distribution of household income are presented (analogous to the different states of the world in decision theory). It is hoped that this study may serve as a starting point for needed revisions of data collection procedures pertaining to household income (as cross-classified with other variables) as well as for analytical work to systematically measure household income for its effects on transportation and land-use planning.

HOUSING MARKET VS HOUSEHOLD INCOME

Household income, along with household composition, is an important factor in the selection of a housing type and living style. Home ownership rate, a measure of living style, is a direct function of income. In the New York metropolitan area, for households earning less than $4000, only 2 in 10 own their own home, while 6 households in 10 earning $10, 000 own rather than rent. The highest home ownership is in the $25, 000 + income group with 70 percent of the households owning a home. This is, in reality, a measure of the unconstrained desire to own. The income dividing line between renting and owning is approximately $5000-6000, with the low incomes severely constrained in their selection of housing type. The joint effect of income and persons per household yields more of an insight to the actual desire expressed for home ownership (Fig. 1). Table 1 gives a comparison of households earning $5500 with those earning $8500.

Household income is a determinant of home ownership, even when holding household composition (persons per household) constant. Home ownership or the selection of a

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Figure 1. Percent of households renting vs persons per household, stratified by household income.

TABLE 1

HOME OWNERSHIP (%) VS PERSONS PER HOUSEHOLD
(Stratified by Avg. Household Income)

Persons per HH	Avg. Household Income		Home Ownership Rate Ratio ($8500/$5500)
	$5500	$8500	
1	15%	19%	1.26
2	33	42	1.27
3	31	53	1.71
4	38	62	1.63
5	39	72	1.85
6	40	73	1.83
7	44	79	1.80

housing type is not just a selection of a place to live, it denotes a way of living. Associated with the selection of a house are such factors as cost of housing, relative closeness to work, residential density, tenure of residence, amount of space, degree of privacy, and type of neighbors. While income influences housing choice, once this choice is made, transportation-related variables are also influenced. To illustrate, for households of equivalent incomes, the number of autos owned per 100 households is more than twice as great in the single family units as compared to multi-unit structures.

Household income's influence on the selection of housing type must also be studied along with the racial composition of the region's households. Using the 1960 Census as a source, significant differences in home ownership rates are apparent for nonwhites vs whites in the New York metropolitan area. The rates of home ownership by race are given (Table 2) for the households in the region, stratified by household income.

TABLE 2

HOME OWNERSHIP (%) VS RACE
(Stratified by Household Income)

Race	Household Income				All Households
	(< $2999)	($3000-6999)	($7000-7999)	($10,000+)	
White	28%	37%	55%	66%	45%
Nonwhite	10%	17%	32%	48%	18%
Ratio home ownership (white/nonwhite)	2.8	2.2	1.7	1.4	2.5

Forecasting Housing Demand

A future housing demand may be simulated by studying the present relationship of household income vs home-ownership rates and then projecting the income distribution to a future year while holding the income-housing relationship fixed in time. Obviously, this is a simplified technique of estimating future housing demand. It does not implicitly consider such variables as persons per household, or age of head of the household, and does not reflect future federal policy, construction costs, or interest rates for mortgage money. Nevertheless, this technique offers a starting point to estimate the housing demands for a particular housing type, the single family unit. Furthermore, housing demands may be simulated under different assumptions or conditions of income distribution. (This is analogous to decision theory, viewing the rewards or consequences under varying states of the world. Of course, a probability must be associated or computed with each "state of the world.") Three different assumptions of income distribution are presented: (a) a uniform increase of income for each income class, (b) low-income groups gaining at a higher rate of increase than the other income groups, and (c-d) middle or high-income groups gaining at a higher rate of increase. For each assumption, the associated demand for home ownership is computed. The analytical process is as follows:

1. From survey results, the income distribution is determined for the present or survey year (in this case, 1963).

HOME OWNERSHIP RATE VS HOUSEHOLD INCOME

Household Income	Home Ownership Rate	Household Income	Home Ownership Rate
$0-2000	19.6%	$6000-7500	44.0%
2000-3000	20.5	7500-10,000	55.0
3000-4000	20.9	10,000-15,000	60.8
4000-5000	23.8	15,000-25,000	60.8
5000-6000	29.3	25,000 +	71.1

2. Associated with each income group is its calculated (also from survey) rate of home ownership per household.

3. For each income class, a percent growth of income is assigned for the survey year to forecast year.

4. The home ownership rates from item 2 are held constant, with the percent of households in each household group changing at the same rate as the real income change. An illustration of this process is as follows:

ANALYTICAL PROCEDURE TO DISTRIBUTE HOUSEHOLD INCOME

Income Class	Percent of Households in Survey Year	Change
$0-2000	7	0 -2.3
$2000-3000	6	+2.3% -6.0

Explanation: If everyone's income is increased by 50% (over 25 years) and a uniform distribution is assumed for each income class, then all households earning $1333 or more in the survey year will be propelled to the next class. Thus, (1/3) (7%) or 2.3% of the households move to the $2000-3000 income class and (2/3) (7%) or 4.7% of the households remain in the $0-2000 classification. This process continues throughout each income class and is summed up to produce a final (new) distribution.

TABLE 3

HOME OWNERSHIP VS INCOME

Condition (Assumptions)	Survey Findings (1963)	Uniform Increase In Real Income of 2% Per Year	2½% Increase for $0-5000 Income (All Others 2% Increase)	2½% Increase for $10,000 Income (All Others 2% Increase)	2½% Increase for $5-10,000 Income (All Others 2% Increase)	Uniform Increase in Real Income of 3% Per Year
Time (yr)	T_0	$T_0 + 25$	$T_0 + 25$	$T_0 + 25$	$T_0 + 25$	$T_0 + 25$
Results						
(a) Home ownership demand per 100 households	40.6	50.5	51.1	50.6	50.8	53.0
(b) Autos per 1000 households	850	1096	1113	1097	1097	1166
Income Distributions—Percentage Distribution of Households						
Income Class						
$0-2000	7	4.7	4.3	4.7	4.7	4.0
2-3000	6	2.3	2.7	2.3	2.3	3.0
3-4000	9	4.0	2.8	4.0	4.0	2.9
4-5000	10	5.0	4.1	5.0	5.0	2.3
5-6000	13	6.0	8.1	6.0	6.0	6.7
6-7500	16	10.0	6.0	10.0	10.0	5.1
75-10000	17	20.2	24.2	20.2	14.6	17.1
10-15000	14	25.8	25.8	25.8	26.0	29.2
15-25000	6	15.0	15.0	14.2	20.4	19.8
25000 +	2	7.0	7.0	7.8	7.0	10.0
	100	100.0	100.0	100.0	100.0	100.0

5. The total number of home owners per 100 households is determined by multiplying the new number of households (shifted by the income growth) by the established (fixed) home ownership rate, and summing up the results for all income classes. The results of this process are given in Table 3, under Results (a).

Analysis of Results—Housing Demand

A 2 percent increase in real household income (adjusted for cost of living increases) over the next 25 years creates a new pattern or demand for home ownership. The income structure shifts to the right, producing more middle-class families, with (for the first time) sufficient income to contemplate owning a house and enjoying a life in the suburbs. Current construction rates (rate of single family home construction vs multi-family) may have to be modified for the future. To illustrate—in the period between 1957-1964 over 8, 500, 000 new dwelling units were constructed in the New York metropolitan area, of which 43 percent were single family units. (Regional Plan Association Bull. 103, Dec. 1965.) Trends indicate that this percentage of single-family construction should increase to meet the demand of the households. For example, a conservative estimate of a uniform real income increase of 2 percent per year increases the rate of single family home ownership from 40 households in 100 to over 50 per 100.

By perturbing the income distribution, causing each of the income groups to grow at different increase rates, it is possible to view the sensitivity of home ownership demands for the $0-5000, $5000-10, 000, and $10, 000+ income groups. Three cases were considered at a uniform 2 percent income increase for all groups, and with either the low, middle, or high income group increasing at a slightly higher rate of 2½ percent. The results of this analysis show that the lowest household income ($0-5000) is most sensitive to home-ownership demand with slight changes in income. The middle-to-high incomes are relatively insensitive to this same income change.

It is also noted that the increase from present conditions to a uniform 2 percent income increase (over 25 years) produces a significantly greater change of home ownership increase per year, per 1 percent income growth, when compared to the change from a 2 percent to a 3 percent income increase.

Although this analysis on household income vs housing-market demands is simplified, it is hoped that it also reveals the necessity to improve and enrich the data collection and analytical methodology in the housing-market field. Much research is needed to describe the housing consumer, his needs, and the supply of housing to most efficiently fit his demand. The study of household income vs housing demands is but a first step in this direction. The authors of Housing, People and Cities[1] state that

> No major industry in the United States is as deficient in systematic research as the housing industry. . . . Probably the most spectacular deficiency of the housing industry is the lack of adequate market data. The census of the farm population and farm housing involves the expenditure of $1.90 per capita on the farm population. The corresponding census on urban housing and population involves an expenditure of only $0.45 per capita on the urban population. . . . Our major industries conduct systematic and detailed surveys of the buying habits, incomes, residential locations, and social characteristics of their purchases. They use all the elaborate methods of modern market research to diagnose consumer preferences and tastes. No such information is available in any city in the United States for the markets and customers of the housing industry.

Household Income vs Mass-Transit Ridership

What happens to the total number of transit trips if household income increases? Since income (along with residential density) is a strong determinant of auto ownership, it was felt that for the purpose of this analysis auto ownership may be used as a proxy variable for income. The underlying assumption for this substitution is that (holding residential density constant) income and autos may be interchanged in their relationships with total trip generation and mass-transit trip generation.

The strategy for this analysis is as follows: From survey or present conditions, construct statistical relationships between auto ownership, total trip generation, and mass transit ridership (Figs. 2-5). A simulation technique is then employed to yield the incremental change of total trips and mass-transit trips due to incremental changes in auto ownership (presumably caused by incremental changes in household income). The technique evolves as follows: With a sampling of expansion areas[2] as observation points, data were collected on (a) residential density of zone (persons per square mile), (b) autos per household (ratio), (c) number of households in each auto-ownership category (0, 1, 2+ autos), (d) total trip productions, and (e) total mass-transit trip productions. Next, auto-owership rates were related to the distribution of households in each auto-ownership class. To illustrate, an ownership rate of 1.2 autos per household (or, more realistically, 120 autos per 100 households) is equivalent to 30 households owning 2+ autos, 55 households owning 1 auto, and 15 households owning 0 autos. The next step involves the construction of a relationship between total trips generated per household vs residential density stratified by auto ownership. To illustrate, zone A has an auto ownership rate of 1.20 autos per household and an average density of 10,000 persons. Then (Fig. 3) the 100 households composing this zone will generate 672 trips (40 trips by the fifteen 0-auto households, 352 trips by the fifty-five 1-auto households, and 280 trips by the thirty 2+ auto households). The input for step 3 involves the total trip generation for this zone and the auto-ownership distribution per zone. Transit trips are then calculated as a percentage of the total trip-end densities as related to residential density and auto ownership (Fig. 5).

Analysis of Results—Transit Trip-Making

The results of this analysis may be expressed in different ways. For the purpose of this paper it was desired to illustrate the sensitivity of auto ownership as addressed to the following questions: With a constant residential density, what happens to transit-trip productions as you go from 0 to 1-auto households, and progress from 1-auto to

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[1]Meyerson, M., Terrett, B., and Wheaton, W. Housing, People and Cities. McGraw-Hill, 1952.

[2]In expanding the Tri-State home interview survey from a 1 percent sample to its representative universe, the study area was divided into 278 expansion areas, or zones.

multi-auto households? What is the incremental change of total trips and mass-transit trips with incremental changes in auto ownership, progressing by 0.1 increases in auto ownership?

Figure 6 shows the sensitivity of transit trip generation with shifts in auto ownership from 0-1-2+ autos. The transit trip generation rate drops as much as 30 to 35 percent in high residential densities of 100,000 or more when an auto becomes available to a previously auto-less household. In relatively moderate residential densities (10,000-40,000) this drop in transit trip-making is on the order of 5 to 10 percent, while in middle-high densities the decrease is 10 to 20 percent with the availability of 1 auto.

The addition of a second auto is relatively insensitive to transit trip-making. In the residential density range from 2000-100,000, there is a general decrease in transit trips, with the range from +5 to -5 percent. In the very high densities (over 100,000), a sharp increase in transit trips is noted with the addition of a second auto. However, this is more of a statistical anomaly than a significant finding, as relatively few households maintain two autos at this density.

Another view of the results is made possible by studying the share of transit trips to total trips, with changes in auto ownership (Fig. 7). At high residential densities, the transit share of total trips drops 40 percent with the advent of a first auto, while at low

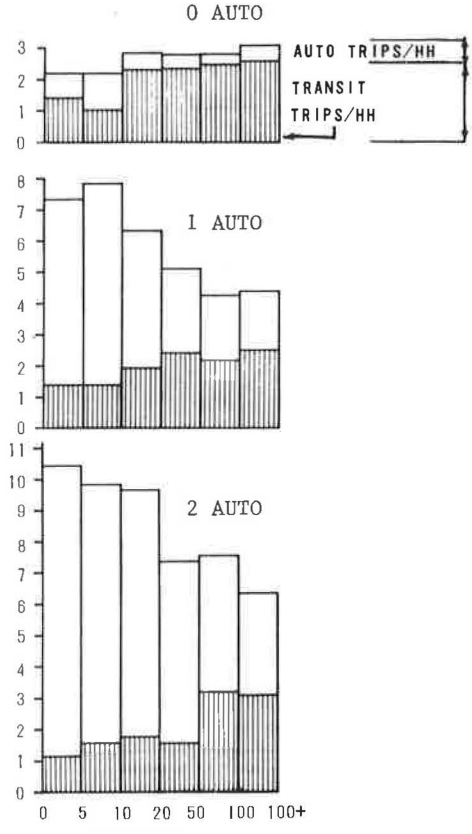

Figure 2. Trip productions vs residential density stratified by auto ownership.

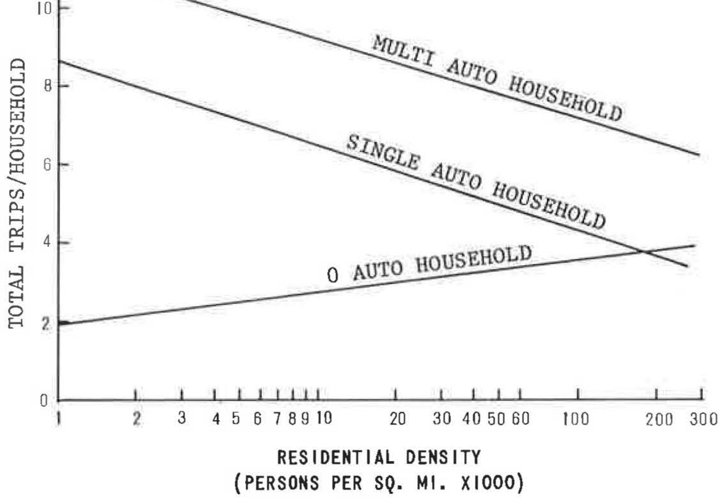

Figure 3. Trip productions per household vs residential density stratified by auto ownership.

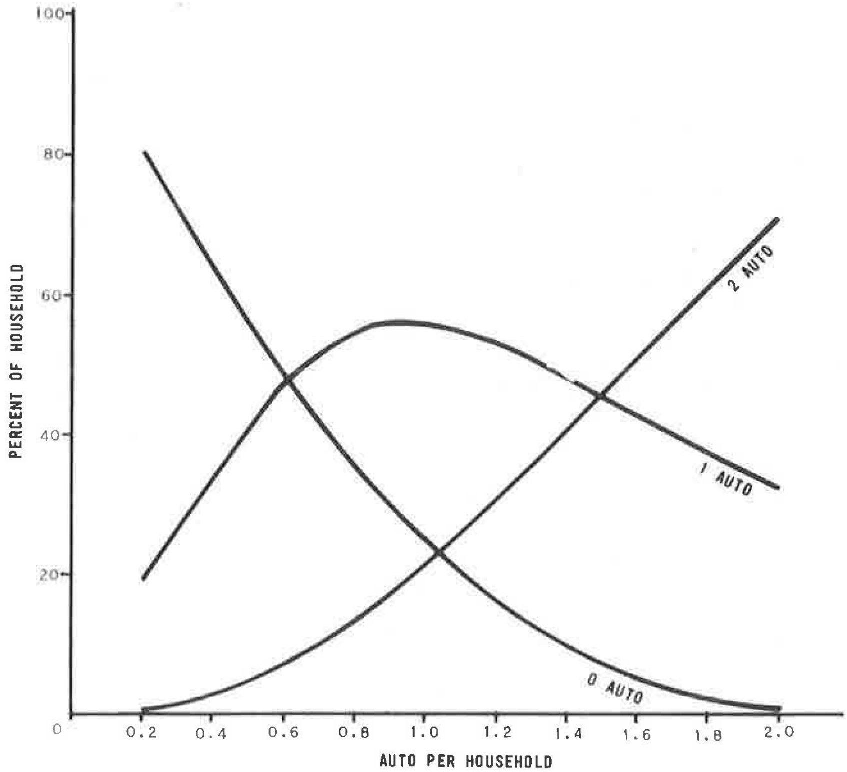

Figure 4. Percent households by ownership category vs average auto ownership.

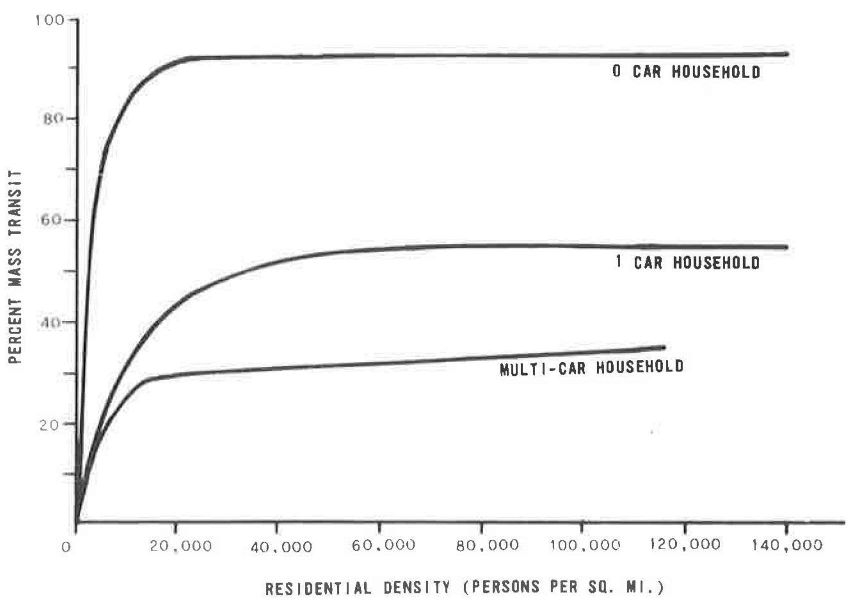

Figure 5. Percent mass transit vs residential density and auto ownership class.

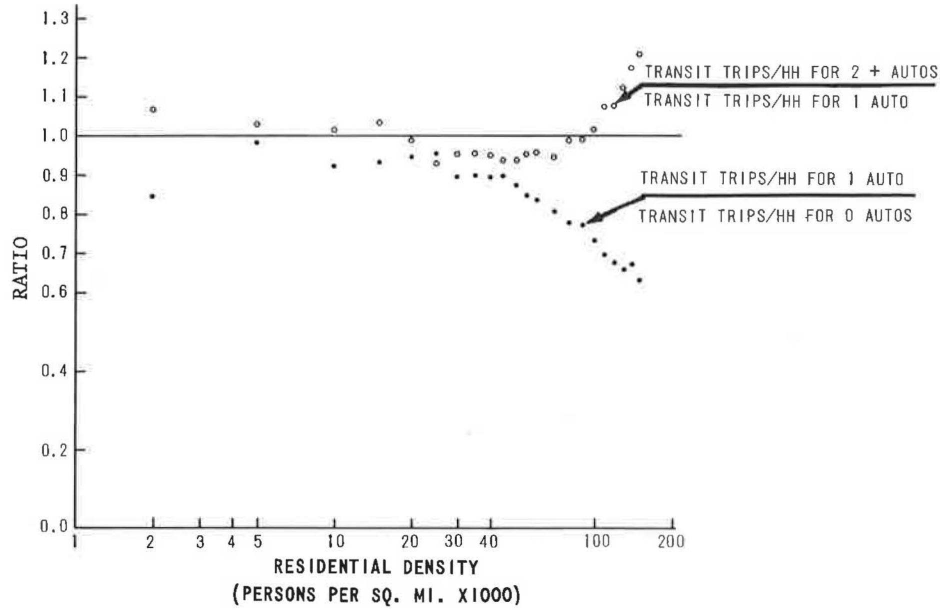

Figure 6. Sensitivity of transit trip generation with changes in residential density and auto ownership.

densities (2000) the decrease is a drastic one of 80 percent. The curve of transit share vs residential density (with change in autos available from 0-1) is curvilinear, showing an asymptotic relationship to a maximum decline of 40 percent at high densities.

Total trip generation and transit trip-making may also be studied across the entire spectrum of auto ownership (Fig. 8-9). Total trips generated is shown to vary directly with autos available and inversely with residential density. As auto availability increases, the differential rates in trip-making between different residential density measures

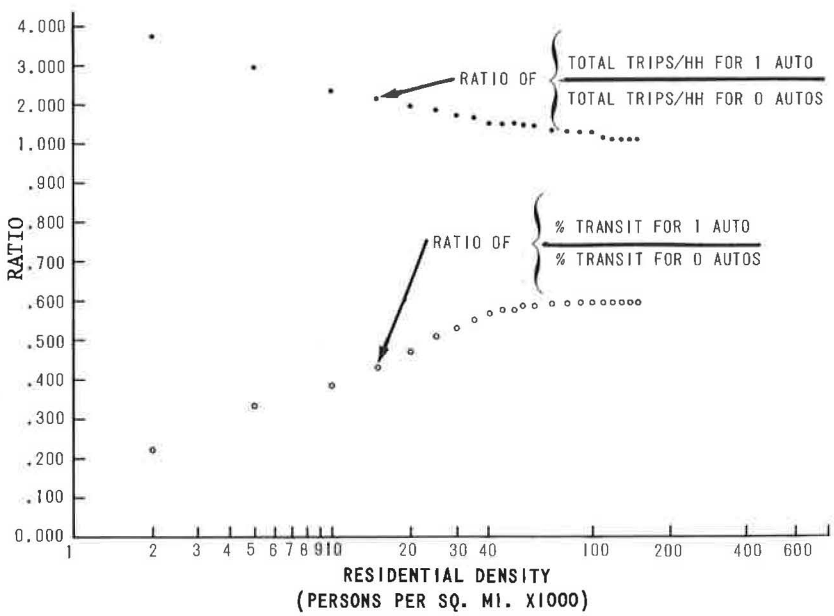

Figure 7. Sensitivity of transit trip share with changes in residential density and auto ownership.

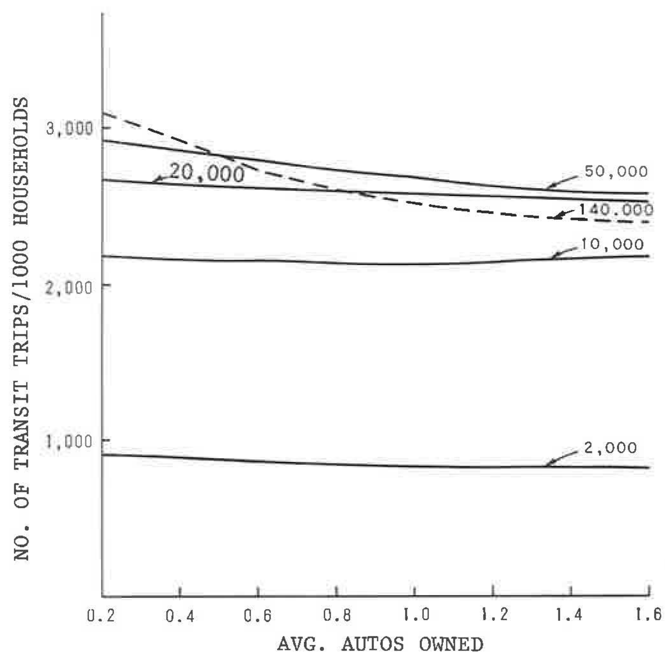

Figure 8. Transit trip production vs auto ownership stratified by residential density.

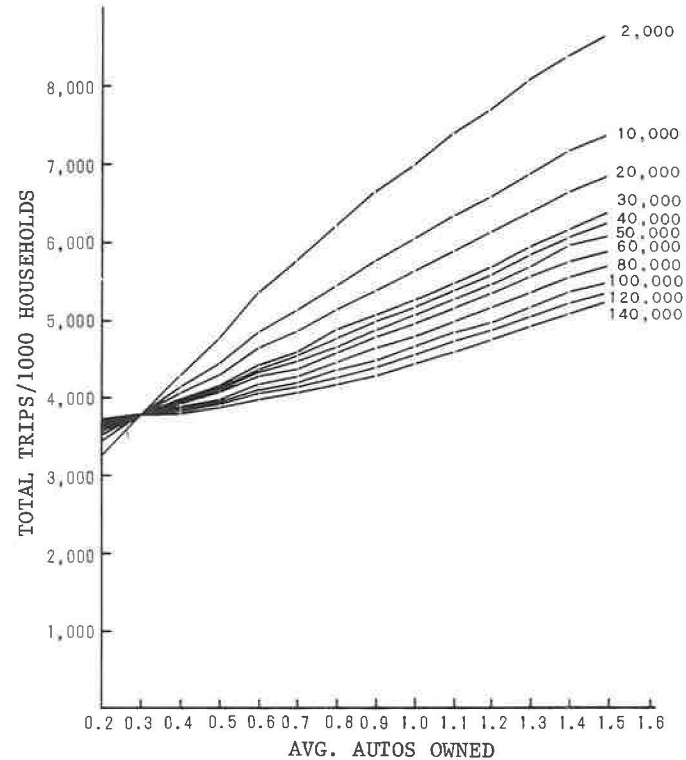

Figure 9. Total trips per household vs residential density (persons per sq mi) and auto ownership.

TABLE 4

SIMULATED TOTAL TRIPS AND TRANSIT TRIPS WITH INPUT OF AUTO OWNERSHIP AND RESIDENTIAL DENSITY

AVE AUTOS OWNED	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	
2000 PRS/SQMI	3241	3749	4282	4745	5347	5735	6204	5528	5965	7370	7691	5079	8397	8630	8935	TOTAL TRIPS
	908	896	884	874	862	854	846	840	837	833	830	827	825	825	823	TRANS TRIPS
5000 PRS/SQMI	3348	3759	4195	4572	5070	5389	5783	6142	6432	6783	7062	7403	7684	7993	8162	TOTAL TRIPS
	1621	1619	1617	1615	1613	1612	1612	1512	1512	1613	1614	1616	1617	1619	1620	TRANS TRIPS
10000 PRS/SQMI	3432	3762	4119	4425	4841	5104	5441	5753	6010	6326	6578	6888	7149	7344	7591	TOTAL TRIPS
	2192	2178	2157	2156	2147	2140	2136	2135	2138	2142	2146	2153	2160	2167	2173	TRANS TRIPS
15000 PRS/SQMI	3459	3748	4064	4334	4707	4962	5247	5534	5772	6067	6302	6594	6841	7027	7260	TOTAL TRIPS
	2432	2418	2404	2392	2379	2370	2362	2355	2351	2347	2344	2341	2340	2340	2338	TRANS TRIPS
20000 PRS/SQMI	3513	3769	4052	4293	4631	4843	5123	5399	5612	5889	6112	6389	6624	6803	7025	TOTAL TRIPS
	2666	2652	2639	2627	2612	2603	2591	2582	2574	2565	2559	2550	2544	2539	2533	TRANS TRIPS
25000 PRS/SQMI	3527	3758	4015	4234	4543	4736	4993	5238	5444	5701	5907	6165	6384	6551	6757	TOTAL TRIPS
	2748	2736	2722	2710	2692	2682	2566	2551	2538	2621	2607	2590	2575	2564	2550	TRANS TRIPS
30000 PRS/SQMI	3520	3714	3937	4124	4401	4571	4809	5041	5241	5494	5698	5956	6178	6351	6558	TOTAL TRIPS
	2788	2762	2734	2710	2679	2658	2634	2613	2596	2575	2559	2540	2524	2513	2498	TRANS TRIPS
35000 PRS/SQMI	3561	3742	3952	4128	4391	4552	4781	5004	5198	5445	5644	5896	6113	6283	6486	TOTAL TRIPS
	2852	2826	2798	2773	2742	2722	2597	2575	2658	2637	2621	2601	2585	2573	2557	TRANS TRIPS
40000 PRS/SQMI	3581	3754	3954	4122	4375	4530	4750	4967	5155	5395	5589	5834	6047	6212	6411	TOTAL TRIPS
	2886	2858	2828	2802	2769	2747	2722	2598	2680	2658	2640	2619	2601	2589	2572	TRANS TRIPS
45000 PRS/SQMI	3579	3746	3941	4104	4350	4500	4715	4926	5110	5345	5534	5774	5982	6144	6338	TOTAL TRIPS
	2898	2871	2842	2817	2784	2763	2737	2713	2694	2570	2652	2629	2611	2597	2579	TRANS TRIPS
50000 PRS/SQMI	3600	3754	3936	4088	4321	4462	4667	4970	5048	5275	5450	5694	5897	6056	6246	TOTAL TRIPS
	2930	2896	2861	2831	2791	2766	2735	2708	2686	2660	2640	2615	2595	2580	2560	TRANS TRIPS
55000 PRS/SQMI	3521	3762	3932	4072	4291	4423	4619	4913	4985	5207	5385	5613	5812	5968	6153	TOTAL TRIPS
	2964	2924	2882	2846	2800	2770	2736	2705	2681	2652	2630	2603	2581	2566	2545	TRANS TRIPS
60000 PRS/SQMI	3641	3770	3927	4056	4262	4385	4570	4757	4923	5137	5311	5533	5727	5880	6061	TOTAL TRIPS
	2991	2943	2893	2850	2796	2760	2720	2534	2657	2526	2601	2572	2550	2533	2511	TRANS TRIPS
70000 PRS/SQMI	3652	3768	3912	4030	4223	4337	4513	4592	4852	5061	5229	5446	5636	5787	5963	TOTAL TRIPS
	3021	2968	2913	2866	2807	2768	2723	2685	2655	2621	2594	2562	2537	2519	2494	TRANS TRIPS
80000 PRS/SQMI	3634	3738	3870	3978	4160	4266	4435	4610	4768	4974	5142	5358	5549	5700	5877	TOTAL TRIPS
	3014	2954	2893	2840	2775	2733	2685	2545	2615	2581	2554	2523	2500	2484	2460	TRANS TRIPS
90000 PRS/SQMI	3643	3738	3861	3961	4131	4230	4391	4556	4707	4904	5065	5272	5455	5601	5771	TOTAL TRIPS
	3029	2963	2897	2839	2769	2722	2571	2627	2595	2559	2530	2497	2472	2455	2431	TRANS TRIPS
100000 PRS/SQMI	3664	3746	3855	3943	4098	4187	4335	4491	4634	4822	4975	5173	5350	5490	5653	TOTAL TRIPS
	3056	2982	2909	2844	2767	2715	2660	2514	2581	2544	2515	2483	2459	2444	2420	TRANS TRIPS
110000 PRS/SQMI	3679	3746	3842	3917	4058	4138	4278	4426	4565	4750	4900	5095	5271	5411	5573	TOTAL TRIPS
	3084	3000	2918	2845	2761	2703	2644	2596	2563	2527	2500	2469	2448	2436	2414	TRANS TRIPS
120000 PRS/SQMI	3708	3765	3850	3917	4047	4120	4251	4392	4525	4702	4845	5035	5205	5342	5498	TOTAL TRIPS
	3115	3024	2936	2857	2765	2703	2639	2587	2551	2512	2482	2449	2425	2411	2388	TRANS TRIPS
130000 PRS/SQMI	3698	3747	3825	3884	4006	4073	4199	4336	4466	4640	4782	4969	5138	5274	5428	TOTAL TRIPS
	3116	3021	2929	2846	2752	2688	2623	2571	2536	2500	2472	2442	2422	2412	2391	TRANS TRIPS
140000 PRS/SQMI	3688	3728	3797	3848	3962	4024	4145	4277	4405	4578	4719	4905	5074	5210	5364	TOTAL TRIPS
	3114	3014	2918	2832	2735	2658	2603	2552	2519	2485	2460	2434	2419	2412	2394	TRANS TRIPS
150000 PRS/SQMI	3708	3736	3792	3832	3933	3985	4095	4221	4343	4509	4645	4825	4989	5122	5272	TOTAL TRIPS
	3145	3037	2932	2839	2734	2663	2593	2538	2503	2467	2441	2414	2398	2390	2372	TRANS TRIPS

TABLE 5

SIMULATED TRIP PRODUCTIONS BY COUNTY

VE AUTOS OWNED	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	
BERGEN	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	714	731	748	762	779	790	801	809	814	819	823	827	829	830	833	TRANS TRIPS
BRONX	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1604	1725	1845	1952	2078	2163	2254	2331	2386	2448	2495	2550	2590	2617	2657	TRANS TRIPS
ESSEX	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1036	1036	1036	1036	1034	1033	1030	1027	1024	1019	1015	1010	1005	1001	996	TRANS TRIPS
HUDSON	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1186	1212	1234	1255	1272	1286	1293	1295	1292	1284	1277	1266	1253	1241	1231	TRANS TRIPS
MIDDLESEX	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	584	604	622	639	658	671	684	694	701	708	714	719	723	725	729	TRANS TRIPS
MONMOUTH	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	581	598	617	634	655	669	685	702	714	730	742	757	769	778	790	TRANS TRIPS
MORRIS	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	341	386	434	475	531	566	611	653	687	729	762	803	838	863	896	TRANS TRIPS
PASSAIC	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	688	680	675	669	666	663	664	666	671	677	683	691	699	706	713	TRANS TRIPS
SOMERSET	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	681	685	692	697	710	717	732	749	765	788	807	832	854	873	893	TRANS TRIPS
UNION	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	764	769	774	779	782	785	786	785	784	781	779	775	771	767	764	TRANS TRIPS
KINGS	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1652	1781	1911	2026	2166	2259	2363	2453	2520	2598	2659	2729	2784	2823	2877	TRANS TRIPS
NASSAU	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	794	832	872	906	949	977	1009	1037	1059	1083	1103	1125	1143	1156	1173	TRANS TRIPS
MANHATTAN	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1697	1834	1968	2087	2223	2315	2408	2482	2531	2583	2622	2663	2689	2704	2732	TRANS TRIPS
QUEENS	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1565	1666	1774	1867	1992	2072	2172	2265	2341	2434	2508	2599	2674	2731	2803	TRANS TRIPS
RICHMOND	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	1527	1651	1785	1900	2056	2155	2281	2398	2495	2613	2708	2825	2923	2996	3089	TRANS TRIPS
ROCKLAND	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	658	716	779	834	907	954	1013	1059	1114	1170	1215	1270	1316	1351	1394	TRANS TRIPS
SUFFOLK	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	670	733	797	853	922	967	1018	1061	1093	1130	1159	1192	1218	1236	1261	TRANS TRIPS
WESTCHSTR	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	917	958	1000	1036	1082	1112	1147	1178	1202	1230	1253	1279	1301	1316	1337	TRANS TRIPS
SWESTERN	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	481	482	485	488	497	502	513	526	539	557	572	592	610	625	642	TRANS TRIPS
GTR BRGPT	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	602	583	566	551	536	525	517	513	512	512	514	517	521	525	529	TRANS TRIPS
SCENTRAL	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	589	584	583	581	586	587	595	606	618	635	650	669	688	704	720	TRANS TRIPS
ANS-DERBY	2320	2680	3080	3420	3900	4200	4600	4980	5300	5700	6020	6420	6760	7020	7340	TOTAL TRIPS
	246	271	300	324	360	382	412	441	466	497	522	554	581	602	627	TRANS TRIPS

increases significantly. Conversely, at low auto ownership levels of 20-40 autos per 100 households, the trip propensity approaches a constant of approximately 4 trips per household for all residential density measures.

For the mass-transit trip generation, at constant residential densities, the number of transit trips is relatively insensitive to incremental changes in auto ownership. For the most part, there are slight decreases in transit trip-making as the auto ownership rates increase. Residential density, rather than auto ownership, determines the transit trip productions, with a low of about 1 trip per household at a density of 2000 to a high of 3 transit trips per household at a density of 40,000-50,000 (Fig. 8).

With the aid of a computer, the simulated results may be tabulated showing the total trips and transit trips per range of residential densities and autos owned (Table 4). Another way of presenting the results is to assign an average residential density to a municipality or county to see how transit and total trips vary with autos (Table 5).

In summary, perhaps too much attention was paid to the description of the results and not enough to the possible uses of the technique. The methodology presented provides a trend of trip-making projected by holding constant relationships between income, autos, density, and trip-making. It is feasible to incorporate this procedure to an overall model of population and employment growth (and related characteristics) to yield a portrait of transit and total trip demand, if these present relationships continue into the future. In addition, transit service may also be readily incorporated in the outlined procedure. The end-product of the analysis presented is a trip-demand portrait of a region if no significant region-shaping planning decisions are made. This is a starting point for viewing new transportation and land-use plans for their changes on the trend or projected plan.

HOUSEHOLD INCOME VS AUTO OWNERSHIP

Household income, along with residential density, is an indicator of auto ownership. Holding density constant (with no. of housing units in the structure a proxy for residential density) auto availability increases with increasing household income for each of the four housing types. However, this rate of increase of autos vs income is not constant

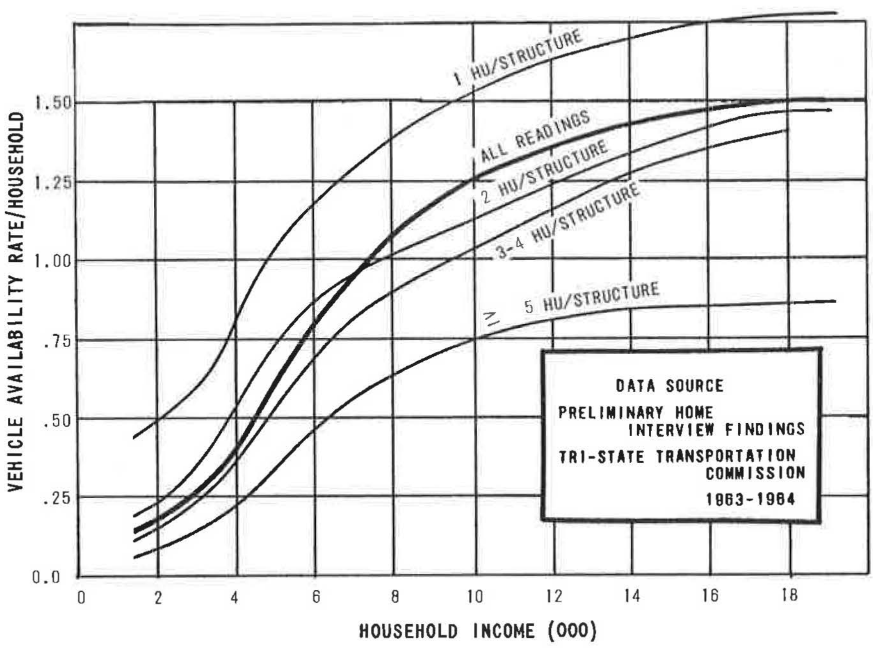

Figure 10. Vehicle availability vs household income stratified by number of housing units in the structure.

throughout the density classes. Figure 10 shows the relationship between autos and income stratified by housing type.

A rate of auto availability vs household income was determined from survey results. (The terms auto ownership and auto availability are used interchangeably.) This rate is held fixed with income forecasted to a future year. This procedure implicitly assumes that the growth in the region between the survey year and the forecast year will approximate the density configuration already intact in the region. The auto ownership rate vs household income is indicated as follows:

Income	Auto Availability
$0-2000	0.15
2000-3000	0.23
3000-4000	0.30
4000-5000	0.50
5000-6000	0.73
6000-7500	0.93
7500-10,000	1.15
10,000-15,000	1.34
15,000-25,000	1.51
25,000 +	1.51

Results of the analytical procedure used to compute the demand for auto ownership under different assumptions of income distribution are given in Table 3, under Results (b).

Analysis of Results—Auto Ownership

An increase of 2 percent per year for 25 years (or a 50 percent increase) produced a change in auto ownership from 85 autos per 100 households to 110 autos per 100 households. The actual increase in the ownership rate was 29 percent, or 14.5 percent per 1 percent increase in real income. The differential increase in auto ownership from (a) a 2 percent increase in real income to (b) a 3 percent increase in real income is less significant, producing a 12.3 percent increase per 1 percent change in real income. This is due to the saturation of autos per household (sufficient number of autos per family to accommodate household needs) regardless of household income.

With perturbations in the income-distribution process, one can view the sensitivity of each of three income groups on their effect on auto ownership. To illustrate, the household demand for autos was computed at a uniform average real increase in income of 2 percent (for all income groups). This may be compared to a 2 percent real income growth for all groups and a 2½ percent income growth in either the (a) $0-5000 income group, or (b) $5-10,000, and (c) $10-15,000 groups. The low income group (a) is most sensitive to changes in auto ownership with a slight change in household income. An additional ½ of 1 percent increase in auto ownership (over the uniform 2 percent increase for all groups) produces an increase of 2 autos per 100 households. The incremental growth of ½ of 1 percent to either of the other income groups produces, in effect, no change in the total autos per 100 household rate, showing the saturation effect of autos on moderate to high incomes.

TIME-DISTANCE SEPARATION OF RESIDENCE AND WORKSITE

One of the important considerations in choosing a place of residence is its relationship with the place of employment. The separation of the home and worksite, measured in time, distance, and cost, dictates to a large degree the shape a region may take. Most basic to the consideration of income and its related land-use planning implications is the relationship between income and place of residence on the one hand, and place of employment and accessibility on the other. It is commonly held that the journey to work, from this standpoint of time, distance, cost, and mode, is directly related to the level of personal income. In essence, as a worker's income increases, he has a correspondingly wider choice as to employment location. The worker at the low end of the economic scale is severely limited in choice and opportunity.

In recent years, metropolitan areas throughout the nation have experienced a steady movement of lower-paying jobs away from the central city (especially in manufacturing). At the same time, the movement of the "middle-class" to the suburbs has left many central cities with a rapidly-increasing share of low-income families. Thus there is an apparent greater separation of home and work for each income class. This denotes a greater demand on the transportation system for the journey to work and the need for new and expanded transportation links to serve this redistributed population. In addition, viewing the average time, cost, and distance from home to work for each income class should reveal the constraints on the relative connection of residence and worksite. There is also a steady increase in distance from work as household income increases. The average trip length in miles (airline distance) and the average trip time for the journey to work as stratified by income is as follows:

Income	Trip Length	Trip Time (min)
$0-1999	2.26	23.7
2000-2999	4.60	32.7
3000-3999	6.07	34.2
4000-4999	5.62	33.4
5000-5999	7.50	32.2
6000-7499	9.16	32.8
7500-9999	11.00	33.3
10,000-14,999	12.00	32.5
15,000-24,999	14.42	32.6
25,000 and over	10.57	27.2

With the exception of the very low incomes ($0-2000) and very high incomes ($25,000 +) all other income classes have a surprisingly constant average trip time to work (about 33 min, with a range of from 32.5 min to 34.2 min for eight income classes). Of course, it is a combination of distance and time that produces the actual cost of the journey to work, such that this cost would increase as household income increases. The data above reflect the importance of the time consideration in the match-up of residence and worksite.

It is suggested that household income be studied in much greater detail in designing for more functional living-working arrangements, and for providing improved access permitting people to flow more freely between home and job.

SUMMARY

Household income is shown to be a determinant in transportation and land-use planning. Simplified procedures are presented to measure the sensitivity of household income with such variables as auto ownership, transit-trip ridership, auto and total trip-making, and home ownership. It is hoped that this paper may stir interest in the systematic evaluation of the variables that are used to simulate transportation demands (of which income is one of many). Innovations in data collection procedures should be suggested and should be designed to permit a more thorough evaluation of these variables over time.

Simplified Techniques for Developing Transportation Plans

Trip Generation in Small Urban Areas

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•MANY smaller urban areas cannot spend large sums of money to gather the necessary data and complete the analysis required for a regular transportation study. The existing procedures are not only expensive but are also very complex and their reliability in smaller areas is not known. It is therefore desirable that simplified and less expensive techniques be investigated for developing transportation plans in smaller urban areas.

PURPOSE

The overall purpose of this research was to investigate simplified techniques for developing transportation plans in smaller urban areas. The specific purpose decided upon for detailed study was a study of socioeconomic and land-use characteristics of urban areas that influence work trip generation and to determine which characteristics can be efficiently used to forecast future work trip generation. Specific work trip generation equations for each urban area were developed which could satisfactorily predict work trip productions suitable for use in the gravity model (4) without requiring an extensive transportation study.

The characteristics selected for forecasting had to satisfy the following conditions:

1. The data used to develop independent variables should be (a) easily obtained from existing records or from simple and inexpensive surveys and (b) capable of explaining future as well as existing trip-generating characteristics. As far as possible, changes in these variables should reflect the influence of the change in the variable on trip generation rates.
2. Reliable and inexpensive methods should be available for forecasting the data used as independent variables.
3. The final trip-generating equations should be easy to use and should contain as few variables as possible, consistent with the required accuracy.

SCOPE

The research was limited to a study of home-based vehicle work trip production in urban areas of less than 200,000 population in which a comprehensive transportation study utilizing the gravity model had been recently completed. Home-based vehicle work trip productions were defined by zone of residence and included trips home to eat a meal and return to work. With the exception of one urban area where only work trip productions with internal destinations were used, the analysis included all work trip productions within the study area even if the destination of the trip was external. Since the study area was delineated to include the anticipated 1980 urbanized area, only a small percentage of the present work trip productions would be attracted to external

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areas. Therefore, it was felt that the inclusion of only internal trips would not significantly affect the study results.

Several areas contributed data on an analysis district basis. Therefore, all data were transposed to a district level for analysis.

The research was limited to simulation of existing generation patterns with no reference to future generation except that the parameters to produce independent variables would be available for future forecasting. These parameters were automobiles owned, persons, residential acreage, and number of dwelling units in each of the various analysis districts.

Discussion

Some of the recent studies in small urban areas used a gravitational concept to describe the distribution of trips between various parts or zones of an urban area (6, 7, 8). When using the gravity model, a smaller sample home interview has been found acceptable to simulate trip distribution. In the Hartford Area Traffic Survey, travel data were collected from only 0.1 percent (or 200) of the dwelling units within the survey area (9). The Southeast Area Traffic Study collected travel data from 2 percent (or 1,400) of the dwelling units within the survey area (10).

In a study to quantify the accuracy and validity of small sample calibration of a gravity model in a small urban area, survey data from Sioux Falls, S.D., which had a 1956 survey area population of 63,000, were used (6). The objectives were (a) to examine the ability of a calibrated gravity model to reproduce the trip distribution patterns in Sioux Falls, and (b) to evaluate simplified procedures of calibrating a gravity model for trip distribution in the same urban area.

To achieve their first objective, a gravity model was calibrated by purpose using the data from a comprehensive origin and destination study. The home interview portion of the comprehensive survey was conducted in a 12.5 percent sample of the nearly 20,000 dwelling units within the Sioux Falls study area. The second objective was achieved by calibrating gravity models by purpose, using only the data from the external cordon survey and various size subsamples from the original home interview survey. Simplified procedures were also used to determine production and attraction factors from detailed socioeconomic data.

The results of the first part of the study indicated that the gravity model adequately simulated trip distribution patterns for the Sioux Falls area. Furthermore, a three-purpose gravity model, home-based auto-driver work, home-based auto-driver non-work, and non-home-based auto-driver, was adequate for the simulations.

The results of the small sample calibration of a gravity model indicated that a sample of about 600 dwelling unit home interviews in combination with the standard external cordon survey provided adequate data for obtaining, by purpose, trip length frequency distributions and average trip length characteristics.

Although a small sample home interview does not yield data for determining zonal trip productions and attractions with a high degree of accuracy, the simplified techniques used in Sioux Falls were found to be satisfactory. Trip generation was based on trip rates observed in the 599 home interview sample and on the truck and taxi surveys, together with detailed socioeconomic data. Sioux Falls did not exhibit any social or economic factors which might affect travel patterns. The city is self-contained with a single center and no strong travel linkages to other urban areas. Therefore, the methods used to simulate productions and attractions in Sioux Falls may not be applicable in areas with different characteristics.

A similar study using data from Fayetteville, N.C., with a 1960 population of 68,500 persons, also indicated that a small sample home interview produced sufficient data for calibrating a three-purpose gravity model (7). The purposes were the same as those in the Sioux Falls study.

The North Carolina study also concluded that a major portion of the variation between the gravity model results and the O-D trip table was due to the prediction of production and attraction factors. The procedure used for determining productions and attractions was considerably different from the procedure used in Sioux Falls. Each zone was classified into one of three economic levels by evaluating its socioeconomic level and by using the personal judgment of persons who were familiar with the area. Classifications were low, medium, and high. The number of dwelling units and number of trips produced were obtained for each zone using the sample size being studied. The number of dwelling units and the number of trips produced were accumulated by level and the number of trips per dwelling unit was determined for each of the three levels. The number of dwelling units in each zone was then multiplied by the trip production rate for the appropriate economic level to determine total trip productions for the zone. The trips produced, by zone, were proportioned by purpose according to the percentages of trips by corresponding purpose in the origin and destination survey data. Trip attractions were developed from zonal employment and population data.

A study in Hutchinson, Kans., with a 1961 metropolitan area population of 41,000, also indicated that a small sample home interview was sufficient to develop trip length frequency distribution and average trip length for calibrating a gravity model (8). Trip generation was determined by regression analysis rather than by trip generation rates as in other studies. The results of the trip generation procedures were also comparable to the origin and destination findings. However, the equations that were developed contained as many as seven terms, thus requiring a substantial amount of data in order to use them.

Summarizing the previous research on simplified techniques for transportation planning in smaller urban areas, it was found that a home interview conducted for a small sample of the dwelling units in the area supplied sufficient data for developing travel time factors for use in the gravity model. However, the determination of accurate production and attraction factors appeared to be the key to gravity model calibration when using a small sample home interview. Yet this aspect of simplified techniques has hardly been researched at all.

In a prior study of trip generation in Lancaster, Pa., trips per auto, per person, and per dwelling unit were studied to determine which trip production rate would produce the best forecasting equation (11). The independent variables were vehicle ownership, residential density, family size, and family income. The study concluded that trips per dwelling unit was the best dependent variable and vehicle ownership and residential density were the best independent variables.

Production and attraction factors are functions of the socioeconomic and land-use characteristics of the particular geographical area being studied. These functions are not only influenced by the characteristics of the particular zone or portion of an urban area studied but also by the area-wide characteristics. If the influence of these characteristics were defined, trip generation techniques and the gravity model could simplify comprehensive planning in the smaller urban areas and reduce its cost.

PROCEDURE

To determine what, if any, simplified procedures were being used, a questionnaire was distributed to 57 highway departments and planning agencies and to 28 universities and colleges. Briefly, the results of the questionnaire and a review of the literature indicated that the most accurate work with simplified techniques involved the gravity model; details are discussed under Data Collection. The key element in the satisfactory use of the gravity model is the accurate determination of the production and attraction factors. Since the production and attraction factors are a function of socioeconomic and land use characteristics, the relationships between automobile ownership, family size, dwelling unit density, and various functions of these characteristics, and home-based vehicle work trip production per dwelling unit were studied to determine the type of relationship and number of variables needed to explain home-based vehicle work trip production per dwelling unit.

Correlation analysis and regression analysis were used to reduce the number of variables to be investigated in further phases of the research and to determine the type of function which could best define vehicle work trip generation. Finally, specific vehicle work trip production equations were developed. After determining the specific trip generation equations for each urban area, the socioeconomic and land use characteristics of each urban area were examined to evaluate the differences in the equations and to develop a single equation which could be used in any of the six areas studied, or in similar areas, to estimate home-based vehicle work trip production by analysis district.

DATA COLLECTION

Questionnaire responses came from 40 highway departments and planning agencies and 12 colleges and universities. The majority of the replies indicated that either no techniques had been applied in the smaller urban areas or that standard procedures accepted by the Bureau of Public Roads or the National Committee on Urban Transportation were used. Multiple cordon roadside interviews or combination external cordon and parking interviews were also used in several areas. Traffic forecasting and distribution was usually determined by growth factor methods such as the Fratar method. In most cases, the growth factors were based on population and vehicle ownership changes. However, replies indicated that a few states had been active in adapting the gravity model to transportation planning in their smaller urban areas.

A further request was sent to each state which indicated recent advances in the use of the gravity model. A letter of explanation along with a data request form was sent to all such states.

The data collection phase of the study was the most frustrating. Cooperation was generally good, but only a few states were able to supply the requested data. In some instances, data were received too late to be included in the analysis. In other cases, the data were incomplete or inconsistent. These inconsistencies were mainly due to the nonstandard classifications of land use and to differences in data collection procedures. Of the many prospective contributors, only six were used in the study.

Study Sites

The initial phase of the research was limited to the four urban areas of Lancaster, York, and Reading, Pa.; and Hutchinson, Kans. After limiting the number of parameters to be studied, the areas of Rock Hill, S. C., and Sheboygan, Wis., were added. Data collected from other areas were not included due to incompleteness. Survey area characteristics are given in Table 1.

The Lancaster study area included the city of Lancaster, the boroughs of East Petersburg and Millersville, Lancaster township and portions of East Lampeter, West Lampeter, Pequea, and Manor townships (12). The area included all of the 1960 urbanized area defined by the Bureau of the Census and the anticipated urbanized area of

TABLE 1

SURVEY AREA CHARACTERISTICS

Characteristic	Lancaster 1963	York 1963	Reading 1964	Hutchinson 1959	Sheboygan 1963	Rock Hill 1964
Size (sq mi)	56	98.9	50	48.6	41.9	73.5
Population	103,931	122,075	178,273	40,864	56,923	43,042
Passenger cars owned	35,705	44,501	60,665	14,760	19,486	12,729
Number of dwelling units	36,381	42,233	63,200	13,078	18,219	12,789
Residential land use (%)	16.3	16.4	15.9	14.9	11.2	9.1
Industrial land use (%)	1.8	2.1	2.6	3.9	3.2	0.5
Transportation land use (%)	7.5	5.3	2.1	11.9	8.1	5.7
Retail land use (%)	0.8	7.8	0.9	1.3	0.6	0.4
Wholesale land use (%)	1.0	NA	1.3	0.7	1.0	0.2
Service land use (%)	0.4	NA	1.3	0.2	1.8	0.2
Public land use (%)	6.4	NA	4.9	6.0	2.8	2.7
Vacant and agricultural land use (%)	65.8	NA	71.0	61.1	71.3	81.2

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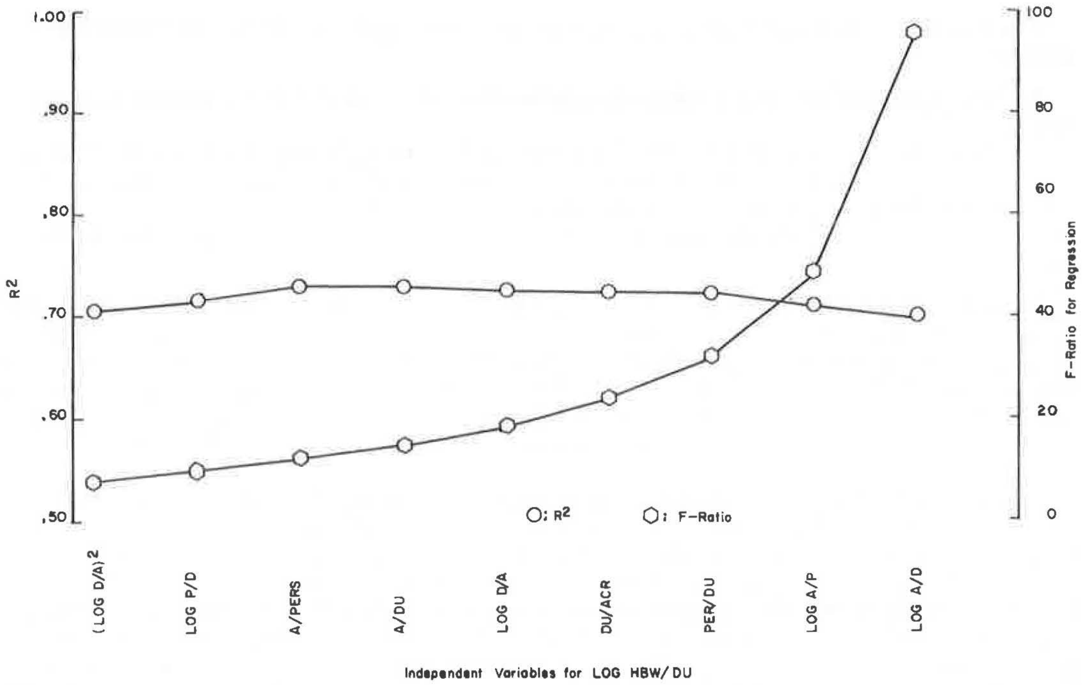

Figure 1. York coefficients of determination and F-ratios for regression on log HBW/DU.

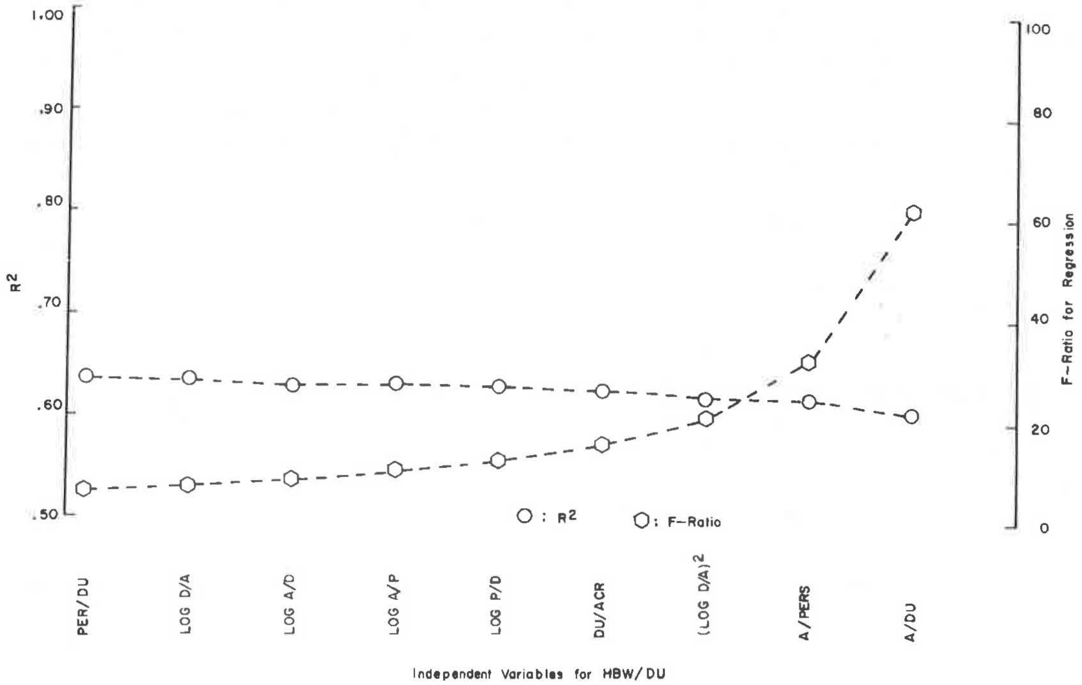

Figure 2. York coefficients of determination and F-ratios for regression on HBW/DU.

termination for each equation and the F ratio for regression. The F ratio for regression was the ratio of the regression mean square to the residual mean square and can be used as a measure of the relative significance of two equations containing the same number of independent variables and the same number of degrees of freedom. The equation with the highest F ratio is the most significant. The values of R^2 and F ratio at the left-most points (Fig. 1) indicate the values for the equation containing all nine independent variables. Reading from left to right, values of R^2 and F ratio for equations containing from 9 independent variables to 1 independent variable are shown. Figure 2 illustrates the order in which the variables were eliminated from the regression on HBW/DU for York and the appropriate values of R^2 and F ratio.

The coefficients of determination (Figs. 1 and 2) clearly indicated that the independent variables explained a higher percentage of the variation in the dependent variable

TABLE 3

YORK REGRESSION OF 5 VARIABLES ON LOG HBW/DU

Observation No.	Observed	Predicted	Deviation
1	146	171	25
2	2434	2384	-50
3	1711	1985	274
4	2493	2623	130
5	1894	1834	-60
6	1884	1616	-268
7	130	119	-11
8	2355	1932	-423
9	366	221	-145
10	3307	3414	107
11	1922	3028	1106
12	2974	3556	582
13	732	781	49
14	2528	2522	-6
15	1748	1740	-8
16	1472	1556	84
17	2587	2244	-343
18	2220	1437	-783
19	1156	752	-404
20	1089	1067	-22
21	1889	1830	-59
22	1740	2104	364
23	59	79	20
24	155	107	-48
25	1307	1330	23
26	1934	2163	229
27	1538	1600	62
28	298	367	69
29	66	86	20
30	671	645	-26
31	634	343	-291
32	2658	2619	-39
33	405	505	100
34	473	528	55
35	745	729	-16
36	317	232	-85
37	1469	1514	45
38	260	292	32
39	2020	2027	7
40	169	229	60
41	1101	1662	561
42	591	570	-21

Group	No. of Observations	Mean Trips	RMSE	% RMSE
0-100	2	62.5	20.0	32.0
100-250	4	150.0	40.8	27.2
250-500	6	353.2	88.6	25.1
500-1000	5	674.6	133.0	19.7
1000-1500	6	1265.7	285.2	22.5
1500-2000	9	1806.7	417.1	23.1
2000-2500	5	2304.4	402.9	17.5
2500-UP	5	2810.8	306.4	10.9
0-UP	42	1324.9	287.8	21.7

when the regression was on log HBW/DU than on HBW/DU. Also, the F ratios were consistently higher when using log HBW/DU as the dependent variable than when using HBW/DU as the dependent variable.

One additional comparison was made before concluding that the log function produced a better relationship than the linear function. This comparison was in the form of a root-mean-square error (18). The RMSE is similar to the standard error of estimate and is computed as follows:

$$RMSE = \sqrt{\frac{\sum_{i=o}^{N} (Y_i - YEST_i)^2}{N}}$$

where Y_i = observed trips produced in district i; $YEST_i$ = estimated trips produced in district i; and N = number of districts.

$$\text{The percent RMSE} = \frac{\text{RMSE} \times 100}{\text{average productions per district}}$$

For example, a 10 percent RMSE indicates that 68 percent of the time the estimated value is within 10 percent of the observed values.

A computer program was written to compute and list estimated values of the dependent variable; to compute the difference between observed and estimated values; to compute the mean number of trips per zone, the RMSE, and the percent RMSE by volume group; and to print the values in table form. Table 3 illustrates these values for log HBW/DU for York. In addition, the overall percent RMSE for both HBW/DU and log

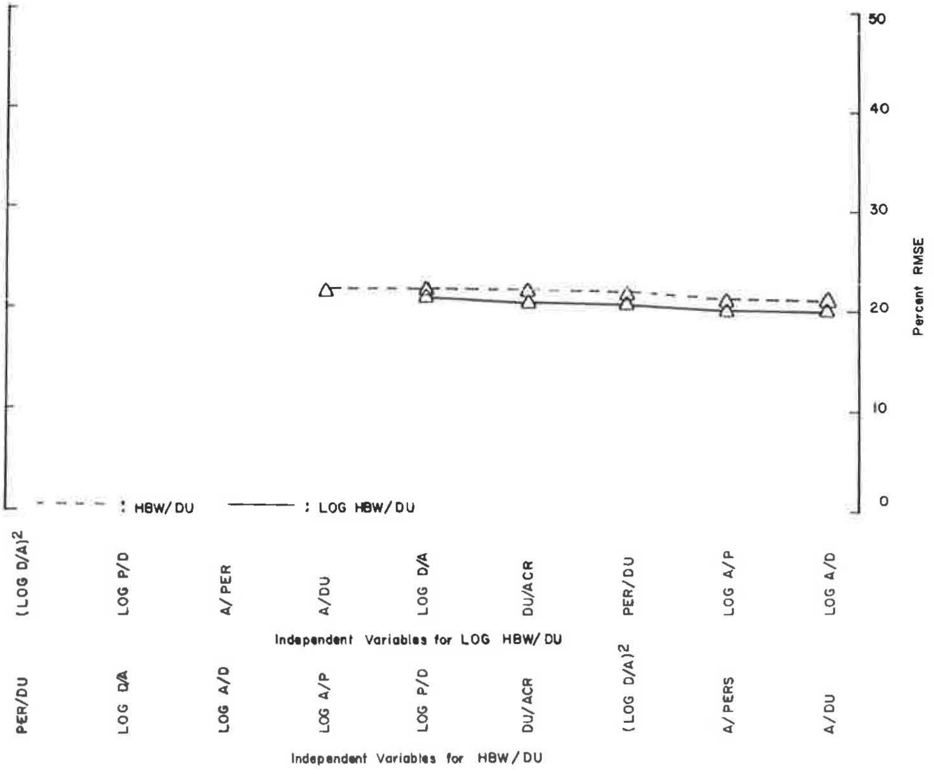

Figure 3. York percent RMSE.

HBW/DU are shown in Figure 3. For comparison purposes, a composite of Figures 1, 2, and 3 is shown in Figure 4.

Composite figures for Lancaster, Reading, and Hutchinson are shown in Figures 5, 6, and 7. The tables of observed and estimated values for the HBW/DU and the log HBW/DU functions for these areas are not given in this report.

An evaluation of tables such as Table 3 indicates that the error between estimated and observed values of trip production was less for York when the dependent variable was log HBW/DU than when it was HBW/DU. This trend was also evident in the tables for the other areas. In general, improved accuracy was noticeable as the number of observations within a volume group increased. As the number of variables in the equations decreased from 6 to 1, the log function increased in accuracy over the base function.

Figures 4 through 7 also indicate that the functions using log HBW/DU as the dependent variables are more accurate in predicting work-trip generation than are the functions using HBW/DU as the dependent variable. In general, accuracy improved as the number of independent variables was decreased from 6 to 1.

As a result of the first part of the research, it was decided that using log HBW/DU as a dependent variable produced a better relationship than did HBW/DU and all further research used log HBW/DU as the dependent variable. However, the specific independent variables which should be included in the equation were not yet determined.

A close examination of the sums of squares contributed by each variable and its correlation to other independent variables indicated that three more variables could be eliminated from all four urban areas without appreciable loss of accuracy of the prediction equation. The three independent variables, A/DU, $(\log D/A)^2$, and log P/D, were grouped and added last in a regression on log HBW/DU. The sum of squares

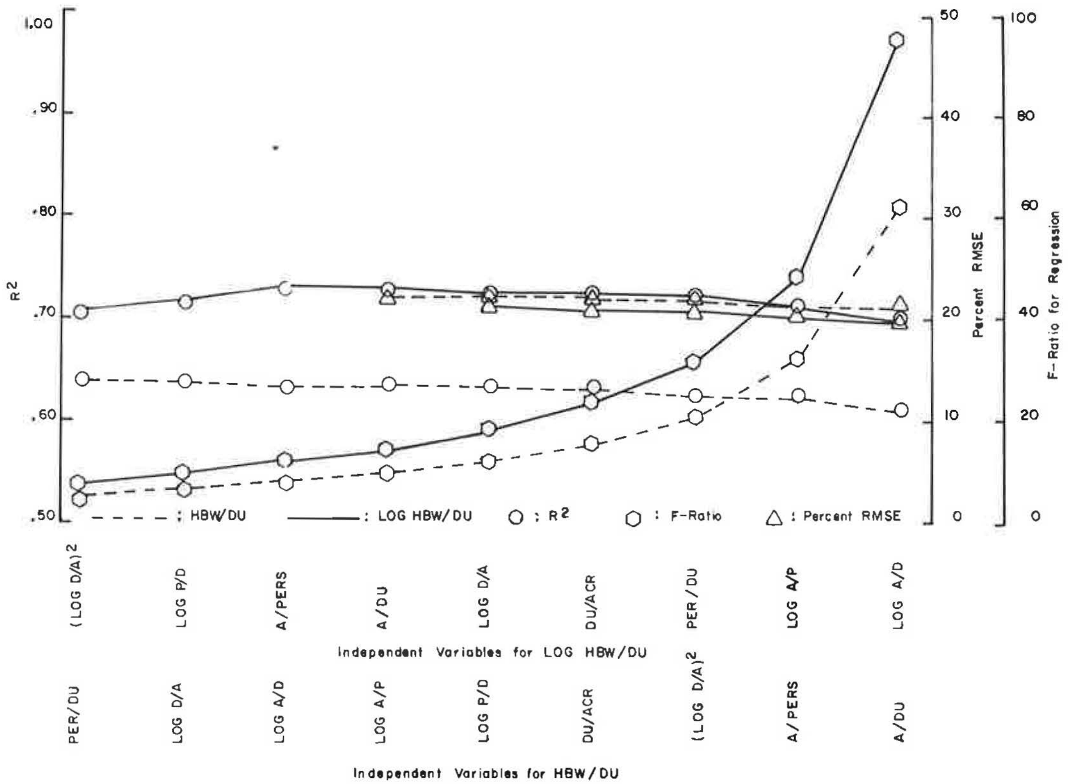

Figure 4. Comparison of York regression.

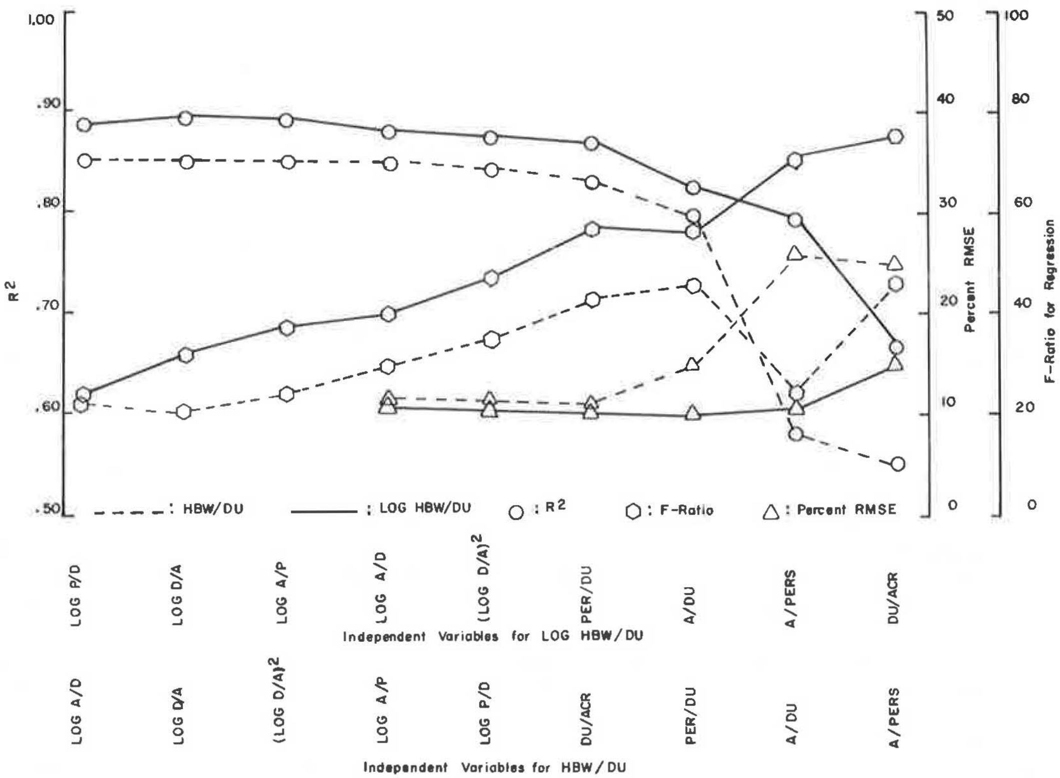

Figure 5. Comparison of Lancaster regression.

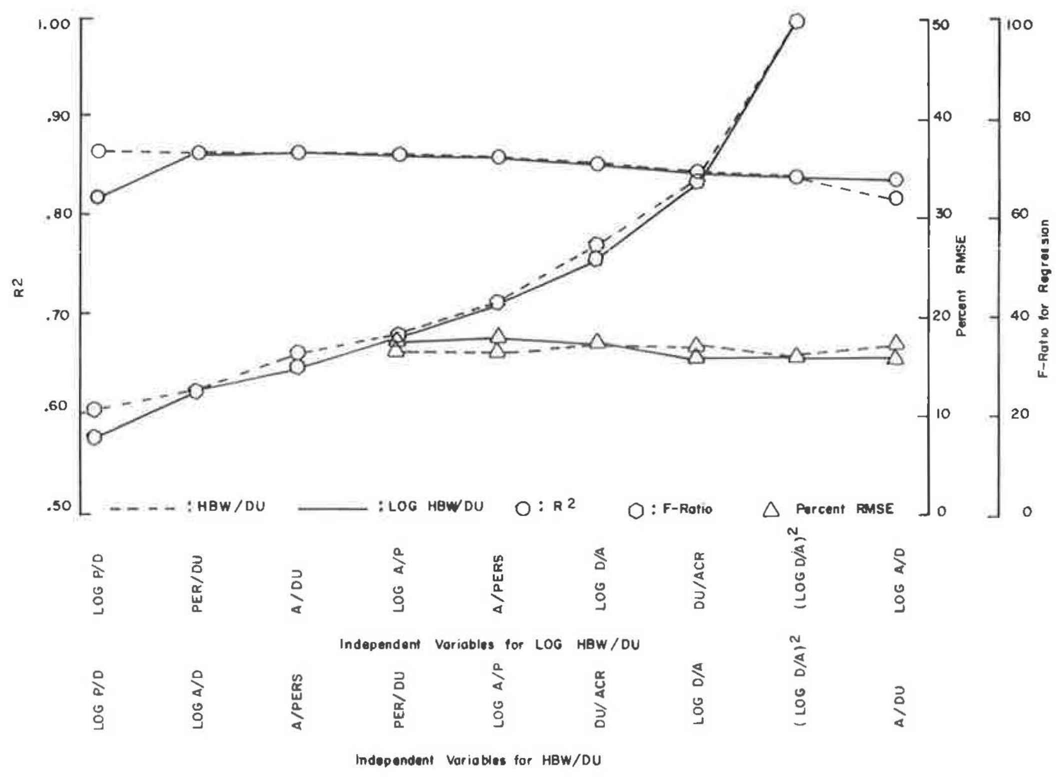

Figure 6. Comparison of [illegible]

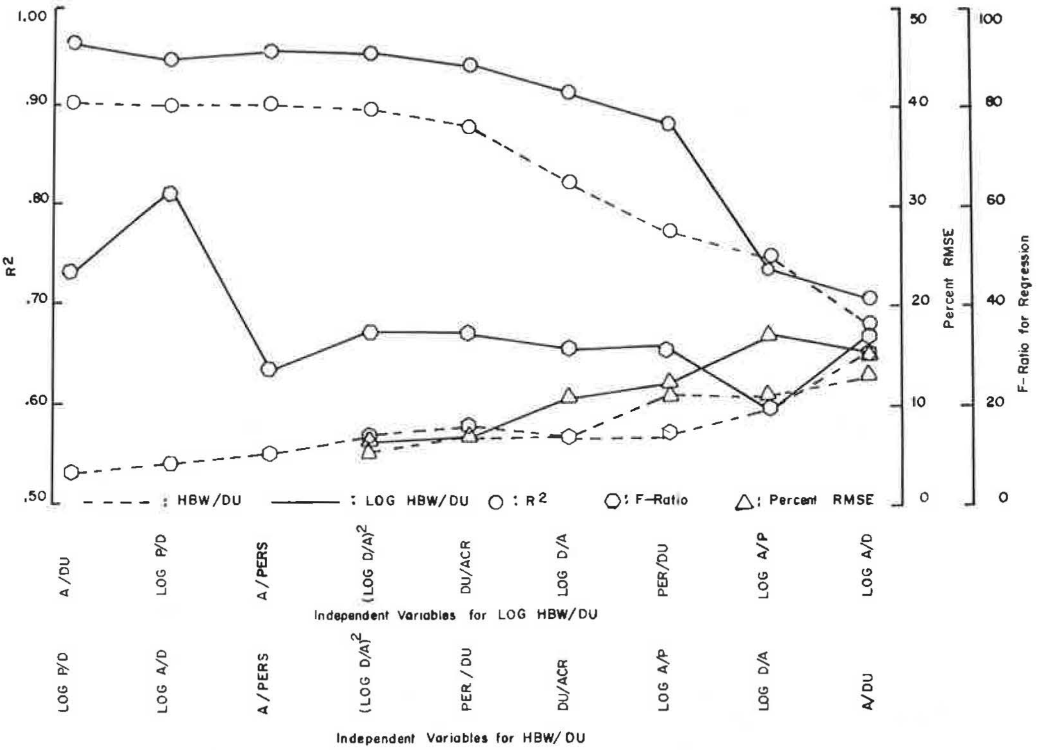

Figure 7. Comparison of Hutchinson regression.

contributed by these three variables was divided by the three degrees of freedom and this mean square tested against the residual mean square. The group of three terms was found to contribute nonsignificantly to explaining the sum of the squared deviations about the regression line and were therefore eliminated from further study.

The remaining six variables, log A/D, log A/P, log D/A, DU/ACR (dwelling units per acre), A/PERS, PER/DU, were then used as independent variables and a regression of these variables on log HBW/DU was performed. Thus far, the analysis had been concerned with the elimination of variables that were not highly significant. Of the remaining variables, some may be significant while others are not significant even though the sums of squared deviations about the regression line explained by the variables may only be slightly different. It was decided to use a regression program that was more accurate in its matrix inversion routine in order to detect these small differences. A multiple linear regression program developed by the West Virginia University Computer Center was selected for the remainder of the research (19).

The same procedure for eliminating variables was utilized for this part of the research. As before, only one variable was eliminated at a time, this being the one which contributed least to explaining the sums of squared deviations about the regression line, without regard to significance, when considered last in the regression process. Data from the urban areas of Sheboygan, Wisconsin, and Rock Hill, South Carolina, were also included in this phase of the research. Correlation matrices for these areas are given in Table 4.

The correlations shown in Table 4 indicate that vehicle ownership is also the most important independent variable in defining work trip generation in the Sheboygan and Rock Hill urban areas. As in the other areas, log A/D was the most significant variable in explaining the variation within the dependent variable.

To determine which of the evaluated terms were significant in the equations, lack of fit was investigated in each area. A stepwise regression was used, using grouped data,

TABLE 4

CORRELATION MATRICES

Item	Log A/D	A/PERS	DU/ACR	PER/DU	Log D/A	Log A/P	Log W/D
			Sheboygan				
Log A/D	1.0000	.7979	-.8292	.7261	-.8148	.8657	.7634
A/PERS		1.0000	-.5404	.2140	-.4893	.9772	.6242
DU/ACR			1.0000	-.6410	.7823	-.6444	-.7431
PER/DU				1.0000	-.8341	.2959	.4747
Log D/A					1.0000	-.5392	-.5686
Log A/P						1.0000	.6809
Log W/D							
			Rock Hill				
Log A/D	1.0000	.8789	-.6983	-.0996	-.6546	.8943	.9522
A/PERS		1.0000	-.3991	-.5141	-.4147	.9819	.8397
DU/ACR			1.0000	-.3750	.9638	-.4135	-.6638
PER/DU				1.0000	-.2666	-.5312	-.0734
Log D/A					1.0000	-.4261	-.6277
Log A/P						1.000	.8430
Log W/D							1.0000

until no significant lack of fit existed. The first term entered into the equation was the last term remaining in the tear-down process. In all areas except Lancaster, this term was log A/D. Additional terms were to be added until an equation with insignificant lack of fit was developed.

A study of the sums of squares explained by each variable in Lancaster indicated that little accuracy would have been lost by forcing log A/D to remain in the equation instead of DU/ACR. Therefore, the variable entered first in the stepwise process was log A/D in all study areas.

It was decided to use a class interval of one-tenth of an auto per dwelling unit to test for lack of fit when computing the regression of log A/D on log HBW/DU. All observations of the independent variable falling within the class interval were assigned the value of the midpoint of the class interval. The maximum error in grouping was therefore limited to one-twentieth of an auto per dwelling unit.

The linear relationship developed from the grouped data had to meet three conditions before it could be said to be the same relationship as that existing in the ungrouped data: The sample slopes of both relationships had to be estimated of the same true slope of the population of which the groups were samples; the regression fitted to the means of the two sets of data had to be linear; and, assuming that the regression fitted to the means was linear and that the sample slopes were estimates of the same true slope, the true pooled within-sets regression coefficient had to equal the true regression coefficient for the means.

The procedure presented by Ostle (16) was used to test the above conditions for each of the six urban areas. The results of the tests indicated that the equation produced from the original data and the equation produced by the grouped data were representative of the same population. The curves for each urban area are shown in Figure 8. The equations developed from grouped data in each urban area are given in Table 5 along with their multiple correlation coefficients and computed and tabulated F ratios.

The results of the regression with grouped data showed that no significant lack of fit existed for a regression of log A/D on log HBW/DU in five of the six urban areas studied. The urban area of Hutchinson did show a significant lack of fit when all analysis districts were considered. However, after eliminating the central business district from the regression analysis, the equation developed showed no significant lack of fit. The reasons for this variation in the central business district were not apparent from

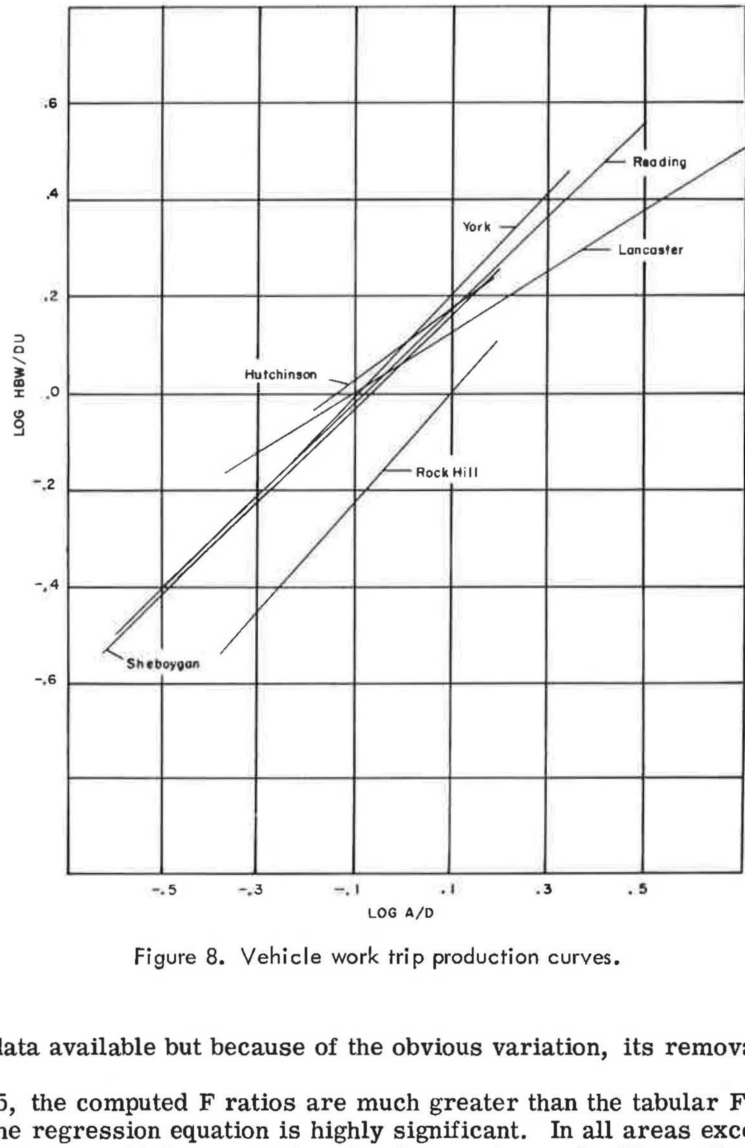

Figure 8. Vehicle work trip production curves.

the limited data available but because of the obvious variation, its removal was felt to be justified.

In Table 5, the computed F ratios are much greater than the tabular F ratios, indicating that the regression equation is highly significant. In all areas except Rock Hill, the Y-intercept at a vehicle ownership rate of one auto per dwelling unit was about 1.25 vehicle work trips per automobile owned. For Rock Hill, the trip production rate for dwelling units having one auto was less than one vehicle work trip per auto owned. The slopes of the linear relationships produced in York, Reading, Sheboygan, and Rock Hill

TABLE 5

VEHICLE WORK TRIP GENERATION EQUATIONS WITH NONSIGNIFICANT LACK OF FIT

Area	Equation	R	Computed F	Tabular F
Reading	Log HBW/DU = .9642 Log A/D + .0745	.91	204.60	4.26
Rock Hill	Log HBW/DU = 1.1408 Log A/D - .1105	.95	238.23	4.35
York	Log HBW/DU = 1.0503 Log A/D + .1028	.83	104.28	4.17
Sheboygan	Log HBW/DU = .9626 Log A/D + .0652	.75	46.67	4.26
Lancaster	Log HBW/DU = .6213 Log A/D + .0650	.84	85.99	4.35
Hutchinson	Log HBW/DU = .7029 Log A/D + .1047	.70	20.39	5.32

were quite similar. The Hutchinson and Lancaster curves also had similar slopes. In addition, the curves developed from the Sheboygan and Reading data had similar intercepts.

The procedure used to investigate the reasons for these variations in slopes and intercepts was similar to that used in previous parts of the research. The effect of the areawide socioeconomic and land use characteristics such as population density, residential density, average family size, vehicle ownership rates, and percentages of the land in various land uses were examined to determine which factors could explain the variations and similarities between urban areas. The six areas were chosen to represent samples of each of these areawide characteristics.

The following equation was developed using the data from the six urban areas:

$$\log HBW/DU = 0.92339 \log A/D + 0.00126\ P/mi^2 - 0.00350\ D/mi^2 + 0.09600\%\ Res - 1.66327$$

where

log HBW/DU = $\log_{10}$ of daily home-based vehicle work trips per dwelling unit produced per zone;

log A/D = $\log_{10}$ automobiles owned per dwelling unit within the zone;

P/mi^2 = total study area population divided by total square miles of developed land within the study area;

D/mi^2 = total dwelling units within the study area divided by total square miles of developed land within the study area; and

%Res = percent of developed area in residential land use.

The above equation had nonsignificant lack of fit at the 0.05 level. The correlation coefficient for this equation was .86768 and the F ratio for regression was 173.0508. This F ratio for regression was developed by dividing the mean square for regression by the mean square for experimental error. The experimental error was developed using the same groupings previously explained. The additional areawide characteristics did not affect the power of the test.

To compare the estimated values of trip generation with the observed value, tables of predicted and observed values, their difference and percent RMSE were computed.

Comparison of these tables and the tables produced from the other equations developed indicate that the equation developed for the overall trip generation pattern yields trip generation values that compare favorably with those estimated by the individual equation developed for each area and with the values observed in the origin and destination studies.

Research by Sosslau and Brokke (20) has developed the following equation for determining the proper sample rate to achieve a predetermined degree of accuracy in sample selection:

$$\text{DU sample rate } (\%) = \left[\frac{1,624}{(\%\ \text{RMSE})\ (\text{Volume } 0.4884)}\right]^2$$

If the sample rate is known, the percent RMSE can be computed for a given volume of district-to-district movements. Since trip productions are nondirectional, this equation can be used to determine the percent RMSE in trip production estimated developed from a given sample size origin and destination home interview survey.

Figures 9 through 14 compare the O-D vehicle work trip productions and the estimated vehicle work trip productions determined from the overall generation equation. They also show the expected error in the origin and destination productions for the sample sizes used in gathering the home interview data. A high percentage of the estimated values of vehicle work trip production fall within the expected accuracy of the values of trip production developed from the origin and destination study. Also, the estimated values are more accurate for the Rock Hill, Sheboygan, and Hutchinson studies, which used a higher percent home interview sample. The zones with the largest error were also the zones that were not estimated accurately even when nine variables were used in the estimating equation.

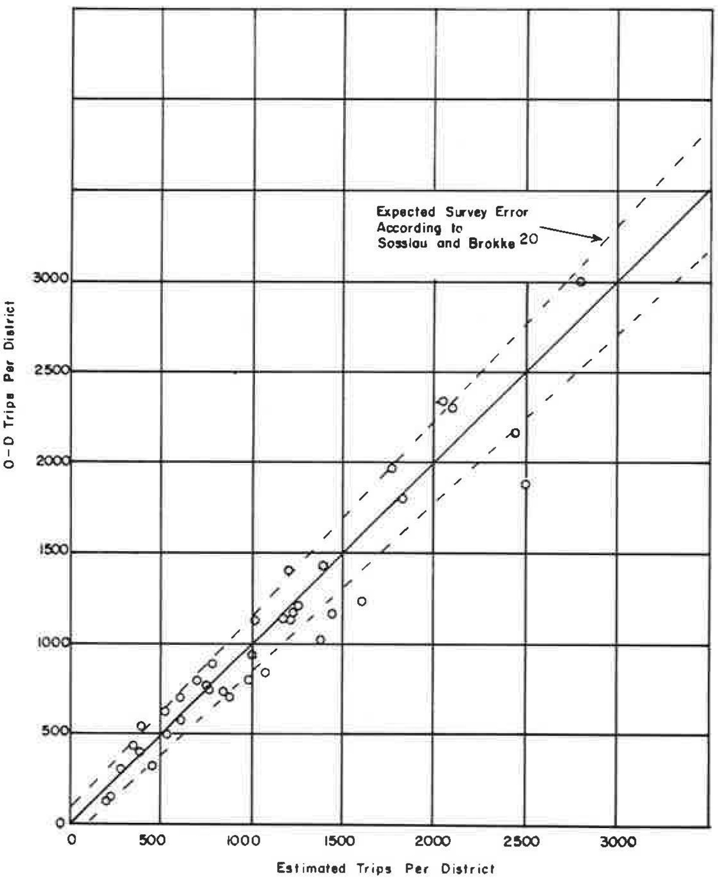

Figure 9. Comparison of Lancaster trip productions.

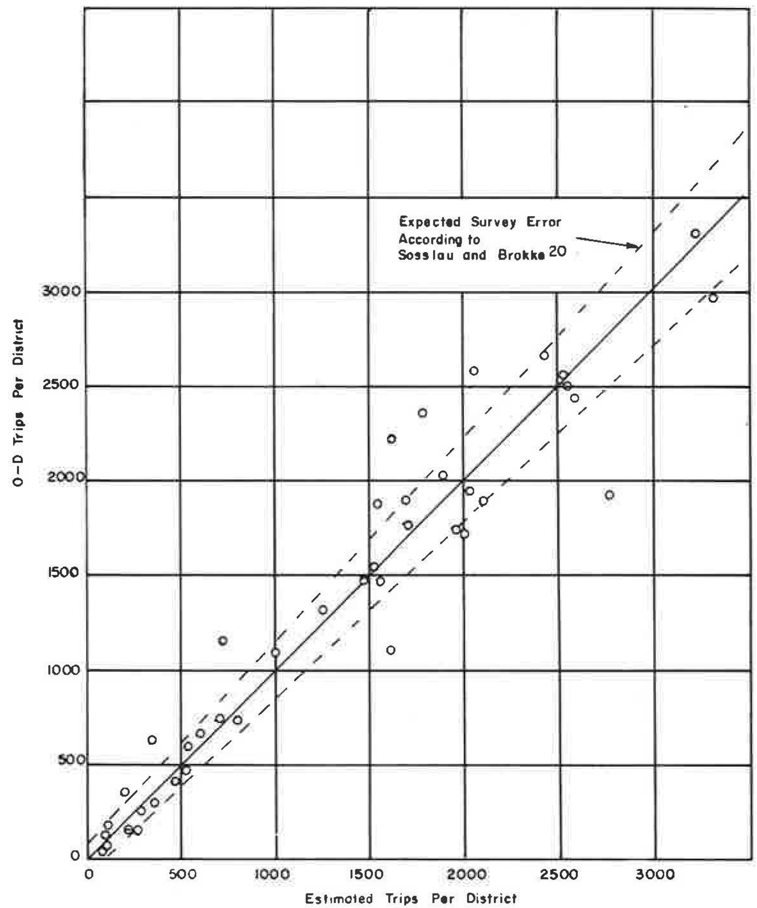

Figure 10. Comparison of York trip productions.

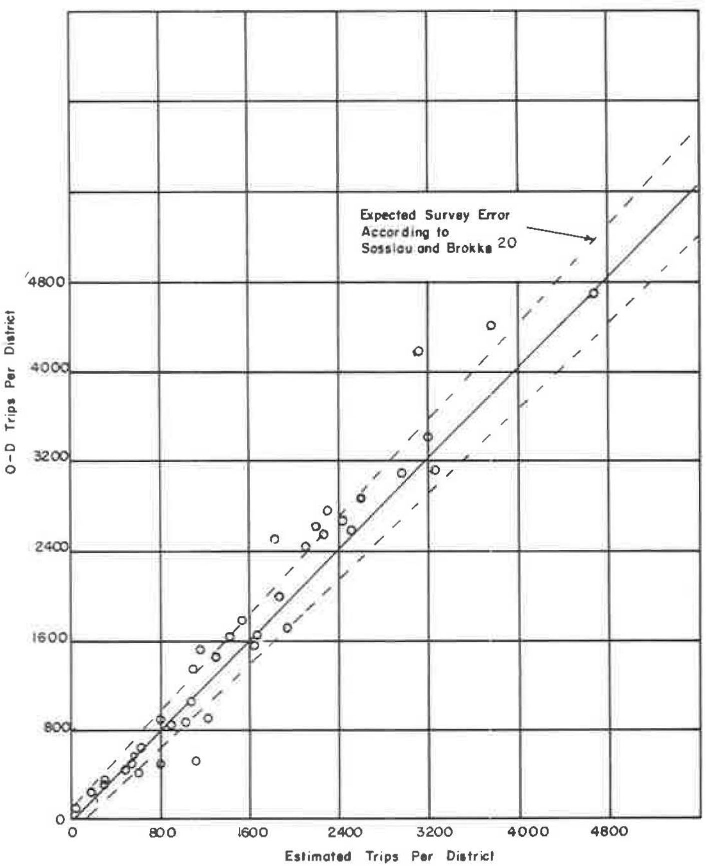

Figure 11. Comparison of Reading trip productions.

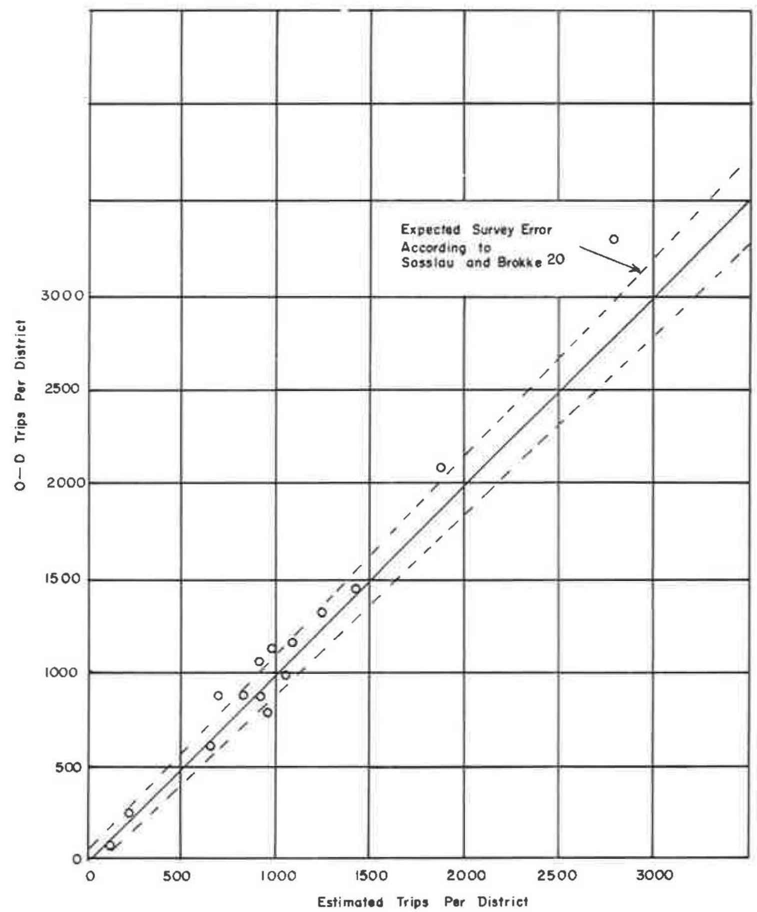

Figure 12. Comparison of Hutchinson trip productions.

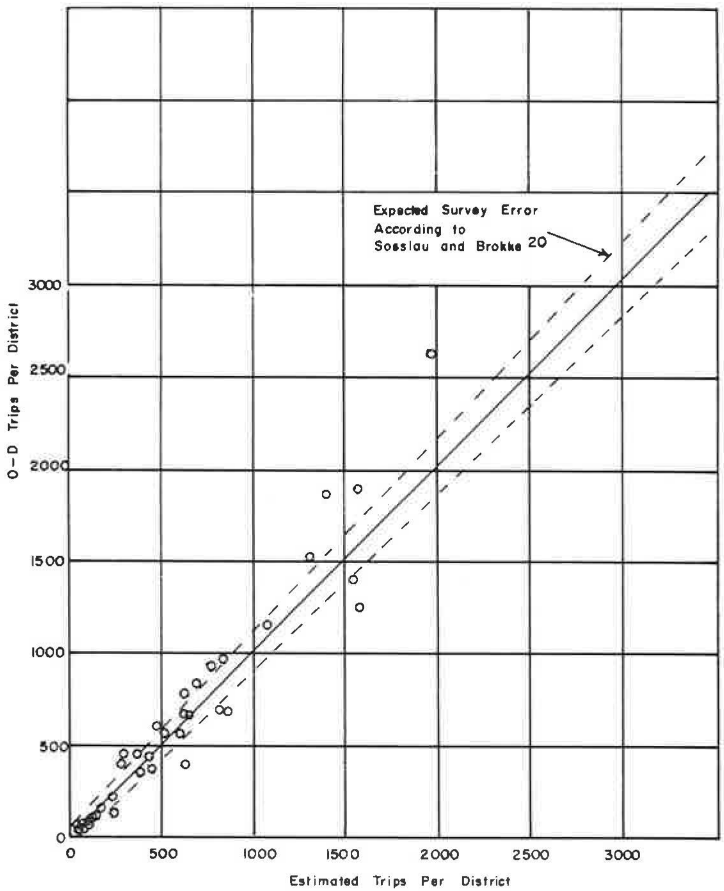

Figure 13. Comparison of Sheboygan trip productions.

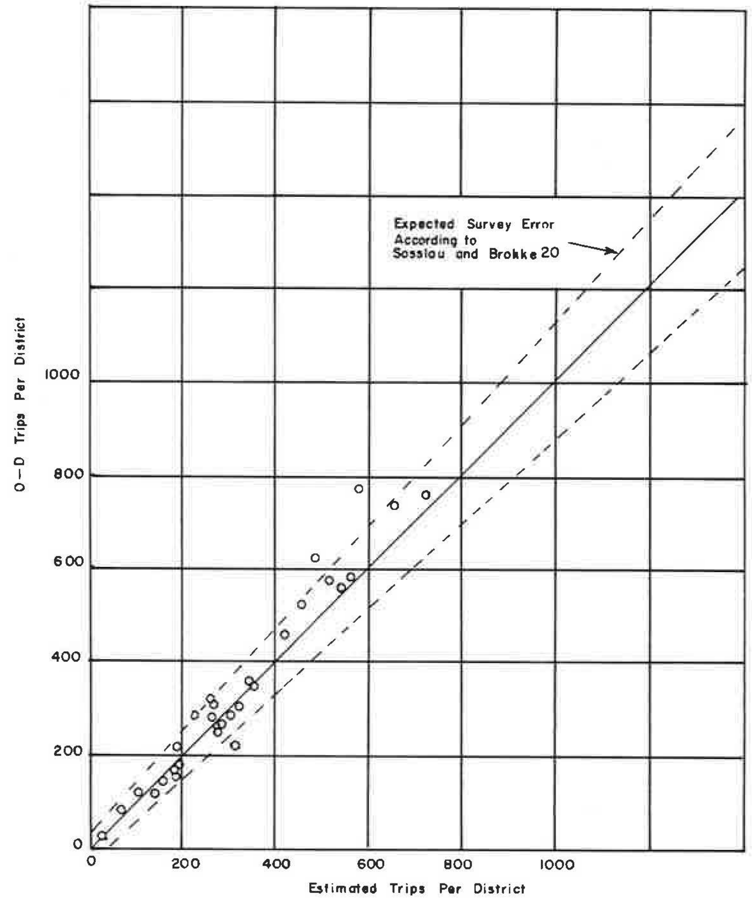

Figure 14. Comparison of Rock Hill trip productions.

CONCLUSIONS

Land-use activity and intensity, employment and financial status, family size, and other socioeconomic and land use variables are important factors in determining vehicle work trip generation. However, the purpose was to investigate simplified and less expensive methods for developing transportation plans in the smaller urban areas. Considering the accuracy obtained while reducing the cost of data collection and analysis, results of this research are encouraging. The major conclusions are as follows:

1. The best indicator of vehicle work trip production was vehicle ownership, and the linear functions developed between log HBW/DU and log A/D satisfactorily explained the relationship.
2. There was a nonsignificant lack of fit in the relationships developed between log HBW/DU and log A/D. The variation of trip generation rates for a given vehicle ownership rate can be statistically attributed to experimental error. This experimental error was due to errors in experimentation, in observation, and in measurement; and the combined effects of factors not specifically measured or analyzed in the research.
3. The district values of vehicle work trip productions predicted by the single equation developed for all six urban areas compared favorably with the district values of vehicle work trip productions observed in the origin and destination studies.
4. The variation in vehicle work trip production patterns among the six urban areas studied was a function of overall population density, overall dwelling unit density, and percentage of land in residential land use. The relationship developed had a nonsignificant lack of fit at the .05 level.
5. The correlation coefficients and the regression analysis have indicated that the other factors which affect trip generation are reflected in vehicle ownership patterns.
6. It is feasible to develop an equation to predict vehicle work trip production in smaller urban areas without conducting an extensive origin and destination study. These values are sufficiently accurate for planning purposes.

RECOMMENDATIONS

Due to data collection errors and inconsistencies in data collection and summarization procedures, the research was restricted to vehicle work trip productions at the analysis district level. The relationships developed at the district level may be the same as those which exist at the zonal level. However, this is not likely since certain characteristics may have been collected with increased accuracy at the district level. At the zonal level, sampling error also becomes a greater influence. Certain characteristics which appear consistently throughout all zones will therefore be collected with more accuracy than characteristics which appear in a nonuniform pattern. If large, these variations between zone and district values will cause variation in correlation coefficients from zone to district levels, thereby changing the results of a regression analysis. Also the neighborhood characteristics are reflected in district values but not in zonal values. Since production and attraction factors must be predicted at the zonal level for zonal distribution and traffic assignment, it is recommended that this research be extended to the zonal level. Also, more urban areas should be included in the research and other purposes should be investigated both for trip production and trip attraction.

The characteristics being considered as independent variables should also be extended to include factors such as the economic, occupational, and social status of the trip-maker. People of different age groups, different employment status, etc., reflect these factors in their travel habits. Although the effect of these factors is reflected to some degree in vehicle ownership, research is recommended to define and quantify these effects.

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Rank Classification: A Procedure for Determining Future Trip Ends

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This paper describes a procedure for forecasting future trip productions and attractions by traffic analysis zones. Traffic analysis zones having characteristics related to trip production and trip attraction were grouped together. A trip generation rate was determined from base year data for each grouping of zones. The generation rate for a group having like characteristics was assumed to hold true for the forecast year. However, changes in the forecast of variables related to trip production and trip attraction can shift a particular zone from its original grouping or cell to another higher or lower trip generation rate group.

•THIS paper outlines a procedure for forecasting person trip productions and attractions by Traffic Analysis Zone (TAZ). The procedure (1) was originally developed at the Puget Sound Regional Transportation Study (PSRTS). It was applied in a rather gross manner by Clark, Coleman, and Rupecks in Missoula, Montana, but the results were not documented. It has been used to compare results with a regression procedure forecast of person trips originally developed for the Albuquerque Transportation Study (2), completed in 1964.

Since September 1966 a continuing comprehensive and cooperative transportation planning program has been under way, directed by the Albuquerque Metropolitan Transportation Planning Department (MTP). The research described in this paper is part of the MTP program.

Although the procedure referred to as "rank classification" was originally developed to forecast total person trips, it has been used to derive vehicle trip productions and attractions in the same manner as for total person trips. PSRTS in 1966 developed an intermediate vehicle forecast for the year 1975 by developing vehicle trip generation rates, rather than total person trip generation rates. The same general procedure was also used at PSRTS to develop transit trip attraction generation rates. The author has no knowledge that it has ever been used to determine transit trip productions.

Several alternative procedures are available for forecasting trips. Regression procedures, as well as land use rates have been used to develop forecast of trips by TAZ. The "Direct Assignment Program," developed at Tri-State, may eliminate the need to segmentalize forecasting as a separate step in planning process. However, regardless of the procedure one selects, they all require some special "hand adjustment" and can reveal serious limitations for any given study area.

For example, one comparison carried out by the MTP revealed less than a 2 percent difference in study area total person trip productions forecasted between the regression and rank classification procedures. However, statistically significant differences of two and three standard deviations were reported at the TAZ level.

FORECASTING PERSON TRIP PRODUCTIONS

For the purpose of the gravity-type trip distribution model, trip ends are treated as trip "productions" or "attractions." Trips are considered to be "produced" at the home

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(whether the home is the origin or destination) and the home is the production end of the trip (such trips are termed "home-based"). The non-home end of a trip is the "attraction" end.

Seven factors which have been found to be related to person trip productions in a nationwide survey by the Bureau of Public Roads (3) are ranked below in order of their relative importance:

Rank	Variable	Beta Coefficients
1	Family size (linear)	.29
2	Car ownership (linear)	.23
3	Income	.14
4	Stage in the family cycle	.13
5	Occupation	.11
6	Density of the neighborhood	.10
7	Distance from the CBD	(insignificant)

Other studies (4, 5, 6) have shown similar relationships, but not necessarily of the same magnitude, which in large part can be explained by the unique area variances, sample bias, and the use of different statistical measures of relationships. However, the fact remains that household size, automobiles owned, and income are most often included as relevant variables to forecast trip generation from the home.

At PSRTS, the following household and environmental characteristics (independent variables) were used to determine the proper grouping of zones for trip production purposes: household characteristics—average automobiles per household, average household size, and median income of household head; environmental characteristics—population per net residential acre, and population per gross acre.

The trip generation rates for home-based person trip productions are expressed in terms of average trips per household by trip purpose. These rates may differ materially from zone to zone, depending on the characteristics of the analysis zone. Analysis zones having similar household and environmental characteristics were grouped, and an average household trip generation rate was calculated for the particular grouping of zones. Each internal analysis zone that had data for more than 25 samples at PSRTS was assigned a ranking (from low to high) on average trips per household. (Detail examination of the variation in the household variables, as well as the average trips per household for zones of small samples could be explained only by sampling variation. These zones were assigned to cell groups by a separate procedure.)

The first step in trip generation rate analysis, regardless of the procedure used, is to select the independent variables to be used in forecasting the dependent variable, in this case, trip productions from the home. The analyst-researcher is usually restricted in the selection of independent variables to those gathered in the initial survey and coded to traffic analysis zones. Variables collected in the home interview survey and found to be related to trip-making must themselves be forecasted before a forecast of trips can be obtained. (In this case, the prudent researcher selects a minimum number of strongly-related variables, rather than a maximum number.)

Next, guided by previous research findings, examination is made of the data at the study area level to see if those variables found to be important determinants of trip generation are relevant to the particular area under study. In the case of trip production from the home, the researcher focuses on the characteristics of the household. The rationale for such an approach is simply that households with different household and environmental characteristics have different travel patterns, different need for travel, and different need for the consumption and utilization of land. For example, the childless married couple living in an apartment on the fringe of downtown, with both persons employed generates quite different amounts and patterns of travel compared to the suburban couple with three school-age children, with only the father employed but the mother active in the local PTA.

It is not only the locational or environmental aspects of the household and the number of members in the household that generate different transportation and land-use needs, but also other factors, such as how the members of the household live. We can never precisely incorporate "style of life" into an explanatory model of trip generation behavior. Nor do we need to, for we can make use of such outward manifestations of this as household size, automobiles owned per household, income levels of the household, and density of the area in which the household is located. In fact, research has revealed these variables to be important determinants of trip generation from the home.

Selecting Household Characteristics

MTP decided to explore the validity of using the "rank classification" procedure, as developed at PSRTS, for forecasting trip productions from the home for the MTP area, since the resultant data could lend itself to more manageable traffic analytical capability. As a first step, a detail analysis of total study area data was made to see if the independent variables identified as significantly related to trip production from the home were also relevant for the MTP area.

Since the original procedure was developed using data from PSRTS, a comparison was made between the equivalent MTP data and the PSRTS data. Figure 1 shows the relationship between average trips per household, by number of persons in the household and number of automobiles owned by the household. The similarity between the two areas was encouraging, so it was decided to pursue further the rank classification analysis for determining trip productions from the home for the MTP area.

Figures 2, 3, and 4 show the relationships of number of persons in the household, number of automobiles per household, and family income of household to the average person trip per household.

For the MTP total study area, at least, each of the household characteristics (the independent variables) shows strong relationships to total trip production from the home (the dependent variable). However, this analysis tells us very little about the possible variance which might occur at the analysis zone level.

Variance of Household Characteristics and Trip Production

In order to examine the variance of household characteristics and trip production at the TAZ level, a nonparametric statistic, Spearman's rank correlation coefficient rho, was selected and is expressed as:

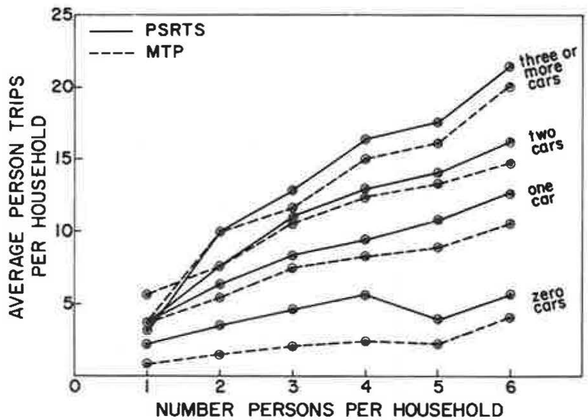
$$\text{Rho} = 1 - \frac{6\,d^2}{N(N^2-1)}$$

The rank correlation coefficient makes no assumptions about the universe from which the sample is taken and is, therefore, referred to as "nonparametric" or "distribution-free." This frees the researcher from the stringent restricting assumptions which the linear regression statistic demands.

The traffic analysis zones were ranked from lowest to highest on the control variable, average trips per household. Thus, a zone ranked 10 on average trips per household might have a rank of 20 on average household size, and a rank of 15 on average automobiles per household. In this manner, each of the independent variable rankings by TAZ is compared to the dependent variable separately, and the rank differences squared are computed and summed over all observations.

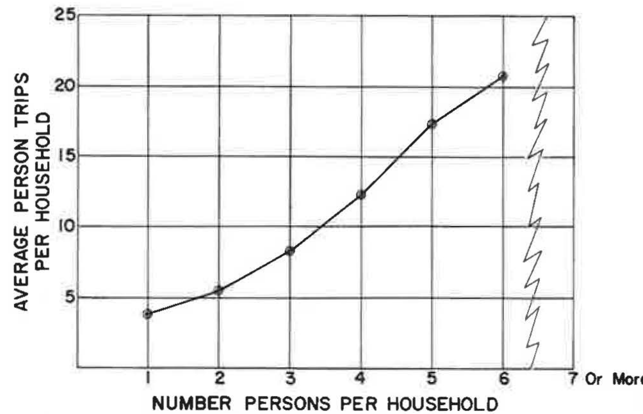
The following table shows the rank correlation coefficient (rho) derived from this analysis. Only zones having more than 10 samples were used in this analysis.

Household Characteristics	No. of Zones	Sum of d^2	Rho
Aver. autos per household	98	41,908.25	.73
Aver. household size	98	69,365.50	.56
Income class	98	91,271.75	.42



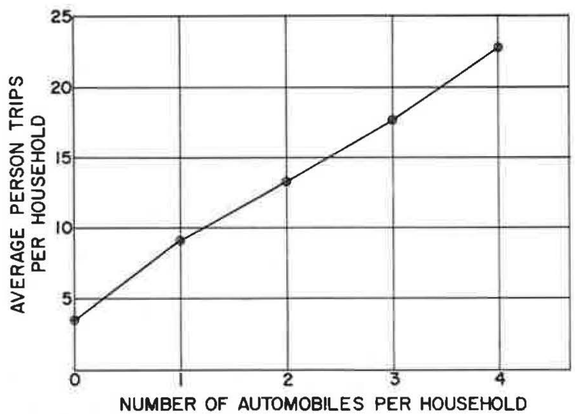
Source: Puget Sound Regional Transportation Study (PSRTS)
Metropolitan Transportation Planning Department (MTP)

Figure 1. Average person trips per household by persons in household and number of automobiles per household.



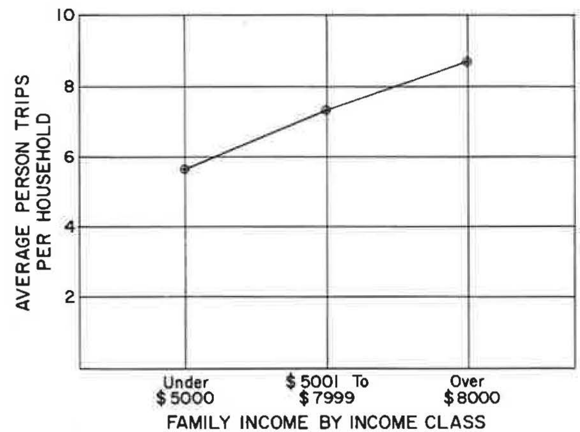
Source: Metropolitan Transportation Planning Department (MTP)

Figure 2. Average person trips per household by number of persons per household.



Source: Metropolitan Transportation Planning Department (MTP)

Figure 3. Average person trips per household by number of automobiles per household.



Source: Metropolitan Transportation Planning Department (MTP)

Figure 4. Average person trips per household by income class.

The two plots of average household size and average automobiles per household against average trips per household for the study area data showed a rather straight line relationship. Also, in the nationwide survey by the Bureau of Public Roads (3), a linear relationship was noted to exist for these two variables. Thus, the following least-squares regression analysis was performed to determine how strong this relationship was when using zonal data:

Variables	Coefficient of Correlation (r)	Coefficient of Determination (r^2)
X_1 = Aver. autos per household	.93	.86
X_2 = Aver. household size	.78	.61

In general, the results of the examination of the relationship of household characteristics to trip production from the home for the MTP data look promising and agree with previous findings.

Selecting Environmental Characteristics

Density of development has often been shown by research to be inversely related to trip generation from the home. As density increases, person trips per household decline because of smaller household sizes, fewer automobiles, lower incomes, and opportunity to make more walking trips. As in the household characteristics analysis, the relationship of zonal density of occupied household units (HU's) to total trip production was examined using the rank correlation coefficient (rho). The following table was derived from this analysis:

Environment Characteristics	No. of Zones	Sum of d^2	Rho
Occupied HU's per residential acre	98	101,245.50	.42
Occupied HU's per gross acre	98	134,559.50	.14

The density relationship for the MTP area appears not to be strongly related to trip production from the home. This is not surprising, since in 1962, when the basic data were gathered, this area was basically a single-family residential area. The high-rise and multiple-unit residential structures existing in 1967 were built since 1963. Even so, less than 7 percent of all housing units in 1967 are in structures containing 10 or more housing units. Considering the unique density of this area, the rank classification procedure, as developed for the PSRTS area, was modified for the MTP study area.

Furthermore, in trying to apply the same procedure to MTP 1962 data as was applied to the PSRTS data, it became apparent that for certain zones the total person trip production rate seemed too high when one examined the various household and density variables. Checking census data, reviewing land-use data, and making field trips to inspect these zones revealed them to be of high family size, medium-to-low car ownership, and low family income—they might be termed "economically depressed."

Also, in other zones where the family income was high, automobile ownership was medium-to-high, and average household size was medium-to-low, average trips per household appeared to be too low. Thus, it was reasoned that for the MTP area, income might be substituted in the rank classification matrix analysis in place of the density variable. This analysis is now being explored further by the MTP research staff.

HOUSE-HOLD CHARAC-TERISTICS	ENVIRONMENTAL CHARACTERISTICS		
	Low	*Medium*	*High*
Low-Low	(1)*	(2)	(3)
High-Low	(4)	(5)	(6)
Low-Medium	(7)	(8)	(9)
High-Medium	(10)	(11)	(12)
Low-High	(13)	(14)	(15)
High-High	(16)	(17)	(18)

(CELL NUMBER)*

Source: Puget Sound Regional Transportation Study (PSRTS)

Figure 5. Rank classification matrix.

HOUSE-HOLD CHARAC-TERISTICS	ENVIRONMENTAL CHARACTERISTICS		
	Low	*Medium*	*High*
Low-Low	—	2.88	3.19
High-Low	5.51	6.03	5.29
Low-Medium	7.57	6.94	6.26
High-Medium	7.96	7.53	6.84
Low-High	8.47	8.38	7.79
High-High	9.08	9.54	—

Source: Puget Sound Regional Transportation Study (PSRTS)

Figure 6. Rank classification matrix, average person trips per household.

The Rank Classification Matrix

The rank classification matrix developed at PSRTS (Fig. 5) will be discussed only as an example of the rank classification matrix approach. An 18-cell matrix is shown combining household characteristics with environmental or density characteristics. The cells are numbered from 1 to 18, beginning in the upper left-hand corner. There are three cells on each horizontal line; for example, cells 4, 5, and 6 contain zones which have like household characteristics and differ only in density. Proceeding from left to right, the density of the zones goes from low to high. In addition, going downward from cell 1 to 16 within the same density classification, averages of the household characteristics associated with trip generation from the home increase.

Figure 6 shows the PSRTS average person trips per household by each cell number. No zones were classified in cells 1 or 18. In general, as density increases, trips decline; while trips increase as household size, automobiles per household, and income increases.

Determining Changes in Cell Group for Forecast Year

The rates for the cell number (Fig. 6) were developed from the 1961 PSRTS survey data. They were used to determine forecast of trip productions from the home for the forecast year. Whether or not a zone changes to a different cell number between the base year and the forecast year depends upon the amount of change in the household and density variables.

Change in Density Classification—The frequency distribution of the 1961 ranks for density were collapsed into three frequency intervals representing density groups as low (0-249 rank intervals), medium (250-449), and high (450-600). The forecasts of population per gross acre and population per net residential acre were assigned ranks using the 1961 rankings. For example, if a zone in the forecast year registered an increase in gross or net population density over 1961, it would be assigned a new rank, the rank assigned such a density in the 1961 table. The 1961 rank was determined by averaging the ranking of population per gross acre and population per net residential acre. However, it was reasoned in determining the forecast year density rank that a change in population per gross acre was of more significance for trip production than a change in the population per net residential acre. Therefore, it was given a weight twice that of the latter rank.

After the forecasted weighted density rank was determined, the zone was classified as being in one of the three density columns of the matrix on the basis of rank intervals (Fig. 5). In cases where zones were on the borderline between density intervals, they were placed according to the geographical density continuity of neighboring zones. Fewer than 15 zones (out of a total of 662) were involved in decisions of this kind (7). A density shift of a zone in the matrix for the forecast year is a horizontal shift and it occurs before a vertical shift, which is based on changes in the forecasted household characteristic variables.

Change in the Household Characteristics Classification—For each cell in the matrix the base year average household size, average automobiles per household, and median income of head of household was known. Also known was the range, the average, and the mode for each of the household characteristic variables within the cell. After the zonal forecast of the household characteristic variables had been completed, each zone was individually examined to see if it should remain in the same cell or be transferred to another cell because of forecasted change in the household characteristics of the zone.

Before a zone was permitted a vertical change in cell-group number because of changes in forecasted household charactertistics, the average household characteristics of two of the three household variables must be equal to the average for the cell to which it was to move. A change of more than one vertical row in the matrix, for example from 4 to 10, was not permitted unless all three variables were at least equal to the cell group averages for cell 10.

Rationale

The analytical rationale behind the development of the rank classification matrix was referred to earlier when discussing "style of life." However, conceptually, one is postulating that a "true" theoretical matrix exists for any given area with a particular style of life. Regardless of the variables used to develop this matrix, if the variables are representative of a given area or that part of the resident's style of life which determines the frequency of trip productions from the home, then it can be reasoned that the variances in the empirically determined trip production rates from the "true" rates are the result of errors in sample selection, data collection, or data-processing and analysis. The simplifying assumptions for this procedure are basically that within any particular cell in the matrix, the zones comprising the cell are more like each other than they are like any of the other zones occupying a different cell. The "likeness" refers to the style-of-life concept, or those variables for a particular area that are the determinants of trip productions from the home. This implies that the best estimate of the "true" rate is the determined rate from the zones occupying a particular cell in the matrix. Thus, if the magnitude of the variables related to trip production from the home change enough in the forecast period, the zone will shift to a new cell in the matrix. The zone is thus placed with zones having similar future household characteristics. All of this, of course, assumes that variables important for determining trip generation from the home today will also be significant determinants in the future.

Conclusion

Admittedly, the procedure may lack statistical sophistication and may be unattractive to computer-oriented people. However, it permits the analyst to understand why he is getting a particular forecast for a particular TAZ and it enables the researcher to question the "reasonableness" of the forecasts derived for small areas. Furthermore, it has been demonstrated to be particularly useful in a continuing transportation planning program for evaluating the effect of small area changes on the original forecast of trips for small areas.

FORECASTING PERSON TRIP ATTRACTIONS

It is possible to clearly demonstrate the utility of selecting household and environmental characteristics for analyzing and forecasting total person trip productions. It is, however, not as clearly demonstrable which of the variables used in forecasting person trip attractions are the best (or the only ones) to use. At the present stage of development, forecasting trip attractions is still the most difficult problem for the researcher.

Nonetheless, the number of trip ends attracted to a particular analysis zone is rationalized to be related to the amounts and type of activities located in the zone. Before a forecast of trip attractions can be made, it is necessary to determine the factors which define and quantify the activity or drawing power of a zone.

Selecting Attraction Variables

The generalized concept of "drawing power" is to trip attractions as the concept of "style of life" is to trip productions. Both are assumed to be capable of operationalizing, but most researchers will agree that operationalizing the drawing power of a zone so it will yield some understanding of the "why" of the drawing power is a much more formidable task. It is one thing to select variables that in the base year reflect a strong relationship to trip attractions, and something else again to forecast these variables with any degree of reliability.

Many studies have found population, employment, and school enrollment related to the forecasting of trip attractions by trip purpose. After much experimentation and analysis at PSRTS these variables were also finally selected. Examination of the attraction rates for these variables at the analysis zone and the analysis district level, based on different combinations of employment and population, showed considerable variation in the person trip attraction rates. Some zones had relatively little or no employment or population in the base year, thus making calculation of rates based on sample data for small areas very unstable, even though the relative amount and type of activity occurring in the zones were similar. This is particularly true for the trip purposes other than work and shop, for which total employment and retail and service employment in the zone were used, respectively.

For the social-recreational and miscellaneous trip purposes, either employment or population was used to determine the person trip generation rates for groups of zones. This was necessary because many zones are primarily residential or nonresidential in character with statistically unreliable numbers of population or employment, yet attracting significant numbers of social-recreational and miscellaneous trips.

The procedure for the grouping of attraction zones for the calculation of person trip attraction rates by trip purpose, expressed as person trip attractions per unit of population, employment, or school enrollment, had to be computed separately for each purpose. Unlike the trip production cell groupings of zones, the individual trip attraction groupings by trip purpose, in which a zone was assigned, need not be the same group for each trip purpose. A zone may be in a high trip attraction rate grouping for the shopping trip purpose, but in a relatively low trip attraction rate grouping for the social-recreational trip purpose.

Grouping Zones for Calculating Trip Attraction Rates

Work Trip Attractions—In examining the employment trip generation rates at PSRTS by zone, considerable variation was noted, particularly for those zones which had a small employment base. In order to assure that the information had statistical stability, zones for which the trip information indicated less than a selected level were omitted from the analysis for determining the grouping of zones. The selected levels of employment were as follows: Seattle—625, remainder of King County—300, Kitsap County—150, Pierce County—300, and Snohomish County—200. This is the equivalent of saying that a zone must have at least 25 or more samples of work trips before it can be considered to influence the establishment of zone groupings for the calculation of the person trip attraction generation rates based on employment.

The grouping of work trip attraction zones together presented less of a problem than the grouping for some of the other trip purposes. This was primarily because the number of home-based work trips that an individual makes in a day is usually limited to two: from home to work, and from work to home. Therefore, the variation in zonal work trip attraction rates (as a function of total employment) was not as great as for some of the other trip purposes. However, some variation was noted by county between zones located within the city vs zones located outside the urban area. In general, the former zones manifested lower home-based work person trip generation rates than the latter. This was because in built-up urban areas the number of opportunities for making a trip from work to shop, or to some other trip purpose, is greater than in the less developed areas, where the employee is more likely to live close to work, and thus, go directly home from work rather than stop along the way for one purpose or another. This was particularly noticeable in Pierce and King Counties.

The person trip attraction rates for the work trip purpose were much more stable at the district level than at the zone level. Districts were then grouped by placing those with similar person trip attraction rates together. The final grouping of districts within county yielded six groups: two each for Pierce and King Counties and one each for Snohomish and Kitsap Counties. The person trip attraction rates for the work trip purpose were then computed for each of these groupings of districts using the data from the zones within the particular districts in the group. The resulting rate was then applied to all zones within the particular district in the group, including those zones which had been excluded from the computation of rates because of an inadequate number of samples in the zone.

Shopping Trip Attractions—Retail and service employment yielded more meaningful shopping trip attraction generation rates than any other combination of employment categories, although there was still considerable variation among zones and among districts. Because of this variation it was necessary to establish more shopping-type trip attraction groupings than were used for work trips. It also required using a combination of grouping districts and, in the case of zones which were predominately major shopping centers, a grouping of zones to form the attraction generation groups.

First, district rates were established. Next, zonal rates were calculated for these zones having at least the following number of retail and service employment: Seattle—250, remainder of King County—120, Kitsap County—60, Pierce County—120, and Snohomish County—80. This minimum employment in a zone represents 10 sampled home-based retail and service employment work trips to the zone. This lower number of samples was used for the shopping trip purpose rather than for the work trip purpose in establishing the calculation of a zonal rate, because of the larger number of trips generated for the shopping purpose by an employee, compared to the work trip purpose.

If the shopping trip attraction rate for a zone exceeded the overall district rate it was separated for a special grouping and the overall district rate was adjusted accordingly. However, only those zones which had either the minimum employment or a generation rate larger than eight trips per retail and service employee were finally included in three generation groupings based on zonal rather than district rates. The zones not meeting these requirements were grouped with the rest of the zones in the district. There were six groupings composed of districts (or partial districts, if any of the zones had been pulled out for a special zonal grouping). This, plus the three special zone groups, yielded nine trip attraction rate groupings for the shopping trip purpose.

Social-Recreational and Miscellaneous Trip Attractions—For social-recreational and miscellaneous home-based trip attraction purposes either total employment or population was used to establish the person trip generation rates. The groupings of zones were always based on one or the other variable, but never both.

First, a person trip generation rate for each zone for the two trip purposes was calculated using employment and population. Zones having less than the minimum total employment as established for the work trip purpose were automatically allocated to the pool of zones which would have the trip generation rate computed on the basis of population. Once the zones had been assigned to either the category for which population was used as the basis of computing the rate or the category for which employment was used, the following procedure was used to further group them within these two general trip generation categories.

Those in the population category were grouped by establishing a frequency distribution of the district trip generation rates by county after the employment zones had been eliminated from the district total. This resulted in six groupings being established: two groups each for King and Pierce Counties and one each for Kitsap and Snohomish Counties. A trip generation rate was then calculated for each of the six groupings based on total population.

For those zones placed into the employment category for computing trip generation rates and having the minimum required employment, a trip generation rate in terms of trips per employee was calculated. This led to 12 separate groups for the social-recreational trip purpose and 13 for the miscellaneous trip purpose. Four of the employment groupings for the two trip purposes were made up of the Seattle and Tacoma central business districts; the Everett and Bremerton central business districts; the Duwamish and Tacoma tideflats industrial areas; and special zones such as the Seattle-Tacoma Airport, Point Defiance Park, and the University of Washington.

School Trip Attractions—Examination of the district trip attraction rates for school trips, based on the number of trips per unit of enrollment, suggested that nine groupings of districts would be required in order to account for the differences among districts. There were two groups set up for Kitsap, Pierce, and Snohomish Counties, individually, and three groups for King County. As one might expect, districts in the more densely populated areas exhibited lower trip generation rates, since in these areas the probability of the student living within walking distance of the school is greater.

Trip Generation Rates for Non-Home-Based and Commercial Vehicle Trips

A separate estimate of the non-home-based trip projections generated by households was made to serve as a control total in comparing with the independently derived number of non-home-based trips. Since by definition a non-home-based trip has neither end of the trip at home, its generation rate is related to a measure of the activity occurring in the zone where the trip begins or ends. The same reasoning applies to commercial vehicle trips.

Population and total employment were the two variables used to represent the amount of activity which produces and attracts non-home-based and commercial vehicle trips. The generation rate is expressed (as were the home-based trip attractions rates) in trips per unit of population or per employee.

The problem of balancing the trip productions and attractions of these two types of trips was resolved by averaging the production and attraction generation rates. This was decided upon after examining, by zone and by district, the differences between the trip production and attraction rates and finding these differences to be small. This is to be expected since for a non-home-based or commercial vehicle trip the production and attraction end of the trip was defined as the origin and destination end of the trip, respectively.

Grouping Zones for Non-Home-Based and Commercial Vehicle Trips

Just as for home-based trip attractions, non-home-based and commercial vehicle trips tend to peak in zones and districts with high levels of commercial and industrial activity. For these zones and districts total employment was used as the variable to represent the activity occurring there. However, in primarily residential areas, total population was used.

The procedure for determining which variable to use for a particular zone or district was the same as that used for home-based social-recreational and miscellaneous trip attractions. Zones having less than the minimum required employment were assigned to use population as the variable for determining trip generation, and the district rate was adjusted accordingly so as not to include these zones in the generation rate calculation based on employment.

Likewise, in grouping zones and districts for determining the trip generation rate, use of the frequency distribution to determine cutting points for the grouping of districts by county was applied in the same manner as when grouping for the social-recreational and miscellaneous trip attractions. No attempt was made to have the same number of groups or the same zones and districts within each group, although the number of groups is almost identical for four of the seven trip purposes.

There were 20 groupings for the non-home-based trip purpose compared to 19 for commercial vehicles. Eight of the groupings for non-home-based trips and seven of the groupings for commercial vehicles were based on population. The remaining 12 groups for both trip purposes used total employment for determining the trip generation rate.

Final Adjustments

The task of classifying zones for the calculation of total person-trip production and attraction generation rates can be thought of as twofold: first, determining future home-based trip productions and trip attractions; second, determining future non-home-based trip productions and trip attractions. Empirically, total trip productions should be equal to total trip attractions. Consequently, a forecast of total trip productions must equal a forecast of total trip attractions. Any difference between the separate forecast of total person trip productions compared to that of total person trip attractions is largely the result of using different sets of variables for determining trip production and attraction generation rates and applying these rates independently.

Where differences occur in total or by trip purpose, adjustments to bring the productions (P's) and attractions (A's) into balance are done by adjusting the number of person trip attractions. This is logically defensible for all trip purposes, except work, because the procedure for forecasting trip productions for these other purposes is more reliable. For work trips, however, the forecast of employment by site location and, therefore, the forecast for the attraction end of the work trip, which is based on a detailed economic forecast analysis, is believed to be the more reliable. As a result, the productions for the work trip purpose are adjusted to the forecast of work trip attractions, which are derived from applying work trip generation rates based on employment.

Special Trip Attractors

The application of the procedure described for forecasting trip attractions by trip purpose by analysis zones should not be applied at the zone level without consideration of any special trip generator, which may make up only part or all of the zone but requires that a separate forecast of these trip attractions be made. For example, trips to airports are increasing faster than either employment or population, and therefore, any rate developed for them using the procedure outlined in this paper would tend to underestimate future attractions. Thus, special generators of this nature have to be forecasted separately. Likewise, future special trip generators, where known, should also be considered as possibly requiring separate consideration in developing zonal forecasts of attractions.

Theory of Trip Attraction

Most researchers agree that in order to develop any theory of trip attraction, one must start by examining how the land is being used and for what purpose. People use land from a transportation planning point of view, because they wish to satisfy certain basic physical and emotional needs, to wit: the need to work, so they may shop for goods and services; the need to play and rest, so they may be rejuvenated in order to continue to work. However, the degree to which people are willing to use land or to be attracted to land in order to satisfy these basic, and usually daily needs, is a function of several interrelated sets of conditions.

The activity occurring on a piece of land suggests to the people which of their needs can be satisfied by interacting with the particular piece of land. Also, the size of the land's activity sets physical limits upon the amount of interaction or attraction that can occur between people and the land's activity in any given length of time. However, the limits of interaction or attraction for several pieces of land of equal size and like activity will vary depending upon several basic locational and functional characteristics of the land: First is the location of the land. The attraction of like sizes and activities of land will be directly related to the land's accessibility to the total number of possible interactions perceived by the user. Second is the accommodation of the land. The attraction of like sizes, activities, and accessibilities of land will be directly related to the land's ability to accommodate the interactions or attractions to the land's activity. Accommodation includes both the ability to facilitate ease of ingress and egress, as well as ability to satisfy the personal needs of the user in a manner that makes the user want to continue to interact with the land's activity. Finally, the amount of interaction or attraction to land having like sizes, activities, location, accessibilities, and accommodations is directly related to the land's general status-image or reputation. This last point, as many businessmen know, is often the difference between a mediocre and a highly successful business.

Conclusion

The procedure for forecasting person trip attractions by trip purpose outlined in this paper leaves much to be desired from a theoretical point of view, nevertheless, it yielded what was felt to be a reasonable forecast of attractions for the PSRTS area. Considerably more systematic research is needed before the forecasting of attractions can compare in sophistication to the forecasting of trip productions.

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