HIGHWAY RESEARCH BOARD

Bulletin 119

Factors Influencing Travel Patterns

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Errata

Trends in Traffic Diversion on Edens Expressway

WILLIAM J. MORTIMER, superintendent of Highways
Cook County, Illinois

●NEARLY 200,000 motorists were interviewed by the Cook County Highway Department on August 31st, September 1st and September 2nd, 1954.

This survey was a follow-up of a similar road interview type survey held on the same days (Tuesday, Wednesday and Thursday) in August and September of 1950.

During the three day survey, 300 men from the Cook County Highway Department were used to secure the facts on origins and destinations.

This year's follow-up survey was refined as a result of the experience gained in 1950. The field structure of the survey was established in 1950. This structure was maintained in the 1954 follow-up with several field improvements and the addition of interview stations along Edens Expressway which was not open to traffic in 1950.

The survey consisted of road interview stations across three screen lines on routes paralleling Edens Expressway. Figure 1 shows the station locations. All these stations were operated for 16 hours beginning at 6 A. M. and concluding at 10 P. M. The five screen line stations A were operated on Tuesday, August 31; the seven B line stations on Wednesday, September 1; and the seven C line stations on Thursday, September 2. In this total of 19 interview stations, traffic volumes varied from 3,000 to 35,000 vehicles in 24 hours.

Consideration was given to the number of lanes, existence of median strips, proximity to large industrial plant areas, variation in illumination, quantity of truck traffic, proximity to signalized or stop-signed intersections, and sight distance. Of all of the variables affecting the station set-up, most important was the item of traffic volumes at peak hours. This obviously, had a direct bearing on the number of personnel required to secure interviews.

Despite the difficulties encountered in such a large operation, 74.9 percent of all motorists passing through the stations were interviewed. A higher percentage was, of course, obtained at stations of lesser volume.

Figure 1 shows the location of the stations and their comparative 1950-1954 volumes.

Volume counts were maintained at all stations by mechanical counters, registering fifteen minute and hourly totals.

Table 1 shows the 16-hour-total volume comparisons for 1950 and 1954. These 16-hour totals represent 87.8 percent of the 3-day, 24-hour volumes in 1950, and 88.5 percent of the 3-day, 24-hour volumes in 1954.

Figures 2 and 3 show the origins and destinations by six general areas of south bound traffic through Line B.

TRAFFIC DIVERSION

Edens Expressway was opened to full traffic use in December 1950. This expressway was located and designed on the basis of the findings of our 1941 origin-and-destination survey.

In this survey, the last four digets of the state license plates were noted by observers at 380 recording stations, two hundred of which were located outside of Chicago. The observations of this survey were analyzed by business-machine methods.

From this information traffic was assigned to Edens Expressway on the basis of optimum time-distance. As the work of traffic assignment progressed, it became apparent that improvements in techniques were necessary to achieve stability in traffic assignment results. As a result it was decided to conduct a before and after study to add knowledge to the field of traffic assignment and its subdivisions.

The commonly accepted principal subject divisions in traffic assignment are: (1) traffic diversion, (2) traffic "generation", and (3) normal growth.

Traffic diversion as commonly used denotes the traffic which is drawn to a new or improved facility from alternate existing routes. It must be pointed out that the notion of diversion need not be limited to new or improved facilities but can occur from a relative change in the usefulness of such alternate routes.

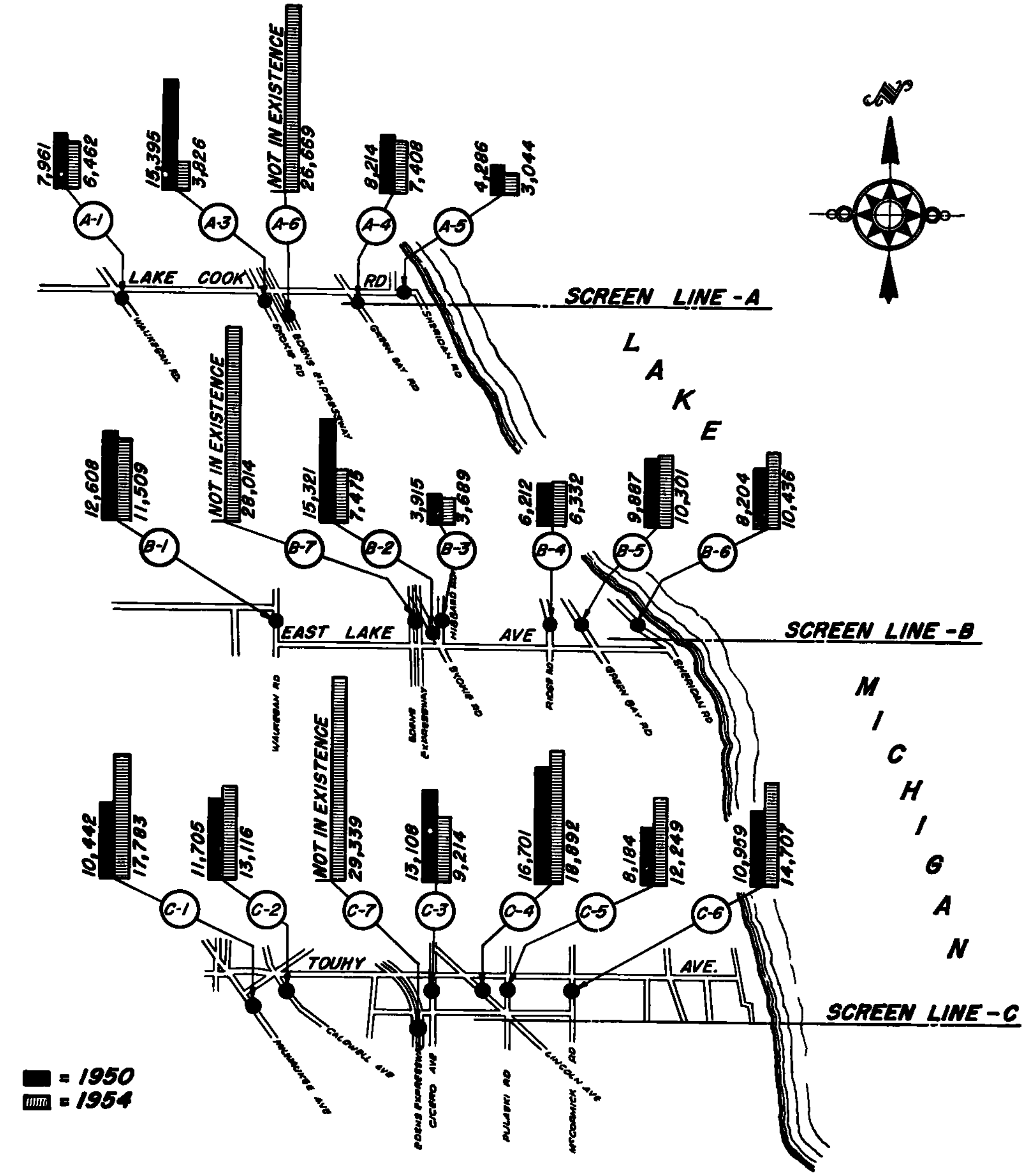


Figure 1. North and south 16 hour 2 way traffic volumes.

Traffic generation includes by common acceptance two categories: (1) primary generation which is that traffic "created by" a new facility and (2) secondary generation which is that traffic resulting from intensified land use as a result of expressway construction.

The commonly accepted implication in the term "generation" is that the new facility creates vehicular traffic and that the created traffic did not exist before the construction of the new and generating facility.

Normal growth is generally defined as that traffic increase due to growth in vehicle registration and population.

Table 1 gives a clear indication of the diversion which has occurred on the facilities under study in our 1950-1954 study. At this time it should be pointed out that for this discussion diversion is considered to include two aspects: (1) diversion onto the Expressway from within the subject corridor and (2) diversion from outside the subject corridor.

TABLE 1

16 HOUR TOTAL VOLUME COMPARISONS FOR EDENS ORIGIN-DESTINATION SURVEY

Station	Location	1950 Volume	% of Total	1954 Volume	% of Total
Total for all A Stations		35,856		47,409	
A-1	Waukegan Rd.	7,961	22.2	6,462	13.6
A-3	Old Skokie	15,395	42.9	3,826	8.1
A-4	Green Bay Rd.	8,214	22.9	7,408	15.6
A-5	Sheridan Rd.	4,286	12.0	3,044	6.4
A-6	Edens Expressway	....	.....	26,669	56.3
Total for all B Stations		56,147		77,756	
B-1	Waukegan Rd.	12,608	22.5	11,509	14.9
B-2	Skokie Rd.	15,321	27.2	7,475	9.6
B-3	Hibbard Rd.	3,915	7.0	3,689	4.7
B-4	Ridge Rd.	6,212	11.1	6,332	8.1
B-5	Green Bay Rd.	9,887	17.6	10,301	13.2
B-6	Sheridan Rd.	8,204	14.6	10,436	13.4
B-7	Edens Expressway	....	.....	28,014	36.1
Total for all C Stations		71,099		115,300	
C-1	Milwaukee Ave.	10,442	14.7	17,783	15.4
C-2	Caldwell Ave.	11,705	16.5	13,116	11.4
C-3	Cicero Ave.	13,108	18.4	9,214	8.0
C-4	Lincoln Ave.	16,701	23.5	18,892	16.4
C-5	Crawford Ave.	8,184	11.5	12,249	10.6
C-6	McCormick Blvd.	10,959	15.4	14,707	12.8
C-7	Edens Expressway	....	.....	29,339	25.4

Table 1 illustrates the diversion experienced onto the expressway from within the subject corridor. This subject corridor was arbitrarily determined by the geographical extent of this survey. Screen Line A, which is the farthest north, extends on the east from Sheridan Road adjacent to Lake Michigan, to Waukegan Road, on the west, a width of nearly four miles. The width of the corridor at the B line is nearly 5½ miles. This screen line is also located between Sheridan Road and Waukegan Road. At the south screen line the width of the corridor is 4½ miles. The south end of the subject corridor is between McCormick Boulevard on the east and Milwaukee Avenue on the west.

To establish a measure of comparison between 1950 and 1954 traffic volumes, a normal growth factor had to be determined. Several approaches were possible for this purpose: (1) county-wide vehicle registration increase; (2) vehicle registration increase limited to the subject corridor; (3) motor-fuel-tax increase for the survey area in Cook County outside the City of Chicago; and (4) various indices of population growth.

After examining these possibilities it was decided that an unbiased estimate of normal growth could best be achieved by selecting as a base the vehicle registration 1950-1954 index within the limits of the subject corridor. This was found to be 28.8 percent, which was a substantially higher index than any of the others available for use. Although 28.8 percent was the average for all the communities in the corridor, there was a wide variation about this average.

Included in this corridor are 23 communities with a total 1954 population of 353,000 ranging in size from 2,500 to 80,000. The total vehicle registration in 1954 for these communities is 90,000, ranging from 250 vehicles to 25,000 vehicles.

Five charts showing hourly traffic volume comparisons for Line A were constructed to give the relation between the actual 1954 volumes and the expected 1954 volumes

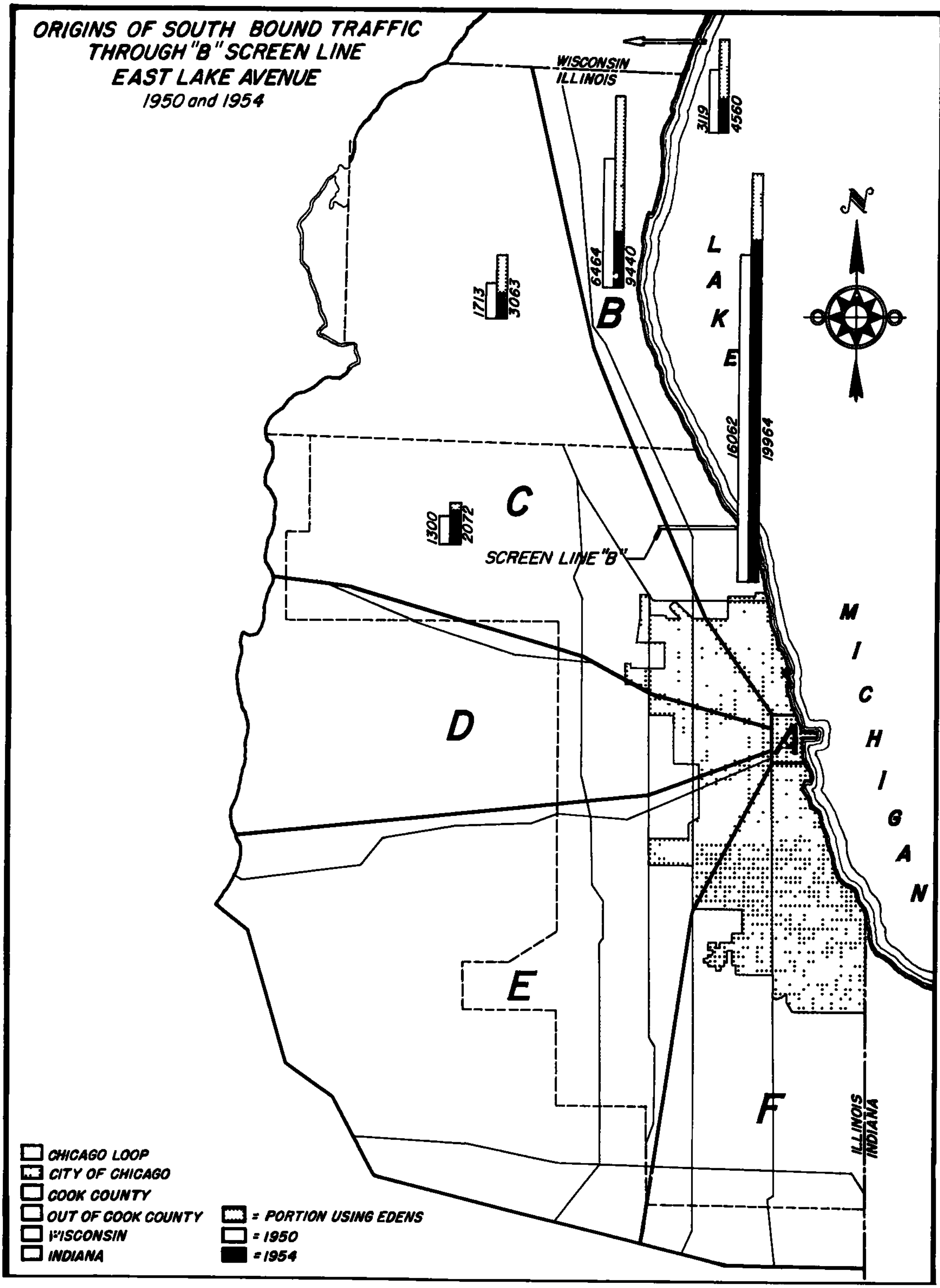

ORIGINS OF SOUTH BOUND TRAFFIC
THROUGH "B" SCREEN LINE
EAST LAKE AVENUE
1950 and 1954
WISCONSIN
ILLINOIS
3119
4560
6464
9440
1713
3063
1300
2072
16062
19964
LAKE
MICHIGAN
N
A
B
C
D
E
F
SCREEN LINE "B"
ILLINOIS
INDIANA
CHICAGO LOOP
CITY OF CHICAGO
COOK COUNTY
OUT OF COOK COUNTY
WISCONSIN
INDIANA
= PORTION USING EDENS
= 1950
= 1954

Figure 2.

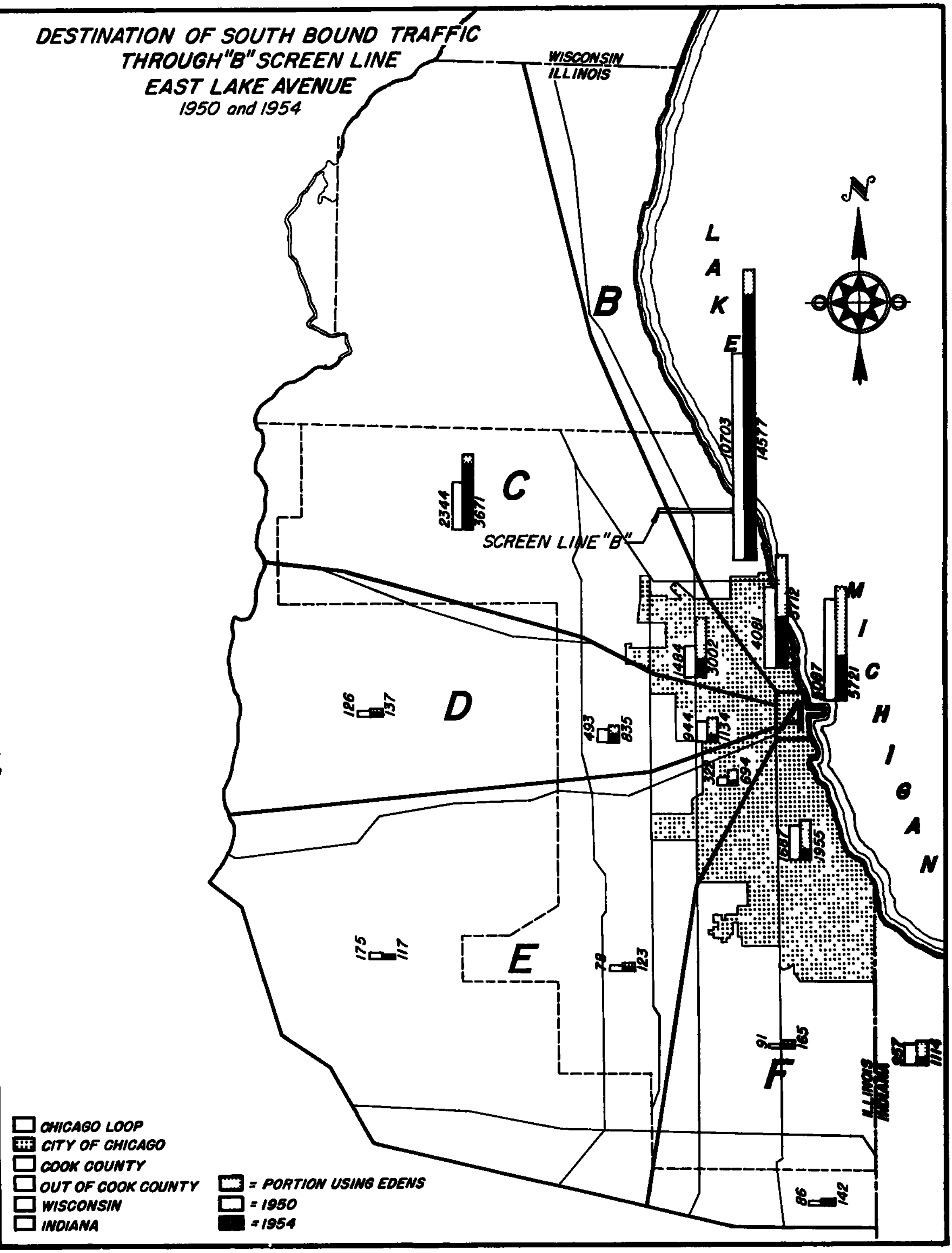

DESTINATION OF SOUTH BOUND TRAFFIC
THROUGH "B" SCREEN LINE
EAST LAKE AVENUE
1950 and 1954
WISCONSIN
ILLINOIS
LAKE
MICHIGAN
B
C
D
E
F
SCREEN LINE "B"
10703
14577
2344
3671
4081
3112
1484
3002
1087
3721
126
137
493
835
944
1134
328
694
1687
1955
175
117
78
123
91
165
86
142
ILLINOIS
INDIANA
CHICAGO LOOP
CITY OF CHICAGO
COOK COUNTY
OUT OF COOK COUNTY
WISCONSIN
INDIANA
= PORTION USING EDENS
= 1950
= 1954

Figure 3.

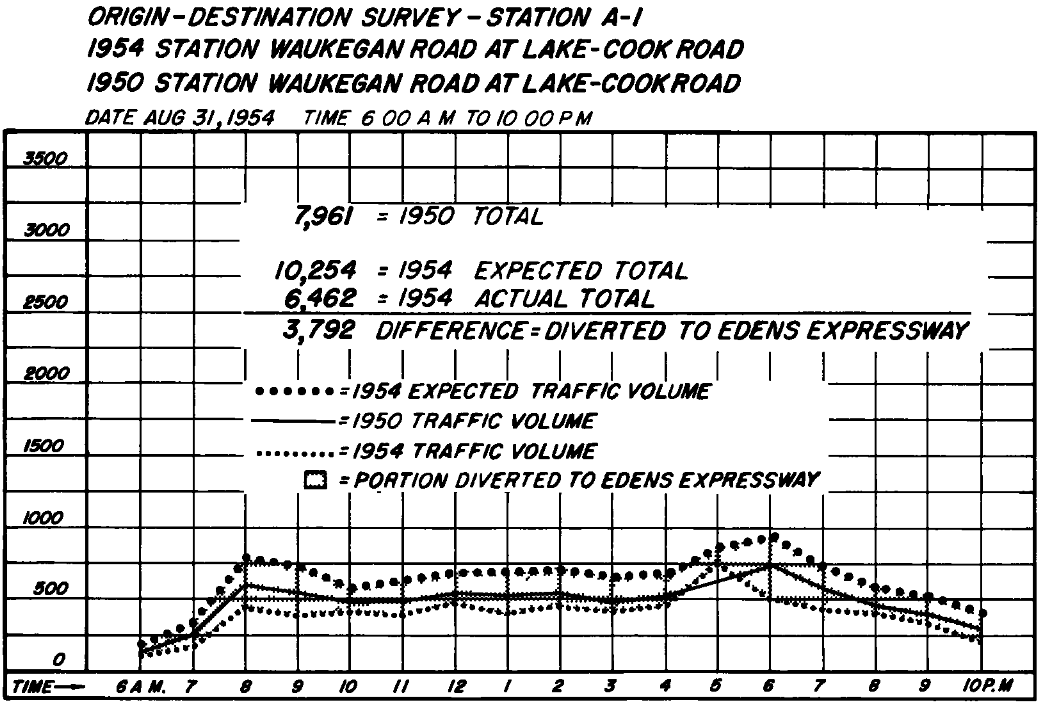


Figure 4. Hourly traffic volume comparisons, 1950 and 1954.

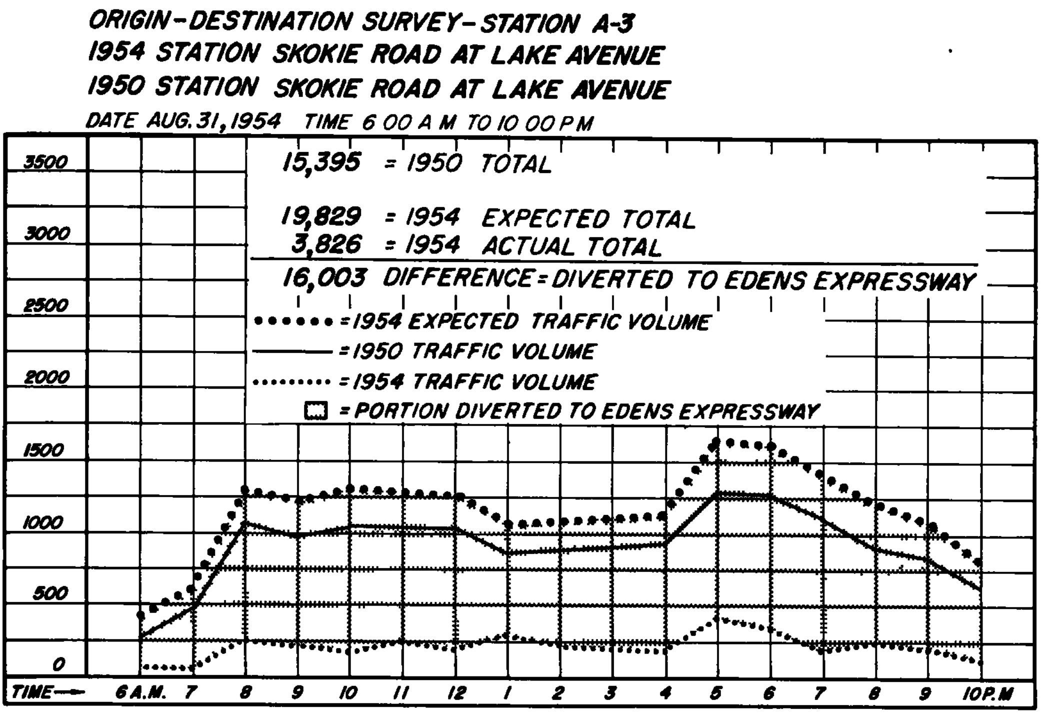


Figure 5. Hourly traffic volume comparisons, 1950 and 1954.

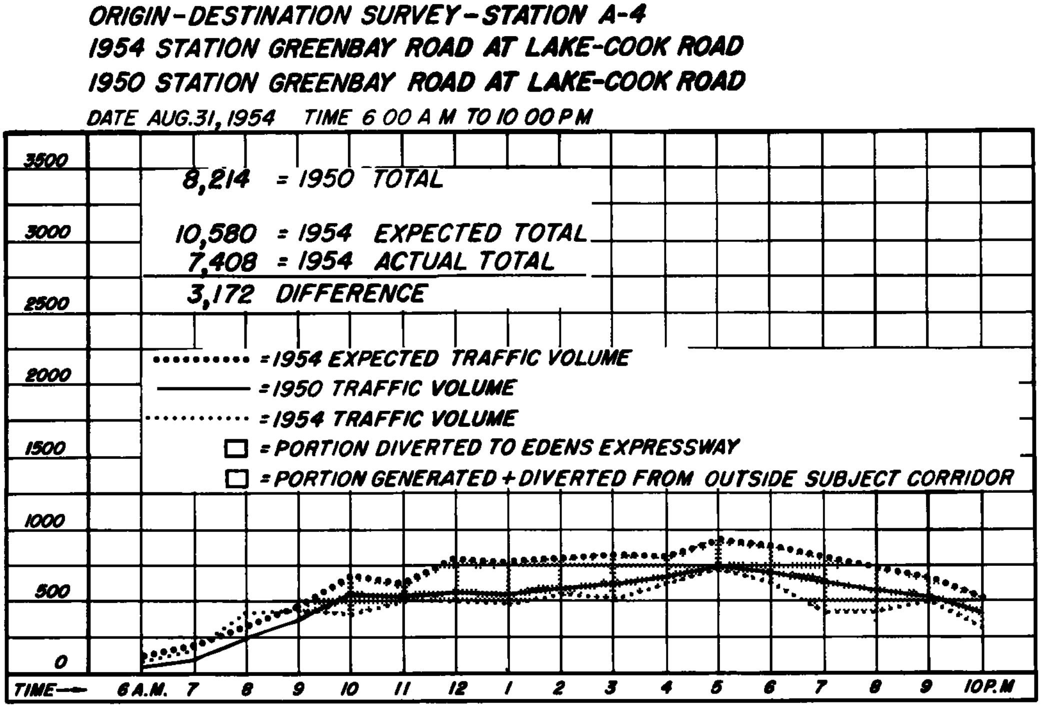


Figure 6. Hourly traffic volume comparisons, 1950 and 1954.

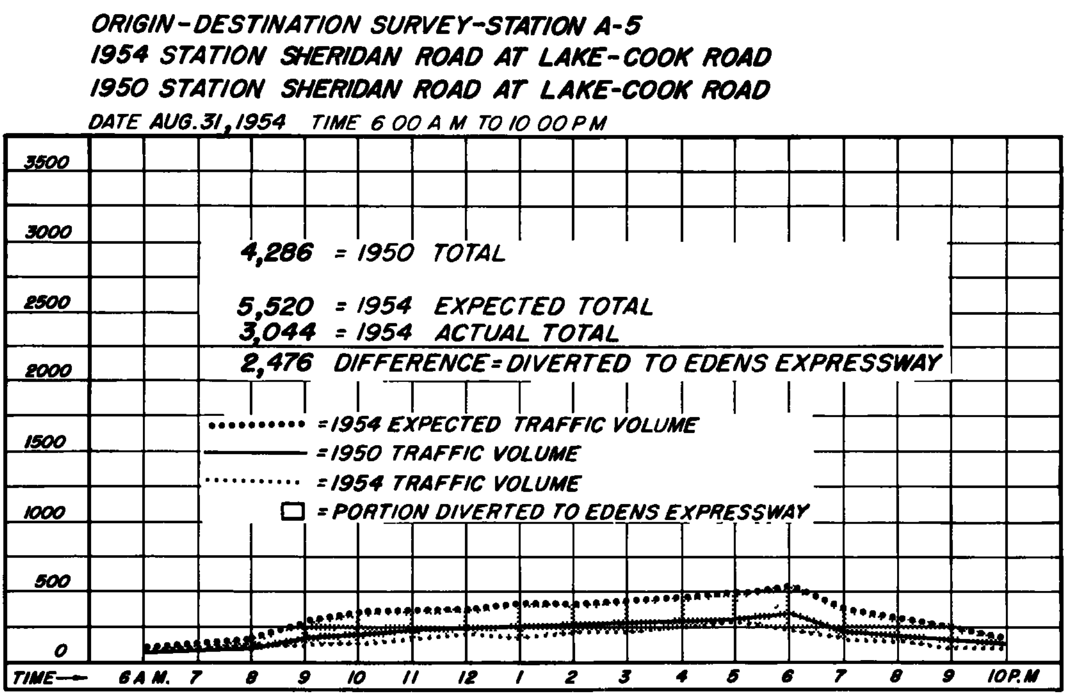


Figure 7. Hourly traffic volume comparisons, 1950 and 1954.

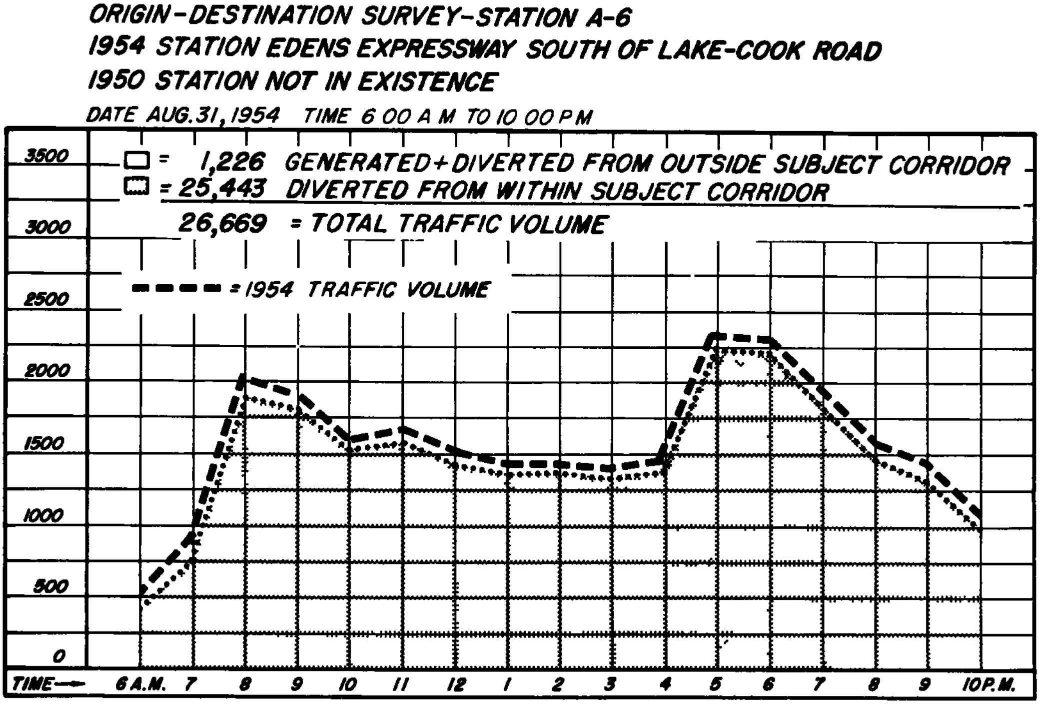


Figure 8. Hourly traffic volume comparisons.

based on the expansion of the 1950 actual volumes by the use of the normal growth factor of +28.8 percent. Each of these charts shows the hourly performance for its respective survey station.

An examination of these charts shows the existence of a substantial section of the diversion gradient. Skokie Highway, which is most nearly adjacent to Edens, shows 80.7 percent diversion to Edens. The percentage of diversion from Green Bay Road and Sheridan Road to the east are 30.0 percent and 44.9 percent, respectively. Waukegan Road, which is west of Skokie and Edens, shows a diversion of 37.0 percent. The total volume diverted to Edens from the A screen line from within the subject corridor was 25,443 vehicles in 16 hours. All of the A stations show a substantial degree of diversion to Edens Expressway.

Even more startling is the diversion gradient at the B screen line. The table below illustrates the gradient characteristic on both sides of the expressway. The gradient nearly vanishes to the east at Sheridan Road. On the west, Waukegan Road conforms to the same gradient it had at the A screen line to the north.

PERCENTAGE OF DIVERSION TO EDENS EXPRESSWAY, B SCREEN LINE STATIONS

Station	Waukegan Rd. B-1	Edens Expwy. B-7	Skokie Rd. B-2	Hibbard Rd. B-3	Ridge Rd. B-4	Green Bay Rd. B-5	Sheridan Rd. B-6
* % Diverted To Edens	29.1	----	62.1	26.8	20.9	19.1	1.2

*The percentage shown is the ratio of diverted traffic to total expected traffic for each station.

Graphically, traffic assignment to the expressway can be represented as a function of different variables. Four such variables considered are (1) the time ratio, (2) the distance ratio, (3) the time saved, and (4) the maximum miles of available expressway.

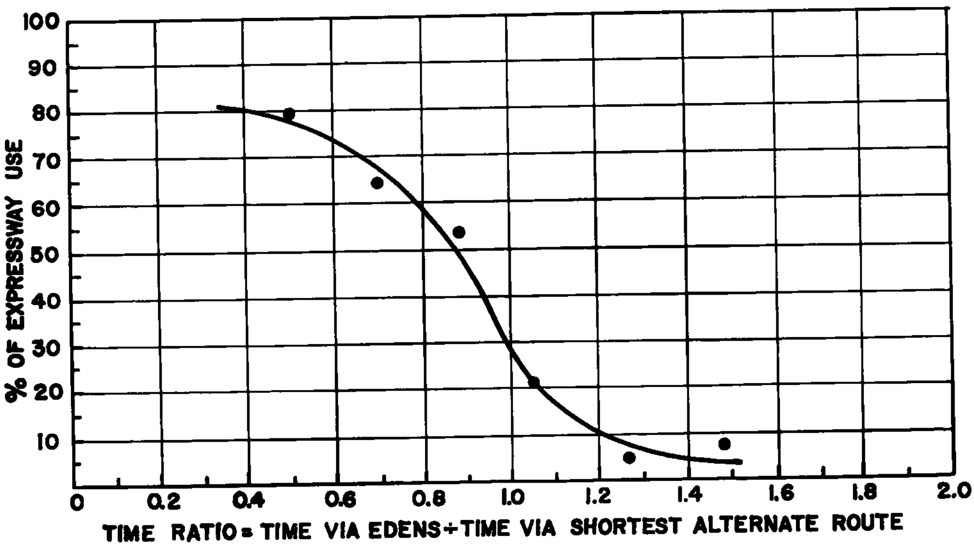


Figure 9. 1954 origin destination traffic survey traffic assignment to Edens expressway.

Figures 9 through 12 show these relationships. The time ratio is defined to be the time via Edens Expressway divided by the time via the shortest alternate route. When the time ratio is 0. 5, about 80 percent expressway usage can be expected and when the time ratio exceeds 1. 5, little or no expressway usage is found. The time ratio gives a fairly stable measure of traffic assignment.

The distance ratio is a less stable measurement of traffic assignment, but does give a fair picture. When the distance ratio is 0. 7, about 75 percent expressway usage is found. One might expect this percentage to be much higher, but it should be pointed out that due to the nature of Edens Expressway, there is a lack of trips on which distance can be saved by using the expressway and, in such cases where distance can be saved, the trip is likely to be relatively short, so that expressway travel is less desirable. On the other end of the curve, when the distance ratio exceeds 1. 5. less than 10% express-

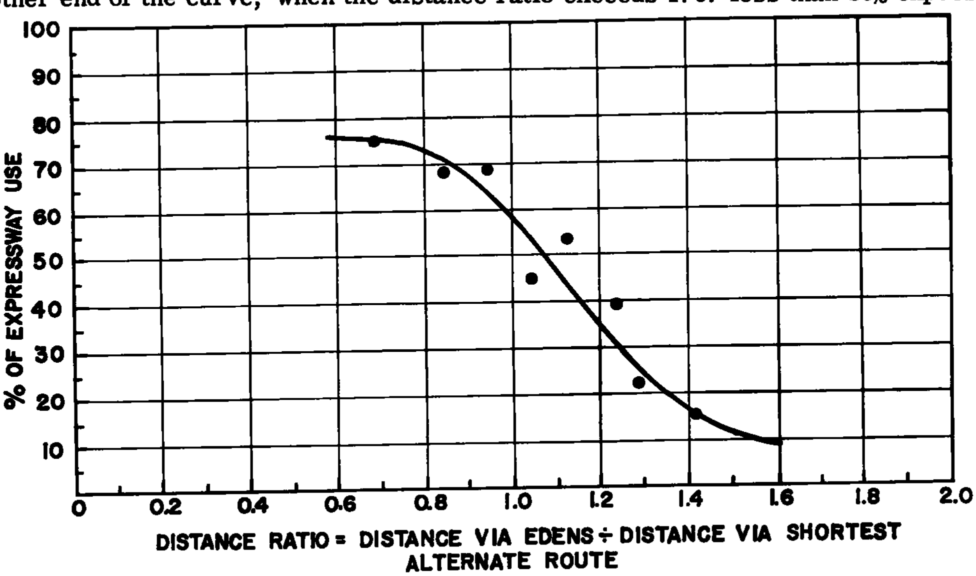


Figure 10. 1954 origin destination traffic survey traffic assignment to Edens expressway.

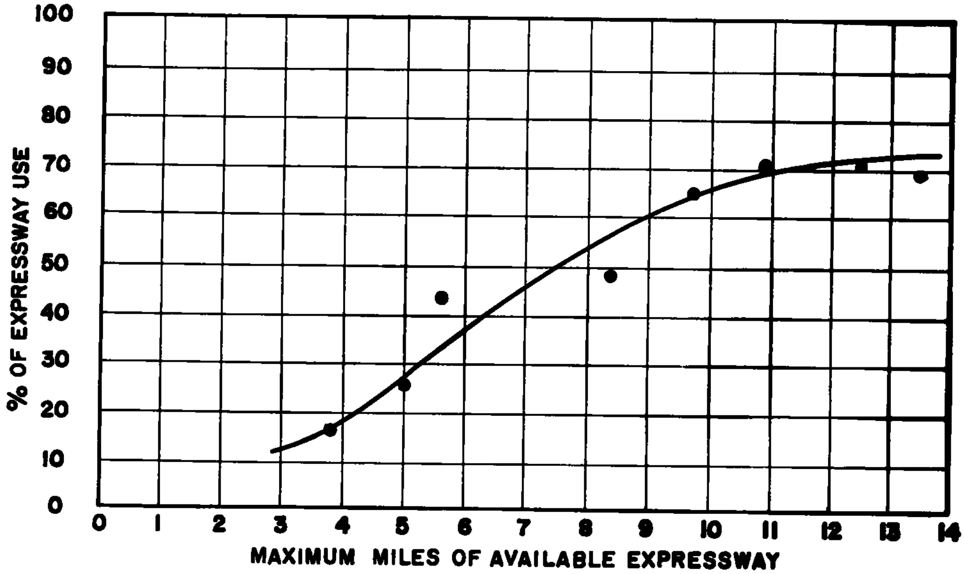


Figure 11. 1954 origin destination traffic survey traffic assignment to Edens expressway.

way usage is expected.

Figure 11 shows percentage of expressway use as a function of time saved by traveling via the expressway. This seems to be a very stable indicator of traffic assignment. When using the expressway results in a loss of 10 minutes, about 10 percent usage is found. When there is no time saved by using Edens, the usage is about 25 percent and when as much as 30 minutes can be saved, over 90 percent usage is found. This is only possible on relatively long trips, indicating a relationship to total trip length.

Figure 12 shows expressway usage as a function of the maximum miles of expressway available for a particular trip. There is a very definite tendency toward a higher percentage of expressway use as more expressway is available for a trip.

When less than four miles of expressway can be used for a trip, less than 20 percent expressway usage is found. When the entire 13.5 miles of the expressway can be used

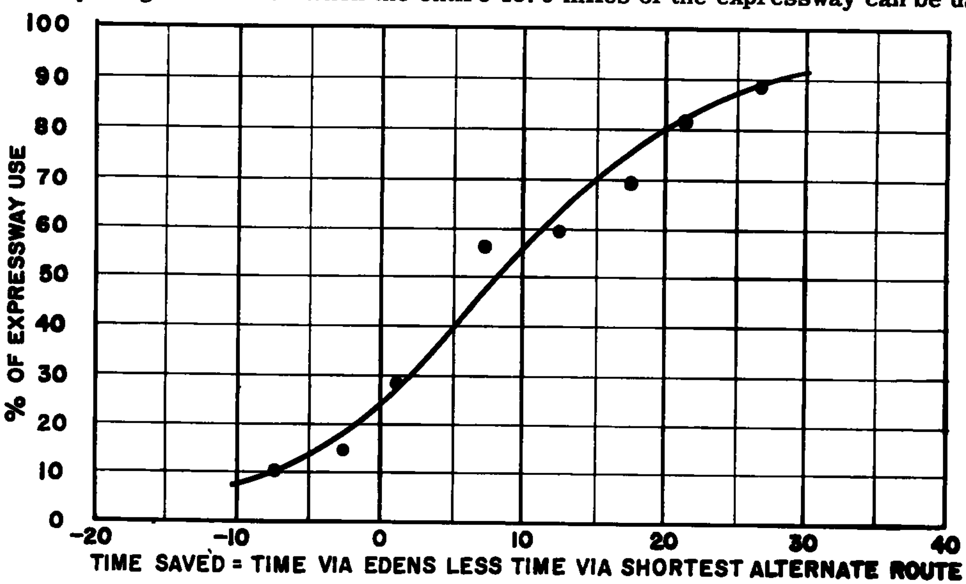


Figure 12. 1954 origin destination traffic survey traffic assignment to Edens expressway.

TABLE 2

GENERATION OF TRAFFIC PASSING THROUGH SCREEN LINE A

Origin	Total 1954 Traffic	Total Generation 1950-1954	Generation by Edens Exp.	% Generation by Edens
Evanston	2,165	345	345	15.9
Glencoe	2,518	1,458	0	0
Glenview	642	78	34	5.3
Golf	10	0	0	0
Kenilworth	142	18	17	12.0
Morton Grove	187	26	26	13.9
Northbrook	1,936	547	4	0.2
Northfield	254	74	40	15.7
Skokie	654	79	79	12.1
Wilmette	787	152	152	19.3
Winnetka	1,212	112	79	6.5
Deerfield	2,136	442	442	20.7
Highland Park	8,073	729	729	9.0
Lake Bluff	226	11	2	0.9
Libertyville	397	142	142	35.8
Mundelein	134	70	70	52.2
North Chicago	934	—236	0	0
Waukegan	1,835	—418	0	0
Winthrop Harbor	33	— 32	0	0
Zion	210	53	53	25.2

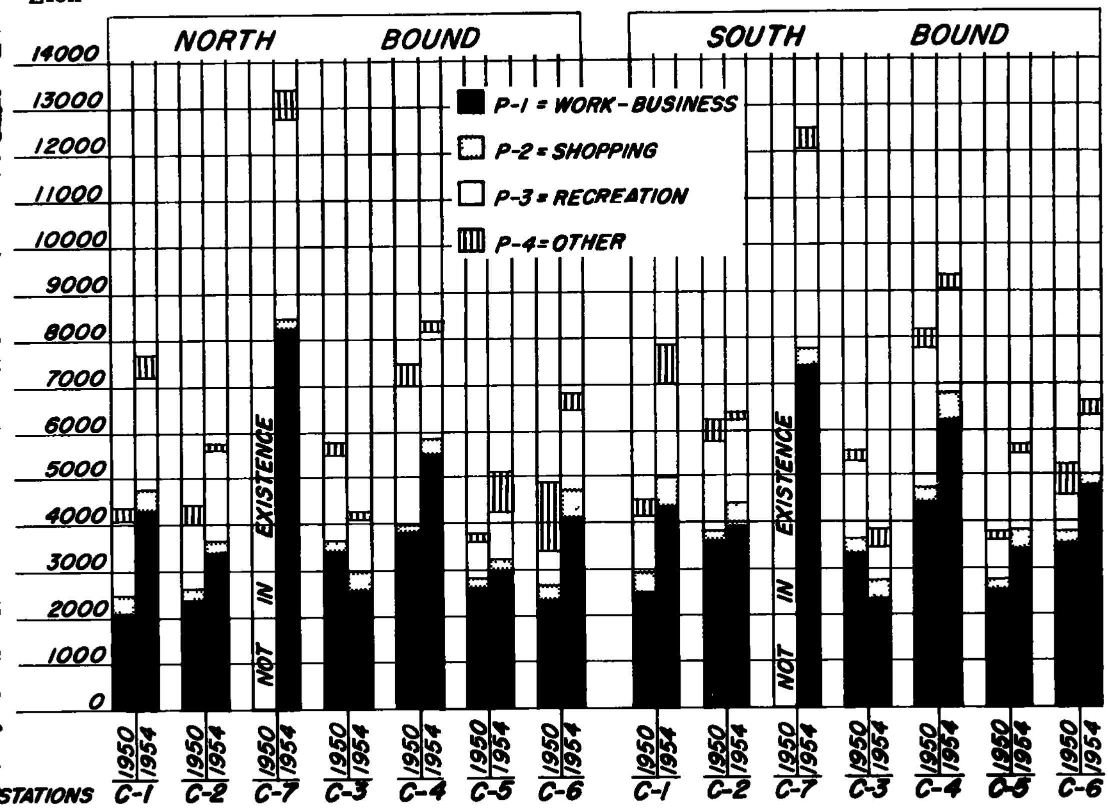


Figure 13. 1950 and 1954 comparison of trip purpose for passenger cars.

for a trip, about 70 percent usage is found. The curve flattens out rapidly after the point where about 10 miles of expressway is available. The number of miles of expressway available, although a fairly good indicator of expressway usage, is not as good as either the time ratio, or the time saved, but seems to be slightly better than the distance ratio.

A multiple regression study was done on the basis of zone to zone transfers to develop an equation predicting the proportion of expressway use as a function of three variables. The resulting equation follows:

$$Y = .368 - .262\,X_1 + .103\,\frac{X_2 + 6}{10} + .255\,\frac{X_3}{10}$$

where Y = estimated proportion of expressway use.
X_1 = the time ratio (as previously defined).
X_2 = the time saved in minutes by using Edens Expressway.
X_3 = the length in miles of expressway use for the trip involved.

There are 86 degrees of freedom for testing the significance of the regression coefficients. All three show significance above the 0.01 level.

TABLE 3

GENERATION OF TRAFFIC PASSING THROUGH SCREEN LINE B

Origin	Total 1954 Traffic	Total Generation 1950-1954	Generation by Edens Exp.	% Generation by Edens
Evanston	7,668	1,598	300	3.9
Glencoe	2,892	0	0	0
Glenview	3,723	−235	0	0
Golf	39	0	0	0
Kenilworth	2,074	70	0	0
Morton Grove	456	21	9	2.0
Northbrook	3,693	0	0	0
Northfield	1,132	114	42	3.7
Skokie	1,663	258	258	15.5
Wilmette	6,723	1,236	55	0.8
Winnetka	6,628	−380	0	0
Deerfield	1,279	99	48	3.8
Highland Park	4,473	712	712	15.9
Lake Bluff	204	− 58	0	0
Libertyville	369	86	86	23.3
Mundelein	131	49	49	37.4
North Chicago	905	247	247	27.3
Waukegan	1,637	−117	0	0
Winthrop Harbor	20	− 30	0	0
Zion	169	0	0	0

The multiple correlation coefficient is 0.794, indicating that the regression equation gives a fairly good estimate of the proportion of expressway use.

TRAFFIC GENERATION

In any new concept considerable latitude in results is experienced up to a point where terminology and technique achieve maximum refinement, understanding and acceptance. Any problem statement is at the mercy of the definition of the terms currently used. In view of this, it is most important that a concise definition of traffic generation be re-

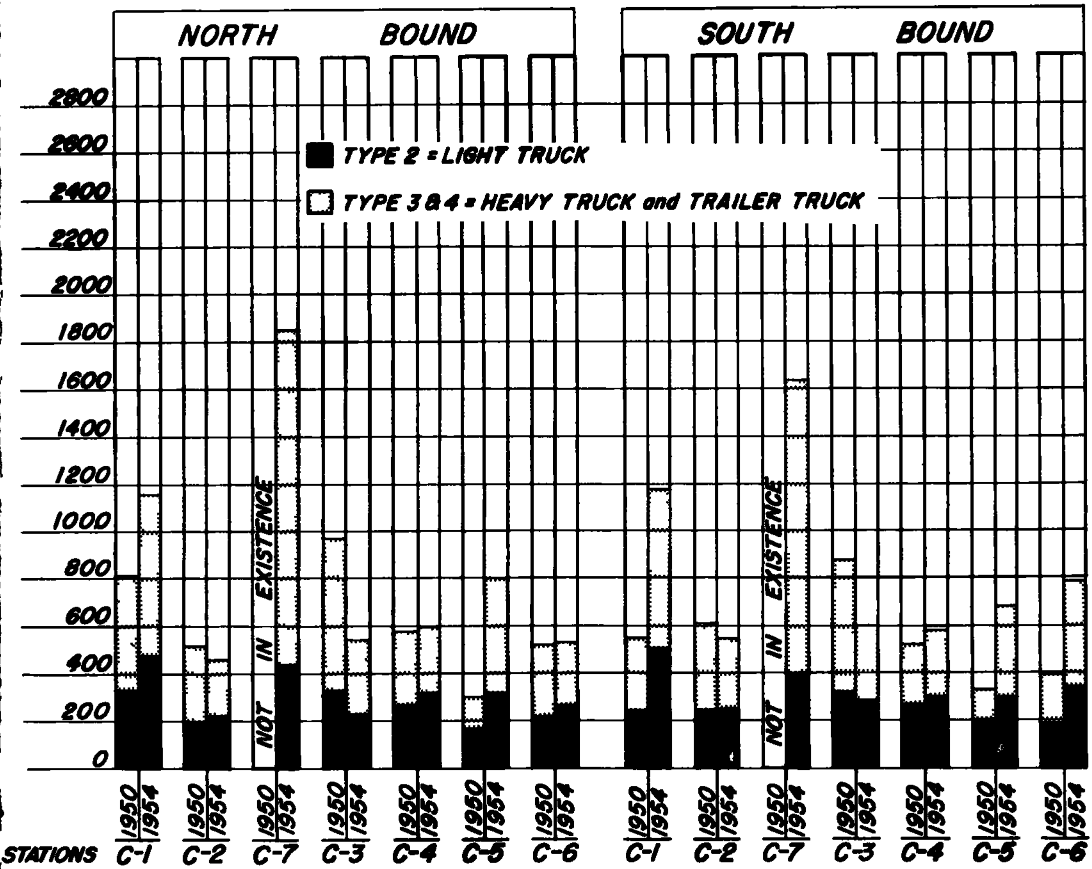


Figure 14. 1950 and 1954 comparison of truck traffic.

stated for this discussion.

In our staff discussions regarding traffic generation attributable directly to a new expressway, there appeared considerable misunderstanding as to the relative significance of the term "generation" to "diversion." Included in existing terminology there appear definitions for primary and secondary generation which merely add fuel to the misunderstanding of the problem.

The currently accepted definition of primary generation was previously stated to be "that traffic created by a new facility." To many in this field of endeavor, this definition is reported to be vague in the sense that a highway cannot create. Attempts have been made, some with moderate degrees of success, to show that there has been no incrase in the number of trips beyond that expected by normal growth and that any increase in traffic volume would merely reflect a change in mode of travel. If such is the case, then generation would have to be explained in terms of this change and might even be less mystifying if a specially symbolic name were set aside for it.

The currently accepted definition of secondary generation was stated to be "traffic resulting from intensified land use." If it could be shown that there were such an intensified land use after the creation of an expressway, then by this definition, this intensified use would be called secondary generation. However, it must be pointed out that intensified land use can result from many factors, only one of which is expressway construction. Other factors influencing intensified land use may be: industrial development, shopping-center development, trends toward metropolitan decentralization, economic growth. If specific weight factors could be attached to each of these components of intensified land use, then we might arrive at some tangible measure of any one factor any one factor including the influence of expressways. To arrive at such weights would certainly require a tremendous improvement and expansion in origin

TABLE 4

GENERATION OF TRAFFIC PASSING THROUGH SCREEN LINE C

Origin	Total 1954 Traffic	Total Generation 1950-1954	Generation by Edens Exp.	% Generation by Edens
Evanston	5,263	835	106	2.0
Glencoe	1,093	152	105	9.6
Glenview	3,189	– 196	0	0
Golf	54	– 54	0	0
Kenilworth	217	5	0	0
Morton Grove	2,366	536	232	9.8
Northbrook	1,543	50	50	3.2
Northfield	463	22	12	2.6
Skokie	11,867	1,643	0	0
Wilmette	1,532	252	125	8.2
Winnetka	998	– 15	0	0
Deerfield	546	89	78	14.3
Highland Park	1,911	421	407	21.3
Lake Bluff	108	0	0	0
Libertyville	412	58	23	5.6
Mundelein	232	– 84	0	0
North Chicago	534	– 106	0	0
Waukegan	1,137	81	81	7.1
Winthrop Harbor	19	0	0	0
Zion	149	47	40	26.8

destination survey techniques.

One of the approaches to this problem would be to recognize that diversion is the principal effect of an expressway on parallel routes. Intensified land use, for example, could certainly be considered as a qualitative aspect of diversion. To assume that a new homeowner would buy a car only because an expressway exists if obviously weak. In all probability a new homeowner possessed his vehicle prior to moving into the vicinity of an expressway and, therefore, can be considered within the category of diverted traffic.

During staff discussions, and after trying several techniques to isolate the component of generation, it was offered that one way to measure this component would be the home interview technique. This technique, in contrast to other techniques involved, gives a more-direct measure by eliminating vague assumptions. It is unreasonable to assume that all growth beyond a certain point can be accounted for by any one factor, expressway construction or otherwise. It seems fairly clear that all factors involved are interrelated and that the isolation of any one would be extremely difficult. However, this approach does not aid in solving the problem. To attempt a solution one must make assumptions for explanatory purposes and, by the methods of trial and error, may find it necessary to change these assumptions.

Twenty communities were selected as being those "most" affected by Edens Expressway.

For each community, a factor for vehicle registration growth 1950-1954, was determined.

The first problem was to compute the total volume of generated traffic originating in each of these 20 communities. One must be careful in doing this not to erroneously assign all such generated traffic to the expressway. This can be avoided by a breakdown by individual stations. In many cases, substantial generation was found on stations other than the expressway. Tables 2, 3, and 4 show the generation data for each of the 20 communities at each of the three screen lines.

Highland Park is probably the most-favorably located town for using Edens Expressway, consequently, one might expect to find a large amount of traffic generation from Highland Park. This expectation seems justified, for at the A screen line, 729 of the 8,073 vehicles from Highland Park were generated by the expressway. This is about 9.0

percent. Of these, 51.5 percent were passenger car business trips and 36.8 percent trucks. The remainder were shopping and recreation trips.

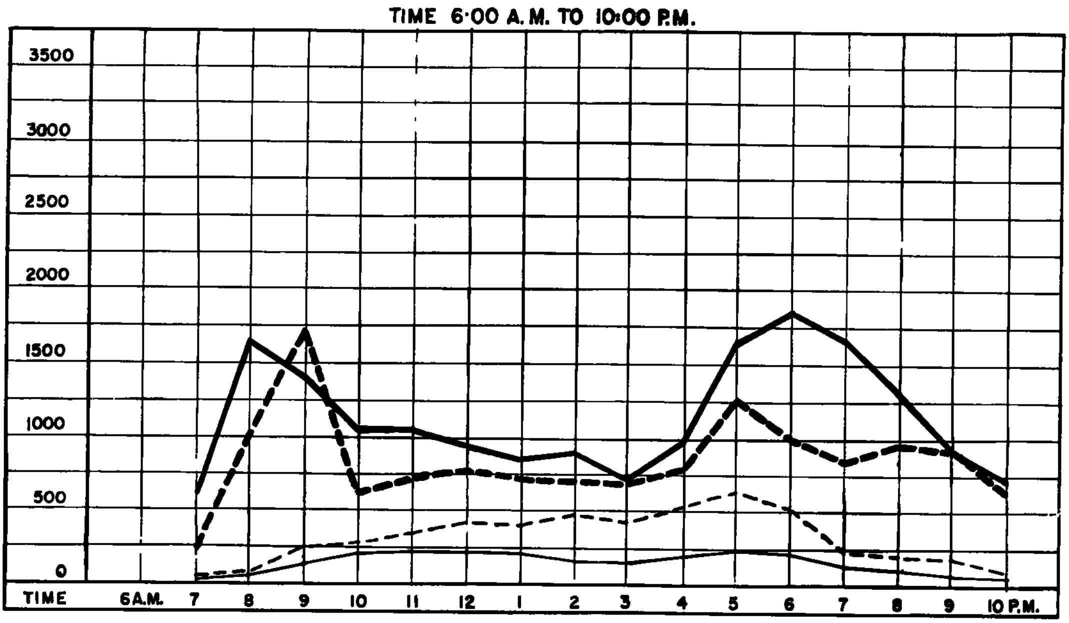
At the B line, Highland Park again shows substantial generation. The number of generated trips is 712, 36.8 percent being business trips, 55.6 percent recreation, and the remainder, trucks.

Highland Park at the C screen line, showed 21.3 percent generation, accounted for by Edens. Of 407 trips generated by Edens, 41.5 percent were passenger car business trips, 31.9 percent recreation, 18.2 percent trucks, and the remainder shopping and miscellaneous.

In general, the appearance of generation of traffic by the expressway was sketchy. In those cases where marked generation did appear, an important factor was the location of the community with respect to the expressway.

One might wonder about the length of the generated trips as well as the purpose of these trips. Following the generated trips from Highland Park through the three screen lines, a sharp dropoff in volume appears between the B and C screen lines. At the C screen line there are still well over half of the generated trips which appeared at the A screen line. Many of these vehicles were destined for the Loop and the north and northwest sides of Chicago, so it can be safely concluded that at least half of the trips generated from Highland Park were of 20 or more miles in length and used the full length of Edens Expressway. More than 90 percent of the generated trips were of 10 miles or more in length and used over half of the full length of Edens.

This seems to conform to the ideas on traffic assignment presented in the discussion of diversion. The amount of generation will be closely correlated with length of trip, length of expressway available for the trip, time ratio, and distance ratio, where time



CLASSIFICATION	%	
"A" STATIONS North & South	MALE	FEMALE
ALL "A" STATIONS	80.0	20.0
NON-EXPRESSWAY	71.3	28.7
EXPRESSWAY	87.6	12.4
5 STATE EXPERIENCE*	67.0	33.0

*PUBLIC ROADS, Dec, 1954, Motor-Vehicle-Use Studies in Six States.

Figure 15. Highway usage variations, origin-destination survey, A screen line stations, male and female drivers, north and south.

and distance comparisons are made with the best alternate mode of transportation, as well as with expressway versus alternate routes. If these functional relationships can be found, traffic generation will lose much of its mystic characteristics and probably can be readily explained in terms of a shifting in mode of transportation.

It should be noted that traffic generation is highly correlated with diversion and that generation will never appear in the absence of diversion, except in the purely artificial case where a new facility is built where no facility of any kind previously existed.

The approach to traffic generation used here only considers the growth of traffic originating in a particular zone or community. The identical approach could be used for traffic destined to a particular community.

Another way is to consider the generation of traffic between pairs of zones. This will present complexities as far as the computational work is concerned, in that a growth factor should be determined which is a function of the two growth factors (i. e., the growth factors of the particular pair of zones).[1]

However, the advantage to this approach is that it allows immediate comparisons between varying degrees of generation and length of trip, length of expressway available for the trip, etc. One big disadvantage is that where a large number of zones are used, the interchange between any pair of zones will be relatively small. One would clearly be treading on dangerous ground if he spoke of a generation of 10 or 15 vehicles between a pair of zones, since such a volume might easily be accounted for by pure chance. The suggested technique is to start from the general and work to the particular. In other words, before talking about the generation between Zone A and Zone B, first determine if there is a significant volume of generation for either Zone A or Zone B, taken separately.

This approach tends to minimize the probability of erroneously naming a chance increase generation.

If this approach, with local indices of growth, is to be used the computational labor could be lessened considerably by the use of electronic computing equipment.

TRIP-PURPOSE VARIATION

The information gathered in the field for this comparative 1950-1954 road interview survey included not only origin-and-destination information, vehicle types, and volumes, but also trip purpose data.

Figures 13 and 14 show the trip-purpose variation by type and purpose and truck traffic for all stations in Screen Line C.

Two small tables are also included to show the distribution of passenger-car traffic on Edens Expressway by purpose, and the percentage comparisons of make to female drivers on the expressway and on nonexpressways.

PERCENTAGE DISTRIBUTION OF PASSENGER CAR TRAFFIC ON EDENS EXPRESSWAY STATIONS IN 1954

Station	Work Business	Shopping	Recreation	Other
A-6	56.9	2.5	34.4	6.2
B-7	57.9	2.2	35.6	4.3
C-7	60.7	1.9	33.3	4.1

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[1] Originally it was thought that this method could be used with one average growth factor for all communities, instead of local growth factors. This was tried, but with no reasonable degree of success, and any generation which was present, tended to be obliterated by inconsistent results.

Objective and Subjective Correlates of Expressway Use

E. WILSON CAMPBELL, Chief Traffic Engineer, and
ROBERT S. McCARGAR, Research Assistant, Detroit Metropolitan Area Traffic Study

● THE task of the Detroit Metropolitan Area Traffic Study is to develop a master highway plan for the metropolitan area, including a network of controlled-access expressways. After the expressway network has been determined, the number of vehicles desiring to use each expressway section and interchange must be estimated. This is done by a method commonly termed "traffic assignment." Traffic assignment is the "estimated allocation" of traffic to a proposed highway facility. Traffic is usually allocated after an objective comparison of a route via expressways to a route via city streets, for a group of trips between two zones. Based on comparisons of time, distance or speed, a percentage of trips are assigned or allocated to the proposed expressway.

Traffic assignment serves several useful purposes. First, it provides a method of testing expressway proposals for their ability to serve the traffic needs of an area, and therefore, provides a basis for determining the best locations for expressways. Second, it answers questions regarding the geometric design of facilities, such as: How many lanes are needed? Where should interchanges be placed? How much capacity is needed to facilitate on and off movements? Finally, it provides a basis for a benefit-cost appraisal of a system and is a useful tool in setting construction priorities.

The purpose of this study was to develop a method for assigning traffic to a proposed expressway network in the Detroit Metropolitan Area. Basic data tabulations were obtained from studies of diversion to five expressways in four different cities throughout the United States. In addition, a diversion study was made for the Willow Run Expressway, serving Southwest Detroit, to determine the effect of the local conditions on diversion. Based on the data from these six expressways, the relation of expressway use to objective measurements of time, distance and speed were studied, both singly and in combination. A family of diversion curves relating distance ratio and speed ratio to expressway usage were developed and are presented as a simple and rapid yet accurate tool for use in assigning traffic to a proposed highway facility.

Using data from the Willow Run diversion study, the staff explored the reasons, attitudes and perceptions of drivers in choosing between an expressway route and city street route. It was reasoned that a better understanding of diversion curves and their proper application could be gained by a study of the subjective processes involved in the choice of a route.

METHOD OF ASSIGNMENT

Traffic-Assignment Research to Date

In 1950, the Highway Research Board summarized[1] the practices of the several states in assigning traffic to route proposals. These practices varied from that of using personal judgement, to methods involving measures of time, distance, and cost. No empirical formula had been devised and the analytical approaches were based on theory. There was an obvious lack of agreement as to any "preferred" method of assignment and many engineers indicated that they were not satisfied with the method adopted by their particular agency.

Since 1950, empirical studies of superior street usage have been made in some half-dozen cities in the United States. Tabulations of basic data were obtained from the studies of diversion to the following expressways: (1) Shirley Highway in Arlington, Virginia;[2] (2) Gulf Freeway, Houston, Texas;[3] (3) Willow Run Expressway, Detroit,

[1] Campbell, M. Earl, "Route Selection and Traffic Assignment", Highway Research Board Correlation Service, 1950.
[2] Trueblood, Darel L., "Effect of Travel Time and Distance on Freeway Usage", Bulletin 61, Highway Research Board, January 1952.
[3] "Traffic Assignment to the Gulf Freeway", 3-page bulletin with graph and supporting tabulation, Texas Highway Department, December 15, 1954.

Michigan;[4] (4) Alvarado and Cabrillo Freeways, San Diego, California;[5] and (5) Central Expressway, Dallas, Texas.[6]

The purpose of these studies was to obtain empirical data which could be used in developing diversion curves for use in traffic assignment. Basic data from each of the above studies were obtained by the Detroit staff for comparative purposes and for further study of the relation of expressway usage to objective measurements of time, distance and speed.

Generally, the use of a facility has been related to time or distance variables. Few attempts have been made to show expressway use as a function of two variables. However, this report presents expressway usage in relation to time and distance differentials combined, and distance and speed ratios combined, in addition to the usual comparisons of usage related to time ratio, time differential and distance ratio.

Curves showing the expressway usage for various time ratios are presented next.

Relation of Travel Time to Expressway Use

The most common method of presenting the relation of expressway use to travel time has been by travel-time ratio. The travel-time ratio is calculated by dividing the amount of time required to make a trip via an expressway by the time required for the same trip via the most favorable city street route. Figure 1 shows the percentage of trips via an expressway for various travel-time ratios as determined from several independent studies. The time measurements for these studies were based on: (1) total trip, in which travel time is measured for the entire trip between origin and destination, via the routes being compared, and (2) points of choice, where measurements are made only for that portion of the trip which is not common to both routes. Since a portion of the trip is left out in the point-of-choice analysis, any ratio of time, distance or speed will not be the same as that obtained by a total-trip method of analysis. However, since the portion which is left out is common to both expressway and city street route, differentials of time, distance or speed will be the same by both methods. The Shirley Highway, Dallas, and Willow Run measurements are for the total trip, while the other studies noted are by the point of choice method.

From Figure 1 it is seen that the time-ratio curves have the same general shape. However, the percent of use for a particular time ratio varies among the different expressways. For example, the use of expressways when time ratio is 1.0 (i.e., equal time via expressway and city street) ranges from 48 percent for the Shirley Freeway to 18 percent for the Willow Run Expressway. Thus, for trips having equal time via an expressway and a city street route, assignment by the Shirley curve would be almost three times as much as an assignment by the Willow Run curve. Even though the curves have the same general shape and they group fairly close together on the chart, assignments to a particular expressway using the different curves vary radically. Table 1 shows the results of assignment[7] to six expressways by three time-ratio curves. Assignments were made in turn to the Shirley, Alvarado, Cabrillo, Willow Run and Gulf Freeways, by using time-ratios developed respectively by the Shirley study, Willow Run study and by a third curve which is an average of the curves for which data were available.

Assignments to the six expressways by the Shirley curve, as shown in Table 1, varied from 97.1 percent of the observed volume on the Shirley Freeway to 156.3 percent of the observed volume for the Alvarado Freeway. Assignments to the same six expressways, based on the Willow Run time-ratio curve varied from a low of 56.1 percent of the observed volume using the Shirley Freeway to 97.7 % of the observed trips using the Avarado Freeway.

[4]Unpublished Study by the Staff of the Detroit Metropolitan Area Traffic Study, 1954.

[5]Unpublished Report by the Traffic Division of the California Division of Highways, 1954.

[6]Photostatic Copies of Tabulations for Central Expressway Study in Dallas, Texas, Texas Highway Planning Survey, May 14, 1952.

[7]Using the basic tabulations which were obtained from the various diversion studies, the volume of all zone to zone transfers assigned for various time ratios, as determined by the Shirley study, Willow Run study and an average of all studies, was compared to the volume of zone to zone transfers actually observed using the facilities for corresponding time ratios.

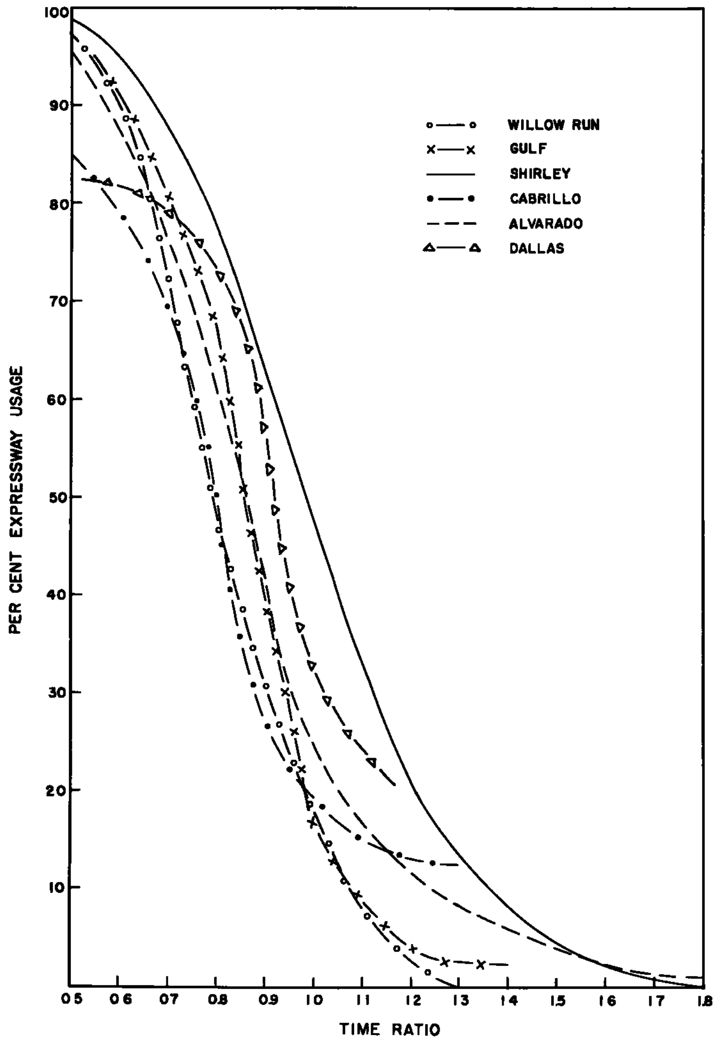

Figure 1. Expressway usage in relation to time ratio.

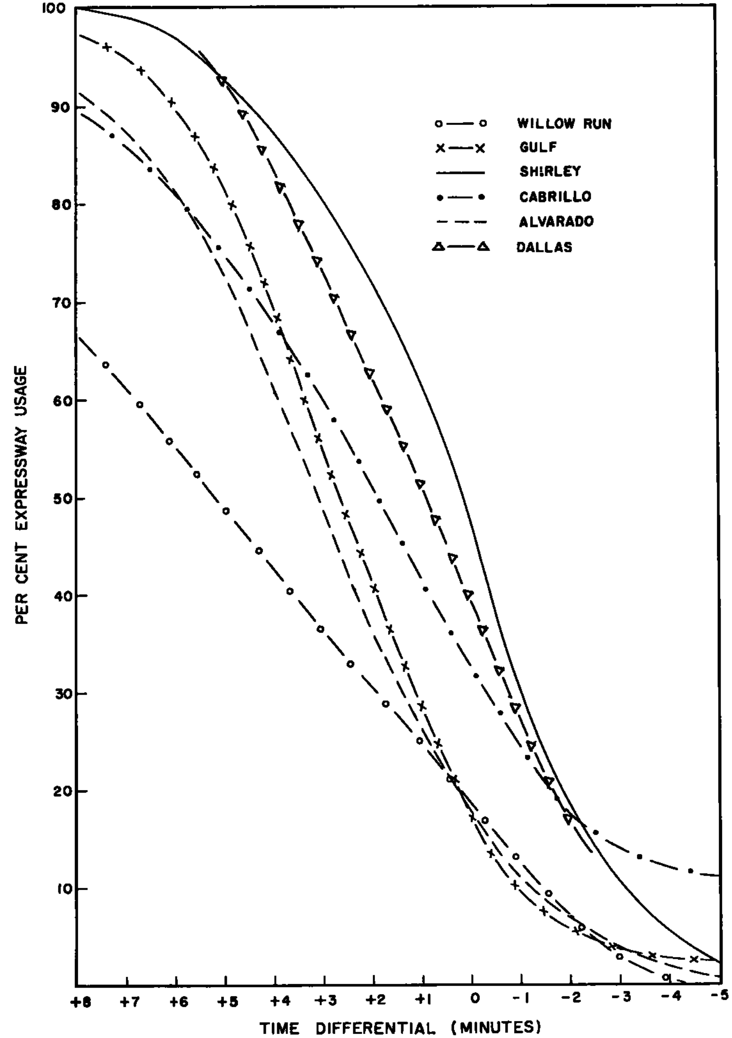

Figure 2. Expressway usage in relation to time differential.

TABLE 1

COMPARISON OF ASSIGNMENTS TO SIX EXPRESSWAYS USING THREE DIFFERENT TIME RATIO CURVES

	Assignment By:					
	Shirley Curve		Willow Run Curve		% Average Curve	
Expressway	% Total[a]	St. Err[b]	% Total	St. Err.	% Total	St. Err.
		Percent		Percent		Percent
Shirley	97.1	± 3.5	56.1	± 18.5	74.2	± 11.7
Cabrillo	135.6	± 15.0	91.5	± 14.1	108.1	± 10.2
Alvarado	156.3	± 13.1	97.0	± 4.1	118.7	± 5.2
Willow Run	152.3	± 18.4	97.7	± 4.2	113.6	± 9.6
Gulf	142.2	± 15.6	81.9	± 14.1	105.3	± 12.1
Dallas	115.5	± 12.3	67.1	± 18.3	81.3	± 10.8

a Total assigned / Total observed using expressway

b Standard error is based on grouped data

Results of assignment by the average time ratio are shown in the last column in Table 1. Generally, the average curve does a better job than either the Shirley or Willow Run curve. However, for certain individual expressways a better assignment is obtained by use of the Shirley or Willow Run curves, as the case may be.

Why is there such a difference in expressway usage based on time ratio? If time ratio is to be used as a basis for estimating the use of a proposed facility, which curve should be used?

To answer the first question, data from individual expressways were examined closely. Average trip lengths, trip times, distance, time, and speed ratios were calculated for various expressways, in search of a clue which might help explain the variation in usage. These measures helped classify the different expressways as to the kind of trips which were being served, and the service the expressway afforded for the average trip. The various averages determined are summarized in Table 2.

Table 2 reveals a variety of trip lengths and times, speed and distance ratios, and other variables, thus indicating that all expressways are not serving the same type of trips and that some expressways offer more advantages than others. For example, the average trip length for Shirley Freeway users is 5.54 miles compared to 13.90 miles for the sample of Willow Run users. The average speed ratio for Shirley users is 1.17 compared to 1.40 for the average trip via the Willow Run Expressway. Similar comparisons can be made using other expressways or other average measures.

An actual case comparison at this point might help to point out the difference in expressways. This example will show how two expressways can logically have different usage for the same time ratio. At a time ratio of 1.0, i.e., equal time via expressway and city streets, the Shirley Expressway shows 48 percent usage and the Willow Run, 18 percent usage. For a trip of 6.0 miles, via the Shirley, the expressway driver must go roughly 20 percent further in using the expressway than the nonexpressway user to equalize times for the same trip. This is because, as speed ratio indicates, travel via the expressway is on the average 20 percent faster than via city streets. Thus, the Shirley user drives 6 miles compared to a 5-mile drive by the nonuser for the same trip. This is a difference of a mile, but as indicated, the travel times are equal. On the other hand, the Willow Run driver must drive 40 percent further in using the expressway to make the travel times equal for the expressway and city street routes, since his speed is on the average 40 percent faster than the speed for the nonexpressway trip. Therefore, he drives 14 miles in the same amount of time it takes to drive 10 miles via the city streets. Thus, a Willow Run user could go 4 miles out of his way to use an expressway, compared to one mile extra for the average user of the Shirley Freeway, when travel times are equal for the expressway and city street routes. This points out one difference in expressways and shows why diversion would not be expected to be the same for each expressway at a time ratio of 1.0. The factor which causes the difference in use of

TABLE 2

SHOWING AVERAGE MEASUREMENTS FOR SIX EXPRESSWAYS

	Shirley	Cabrillo	Alvarado	Gulf	Dallas	Willow Run
Average trip length[a]	5.54	5.10	8.45	5.95	4.19	13.9
Average distance gain via expressway	1.00	1.34	1.36	0.00	0.44	0.83
Average distance lost via expressway	1.27	1.50	3.04	1.40	0.74	2.82
Average trip time [a]	11.74	8.65	13.42	14.14	13.67	23.8
Average time gain via expressway	3.16	2.97	3.60	3.25	2.15	4.75
Average time lost via expressway	2.98	1.81	4.72	2.91	1.16	3.14
Average distance ratio	1.20	1.22	1.35	1.29	1.11	1.20
Average time ratio	1.08	0.90	1.11	1.03	0.87	0.88
Average speed ratio	1.17	1.35	1.28	1.26	1.29	1.40
Average speed for trip via expressway	28	35	37	25	24	35
Average speed for trip via alternate	24	26	29	20	19	25

NOTE: These measurements are averages only for those trips which fell in the samples for the various studies, and do not necessarily represent average values for all traffic on any particular expressway.

[a] Time is expressed in minutes, distance in miles.

individual expressways is, no doubt, the absolute difference in time or distance for transfers having the same ratios. The time-or-distance differential for any particular time ratio varies among different expressways, thus making an expressway more attractive or less attractive and causing differences in use for the same time ratio.

It should be remembered that these time-ratio curves are based on objective measurements of mass movement. The percent usage for any time ratio is a mean value and depends on the range and distribution of percentages of use for that particular time ratio. If all expressways served trips of the same length, had the same accessability, afforded the same speed, then, aside from subjective factors such as drivers' perceptions and attitudes, the usage as based on time ratio should be the same for all expressways. However, it has been pointed out earlier that these basic influence factors are not the same for all expressways; therefore, there is little reason to believe that the use should be the same for all expressways at the same time ratio.

The answer to the question raised earlier, as to which time-ratio curve should be used in assigning to a proposed expressway, is not simple. No single curve will be suitable for all expressways. Therefore, the most-accurate assignment would result from a careful comparison and classification of the facility to be appraised with facilities from which time-ratio curves have been made and selection of a curve developed from the expressway most-closely resembling the facility to be appraised. The task of classifying a future expressway as to kind of trips which would use it and type of service it would provide is very difficult, if not impossible. For example, how can travel times be accurately estimated for some future period when it is difficult to measure them on existing streets? Nevertheless, some sort of classification is desirable in the choice of a time-ratio curve for use in a particular situation.

The fact that expressway use is not the same for all expressways at the same time ratio points out the need for some other tool which could be used to make assignments to any proposed facility. Apparently, at least two variables must be used to explain the variance in expressway use for particular time ratios. However, it is possible that summarizing expressway use by a single variable other than time ratio might combine trips in such a way that the resulting curves relating expressway usage and the variable being tested would be closer for the various expressways than the curves resulting from the time-ratio groupings. Therefore, expressway usage as related to time differential was explored and is presented next.

Expressway Usage as Related to Time Differential

Time differential is the absolute difference in time, stated in minutes, between a trip via expressway and city streets. A negative difference indicates a loss of time via the expressway. Regardless of the method of analysis, i.e., point of choice or total trip, the time differential is the same for any particular zone-to-zone movement.

Figure 2 shows the time-differential curves based on data from the various expressway studies. As in the case of time ratio, the curves have generally the same shape; however, the time-differential curves have a greater spread or scatter. Thus, a greater range in assignment would probably result by using the time-differential curves than with the time-ratio curves. This indicates the need for an even-closer examination and classification of expressways before selecting a curve and making an assignment based on time differential.

Figure 2 shows that when time differential was zero (time ratio equals 1.0) the usage varied from a low of 18 percent for the Gulf Freeway to a high of 48 percent for the Shirley Freeway. When 5 minutes could be saved via an expressway, the use varied from 49 percent as found for the Willow Run Expressway to 93 percent for the Shirley Freeway. The variation in speed ratios and trip lengths again offer logical explanations for the difference in usage of the various facilities. For example, a person can drive 3 or 4 miles out of the way in using the Willow Run Expressway and still save 5 minutes, due to the length of the trip and the possibility of travelling at a considerably higher speed while on the expressway. However, due to the short trips and lower ratio of speed between the Shirley and its alternate, a savings of 5 minutes is not physically possible, unless the trip via expressway is shorter than the trip via city streets. Therefore, a 5-minute time saving becomes much-more important to potential Shirley users because they save distance as well as time via the expressway.

For the Shirley Highway, the time-differential curve gave a higher correlation with expressway usage than the time-ratio curve. Trueblood[8] points out that the time-differential grouping tends to group zone-to-zone movements according to trip length and that this tendency results in a somewhat better correlation. Even though time differential gives a better correlation with the use of a particular expressway, it is apparent that absolute time savings do not provide the same attraction for all expressways. These differences apparently are due to the different trip lengths and speeds involved for the various expressways.

Assignment by the time-differential curves again involves an inspection and classification of expressways and then selection of an appropriate time differential curve. Therefore, the data were grouped by distance differential to see if this grouping would mini-

[8] Trueblood, Darel L., "Effect of Travel Time and Distance on Freeway Usage," Bulletin 61, Highway Research Board, January 1952.

mize the differences in the curves for the various expressways. The distance differential curves are presented next.

Expressway Usage as Related to Distance Differential

Distance differential is the difference in trip length between a trip via an expressway and via city streets. A negative differential indicates that the expressway route is longer than the city-street route.

Figure 3 shows the curves relating distance differential to expressway use for the Shirley Freeway and Willow Run Expressway. Only two of the curves were constructed, since it appears that distance differential has little value as a predictor of expressway usage. From the curves it is seen that the use of the Willow Run Expressway is four times as high as the Shirley for trips losing 3 miles and twice as great for the trips losing 2 miles. These curves are very steep and are, therefore, sensitive to small changes in distance differential. For example, when trip lengths are equal, 65 percent of the trips used the Shirley; however, the loss of a mile drops the expressway usage to 30 percent. This change of a mile on the distance differential scale has the effect of reducing the diversion by more than half.

TABLE 3

SUMMARY OF TEST ASSIGNMENTS TO SIX EXPRESSWAYS BASED ON DISTANCE RATIO

	Distance Ratio Curves Used in Assignments					
	Shirley Curve		Gulf Curve		Average Curve	
Expressway	% Total	SE[a]	% Total	SE	% Total	SE
		percent		percent		
Shirley	98.5	± 3.9	115.4	± 8.6	102.7	± 5.2
Cabrillo	90.7	± 11.5	107.6	± 11.8	95.9	± 11.1
Alvarado	97.4	± 4.6	119.1	± 7.5	104.4	± 4.6
Willow Run	90.9	± 11.0	120.5	± 11.6	104.5	± 10.5
Gulf	89.9	± 12.9	116.6	± 12.9	98.8	± 11.8
Dallas	85.7	± 18.2	102.0	± 14.3	89.0	± 22.2

[a] Standard error based on group data.

It would seem, therefore, that the percentage of expressway use is too sensitive to small changes in distance differential to be useful in traffic assignment.

Distance ratio was the final exploration made into the relationship of expressway usage to single variables. The distance-ratio analysis is presented next.

Relation of Expressway Usage to Distance Ratio

Distance ratio is the ratio of distance via an expressway to distance for the same trip via city streets. Figure 4 shows the percent of use for the various expressways, based on distance ratio. The curves fall close together on the chart, indicating that the range of assignments produced by these curves should not be great. For any distance ratio, the mean value of percentage use is close for all expressways.

When distance ratio is 1.0, indicating equal distances via the expressway and city streets, the use varies from 59 percent for the Shirley Freeway to 75 percent for the Willow Run Expressway. For distance ratios of 0.7 and less, 90 percent or more of the transfers were via the expressway for all the facilities studied. When the distance travelled by the expressway is 60 percent greater than the city streets, (i.e., distance ratio = 1.6) expressway use varied from 3 percent for the Willow Run Expressway to 16 percent for the Central Expressway in Dallas.

Table 3 is a summary of the results of assignment to the six expressways by three distance ratio curves. As in the case of time ratio, the curve which would produce the highest assignment (Gulf), and the one producing the lowest assignment (Shirley), and

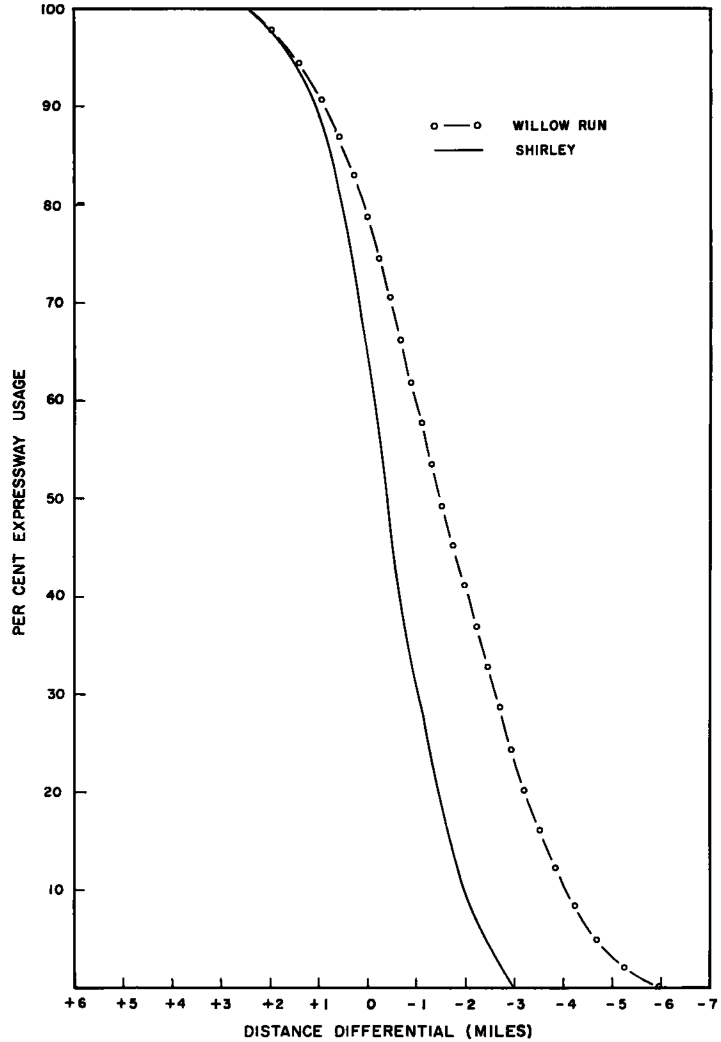

Figure 3. Expressway usage in relation to distance differential.

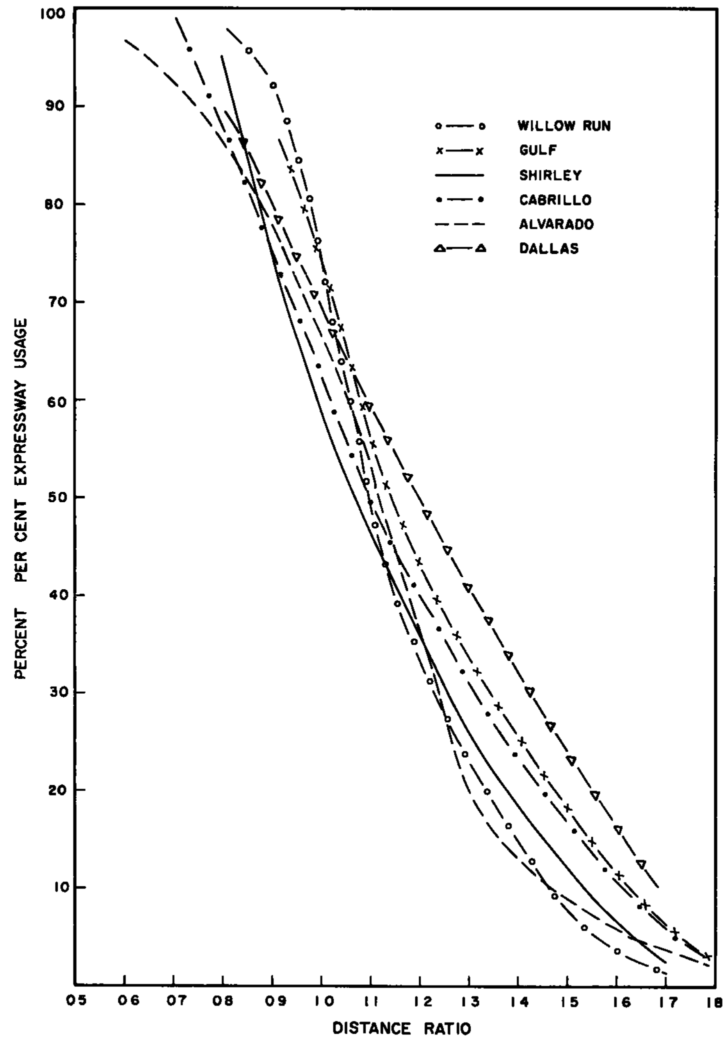

Figure 4. Expressway usage in relation to distance ratio.

a curve which represents an average of the distance ratio curves were used. The Shirley curve assigned 85.7 percent of the trips observed on the Dallas Freeway, and did a better assignment on the Shirley than to the other expressways with an assignment of 98.5 percent. The Gulf curve was consistently high in assignment. It assigned best to the Cabrillo with 107.6 percent of the observed volume and was highest for the Willow Run with 120.5 percent. The average curve assigned to all the surveys within 5 percent of the observed volumes, except the Dallas Expressway (which differed by 11 percent).

Trueblood, in his study of the Shirley Freeway, found that the points had a much-greater scatter when based on distance comparisons than on time comparisons. Because of this scatter of points, the standard error and statistical correlation for the Shirley Freeway were not as good for distance-ratio as for time-ratio comparisons. Generally, however, it appears that the factors which influence expressway usage are more-normally distributed when grouped by distance ratio than when grouped by time ratio; thus, although the scatter of points is greater, the group means for individual distance ratios are closer for all expressways than for time-ratio groupings. For expressways examined in this study, the total assignment was closer when based on distance ratio than when based on any other single variable. The average distance ratio curve assigned to five of the six expressways within 5 percent of the observed volumes using the expressways. Therefore, an assignment could be made to any of these expressways within tolerable limits, using the average distance-ratio curve, thus eliminating the need for classifying expressways in order to pick an appropriate curve.

Assignment by distance ratio probably would work, within tolerable limits, for any particular expressway, as long as the mean trip length and speed ratio fall within the range of trip lengths and speed ratios of the surveys shown in this study. For a single urban expressway, these average values would probably be close to those given in Table 2. However, for a network of expressways, longer trips via an expressway are possible and a greater portion of the trip can be made on an expressway, resulting in higher average speeds and greater absolute time savings for the expressway trip. Because of the higher speeds and greater time savings, the expressway usage would be higher than that shown by the average distance-ratio curve. Therefore, a system which would assign different percentages of trips for the same distance ratio depending upon the relative advantage of particular trips would be desirable. A set of curves based on two or more independent variables appears to be the solution.

The more variables that are used the more difficult it becomes to find the relation between the variables and the percentage of expressway use and, to apply the curves in an assignment problem. Therefore, curves employing only two independent variables were tested.

Aside from subjective influences, such as drivers' attitudes and perceptions, the factors which exert the most influence on a driver's choice of route appeared to be those of time, distance, and speed. Since these three variables are interrelated, curves using any two automatically control the third.

The next section of this report presents the relation of expressway usage to time and distance differential.

Expressway Usage as Related to Time and Distance Differentials

Time and distance differentials were selected because, regardless of the method of study, i.e., point of choice or total trip, they mean the same thing.

Figure 5 shows the relation between expressway usage and time and distance differentials. The curves were constructed empirically by averaging data for the Alvarado, Cabrillo, and Shirley freeways and showing on graph paper the average percent use for each combination of time and distance differentials. Using judgment, curves were smoothed by hand for each 10 percent of expressway usage, resulting in the curves shown on Figure 5.

These curves suggest that time saving can become more attractive or less attractive by varying the distance differential for the same time differential. As an example, for a time-saving of 2 minutes, with no distance loss, about 70 percent of the trips would be via an expressway; however, if 2 miles are lost in order to gain the 2 minutes, the use drops to slightly more than 40 percent. The same reasoning applies to the distance differential. When distances are equal and times are equal, the expressway usage is 50 percent; however, when five minutes can be saved for equal trip lengths, the usage is over 90 percent.

The shape of the curves implies that, as the distance loss becomes greater, the loss looms more and more important to the user, and he must have increasingly greater increments of time gained in exchange for additional unit distance losses. The fact that the curves tend to approach the horizontal as use approaches 100 percent indicates that the rate of exchange of time for distance must become increasingly larger in order to cause an increase in the percentage use for the high percentage use range.

Test assignments were made to the Shirley, Alvarado, and Cabrillo freeways to see what percent of the observed volumes could be predicted by using the curves. Results of the assignment were 89.4 percent for the Shirley, 109.8 percent for the Cabrillo, and 118.0 percent for the Alvarado.

Even though distance-ratio curves assign to these three expressways within 5 percent of the total volumes observed, the standard error for ungrouped data is much higher for distance ratio then for time and distance differentials. Therefore, the error in assignment of individual transfers and, consequently, the error in expressway section and ramp volumes, would be less using the two variable assignment.

Despite the apparent value of the time and distance differentials in assignment, the application is very difficult, since it involves measurement of time for an expressway and city street route. Therefore, a two-variable curve which gives accurate results and, in addition, is simple to handle and easily adapted to mechanical methods of assignment would be desirable.

Expressway Usage as Related to Distance and Speed Ratio

Distance ratios are calculated in the same manner as stated earlier. Speed ratios are obtained by dividing the average speed for a trip via an expressway by the average speed for the same trip via city streets. The curves presented in this section were de-

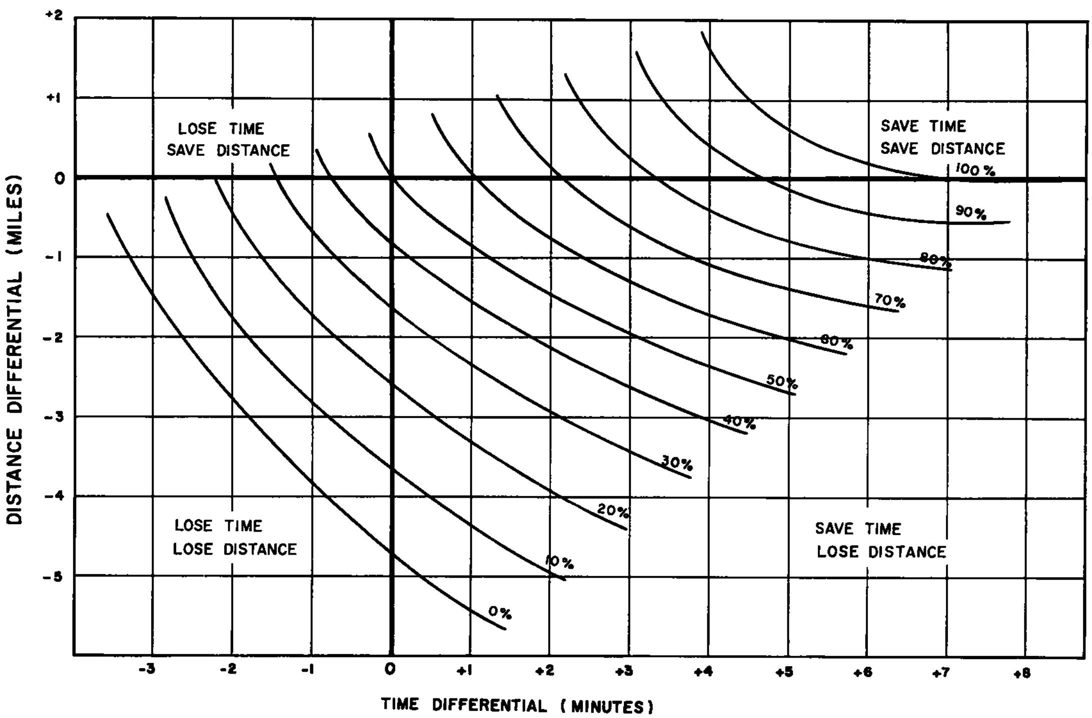

Figure 5. Indifference curves for various percentages of expressway use, based on time and distance differentials.

TABLE 4

REPORTED ADVANTAGES OF THE ROUTE CHOSEN

Advantage	Total	Expressway User	City Street User
Distance oriented advantages:	42	8	34
Shorter (more direct, straighter, less distance)	38	7	31
Nearest, nearest my home, closest route to my home)	4	1	3
Time oriented advantages:	33	26	7
Quicker-faster, save time (reason not given)	10	7	3
Quicker-fewer stops, stop streets, stop lights	13	11	2
Quicker-less traffic, congestion	6	6	-
Quicker-traffic moves faster, thru traffic	1	1	-
Quicker-can go at greater speed	1	1	-
Quicker-better road surface	2	-	2
Traffic and traffic movement:	17	7	10
Less traffic	8	2	6
Fewer stops, stop lights, stop streets, stop signs	7	4	3
Fast moving traffic, thru traffic, stop lights well timed	2	1	1
Road Characteristics:	4	-	4
Better, improved driving surface	2	-	2
Like width, number of lanes, left turn lane	1	-	1
Better road, driving (unspecified)	1	-	1
Miscellaneous	9	1	8
Easier driving - fewer stops	1	1	-
Easier driving - fewer turns	1	-	1
Easier driving - safer	2	-	2
Habit - have always used it, used to it, familiarity, know it best, only one I know	5	-	5
Don't know; directed to go that way	2	2	-
Total	107	44	63

veloped from data taken from the Shirley study because it was the only one made by the total-trip method, and it was felt that any rapid mechanical assignment would have to be based on the total trip. These curves are not adapted, therefore, to assigning transfers which are measured between points of choice. For trip lengths measured by points of choice, distance ratios will be lower than the corresponding total trip ratio for values under 1.0 and higher for ratios over 1.0. Speed ratios will be higher by the point-of-choice method, since the part of the trip which is excluded is nearly always via city streets, thus giving more weight to the higher speeds for the expressway portion of the trip in figuring the average overall speed for the expressway trip.

Figure 6 shows the curves which relate distance ratio, speed ratio, and percent of expressway usage. The addition of the speed ratio variable makes it possible to assign different percentages of expressway use for trips having the same distance ratio but different speed ratios.

For transfers having equal distance by the two routes (distance ratio = 1.0) the amount assigned can vary from 7 percent for a speed ratio of 0.8 (which means speed is less via the expressway than city streets) to 100 percent when the speed ratio is 1.9 or above (see Figure 6). The reason for the difference in use can be seen more clearly through the following explanation:

TABLE 6

ADVANTAGES OF EXPRESSWAY DRIVING

Advantage	Total	Route Used on Last Trip to Downtown Detroit: Used Expressway	Used City Streets	No trip Downtown	Frequency of Using Expressway in Last 6 Mo.: Zero-four Times	Five-Twenty Nine times	Thirty or More Times
I save time in getting where I want to go if I use them.	52	20	17	15	11	15	26
I feet less strain, annoyance and frustration in getting where I want to go.	49	17	15	17	11	19	19
I cut down on the distance I have to travel if I use them.	20	2	11	7	4	9	7
The driving surface of expressways is in better condition than other roads I could use.	11	2	5	4	4	4	3
I can go at the speed I wish to travel.	11	-	3	8	8	3	-
I feel safer going by expressways	10	2	2	6	1	6	3
No particular advantage	15	1	9	5	14	1	-
No answer	5	-	1	4	5	-	-
Total	173	44	63	66	58	57	58

of all individual zone-to-zone transfers were within 15 percent of the observed volumes.

In addition to the reliability and the range of trip types which are covered, these curves have an advantage over other two-variable solutions in the ease with which the ratios can be calculated. To calculate distance ratio, all that is needed is the distance via city streets and distance for the expressway route. Then the distance via expressway is divided by the distance via city streets. Speed ratio can be calculated using only measures of distance, if an assumption is made as to the ratio of speed for pure expressway travel to city street travel.

As an illustration, assume that speed on the expressway is twice the speed for city street travel. In the diagram in Figure 7, two routes are shown for a trip from origin to destination. One, Route C, is via city streets and at a speed of 1. The second route, AXB, is via an expressway, with X representing the expressway portion, at a speed of 2, and A and B at a speed of 1, representing the city street travel in getting to and from the expressway.

Speed ratio is calculated as follows:

$$\text{Speed ratio} = \frac{\text{speed via expressway route}}{\text{speed via city street route}}$$

$$= \frac{\dfrac{\text{distance via expressway}}{\text{time via expressway}}}{\dfrac{\text{distance via city streets}}{\text{time via city streets}}}$$

$$= \frac{\dfrac{X + A + B}{\frac{X}{2} + A + B}}{\dfrac{C}{C}}$$

$$= \frac{X + A + B}{\frac{X}{2} + A + B}$$

$$= \frac{\text{Total Expressway Trip Distance}}{\text{One-half portion on the expressway + distance to and from the expressway}}$$

Therefore, the speed and distance ratios can be calculated from distance measurements with an assumption of ratio of speeds on expressways to speeds on city streets. The assumption of the ratio of speed on expressway to speed on city streets for some future date is just as logical as the assumption of actual speeds and measurements of time for individual streets in the future. These two-variable curves represent a mean percentage of use for the various distance-ratio and speed-ratio groups, just as the distance-ratio curves represented the group behavior of each distance ratio.

As pointed out earlier, there is considerable variation in percentage of expressway use for various distance ratios. Likewise, there is some difference in the percent of trips using an expressway when distance and speed ratios are the same. However, the range of variation is much greater for the single variable distance-ratio curve. The obvious reason for this is that the speed and distance ratio curves give the possibility of many distinctive groupings, thus grouping fewer transfers together, resulting in a smaller range in expressway usage. Distance ratio by itself explains only a portion of the variation in expressway usage. The addition of the speed breakdown within distance ratio helps to explain some of the variation around distance-ratio points.

TABLE 7

DISADVANTAGES OF EXPRESSWAY DRIVING

Advantage	Total	Route Used on Last Trip to Downtown Detroit: Used Expressway	Used City Streets	No trip Downtown	Frequency of Using Expressway in Last 6 Mo.: Zero-Four Times	Five-Twenty Nine times	Thirty or More Times
I lose time in getting where I want to go if I use them.	7	-	6	1	3	4	-
I feel more strain, less at ease and more annoyed and frustrated in getting where I want to go.	2	-	-	2	2	-	-
I increase the distance I have to travel.	27	6	11	10	8	9	10
The driving surface of the expressways is in worse condition than other roads I could use.	20	4	7	9	5	6	9
It is difficult to go at the speed I wish to travel on expressways.	2	2	-	-	-	2	-
I do not feel as safe going by expressway	40	9	19	12	16	14	10
Don't know	2	-	-	2	2	-	-
No Particular disadvantage	68	23	19	26	17	22	29
No answer	5	-	1	4	5	-	-
Total	173	44	63	66	58	57	58

The difference in expressway use when distance and speed ratios are the same could be due to several factors; however, the amount each contributes to the variation is not known. Most important from the standpoint of control is the variation in trip length. For example, a driver making a trip 10 miles long with a distance ratio of 1.0 and speed ratio of 1.5 saves more time using the expressway than a driver making a 5-mile trip with the same distance and speed ratio. Therefore, longer trips will probably divert at slightly higher rates than shorter trips for advantageous ratio combination, even though the distance, speed, and time ratios are the same for both groups of trips. Conversely, when distance- and speed-ratio combinations are disadvantageous for the expressway, the long trips would divert at a slightly lower rate than the short trips. If trip lengths are normally distributed within the distance-speed ratio groupings, then the mean percentage use for the distance-speed ratio group would produce an accurate assignment.

Other factors which cause the variation around the means for distance and speed ratio groups cannot be controlled. For example, some of the variation is due to errors caused by sample variation, grouping of trips at zone centers for measurement purposes, and perceptions and attitudes of drivers.

ANALYSIS OF SUBJECTIVE DATA

The purpose of the second phase of the study was to see what subjective factors correlated with diversion to expressways. In contrast to the previous material, these data were not developed to predict diversion from origin-destination data. However, subjective data could be expected to shed some light on the factors which condition the drivers' choices of routes and make possible more-intelligent use of diversion estimates.

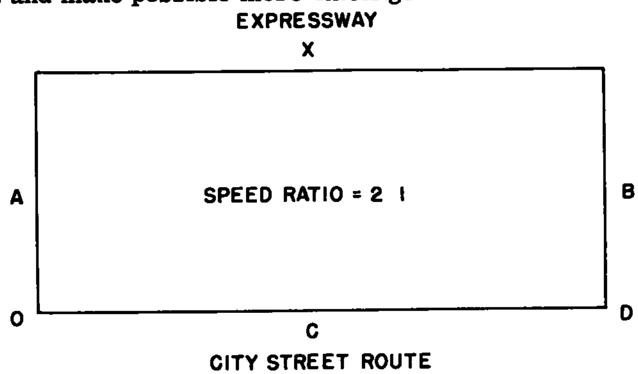

Figure 7. Diagram illustrating a trip between two points O and D via city streets and via an expressway.

Advantage of Route Chosen

One of the primary problems investigated was that of the reasons for choosing one route rather than another. Having evidence from previous studies, it could be expected that both time and distance would come out strongly. But the manner in which this would be expressed was a point of considerable interest. The role played by other factors, especially those which were not objectively measurable, was also a matter of concern.

After naming the route they actually used, drivers were asked to name the advantages they saw in using that route. The results are given in Table 4. Perhaps the most interesting feature of this table is the predominance of distance and time-oriented responses (71 percent of respondents answering the question[9]).

Time savings or other indices based on time can be seen to summarize a wide variety of different motivations for using expressways. The meaning of "quicker" for the driver hinges around two principal dimensions: actual minutes saved and freedom of movement. Although in many cases these go together in the individual's mind, they can vary independently. Safety did not come out strongly in response to this open-ended question.

[9] This figure would undoubtedly be higher if the cases placed in such categories as "less traffic" could be distributed between the categories "quicker, less traffic" and "easier, less traffic."

TABLE 8
PREFERENCE FOR EXPRESSWAY DRIVING AND SATISFACTION WITH EXPRESSWAY EXPERIENCE

	Highly Satis- factory	Fairly Satis- factory	Fairly Unsatis- factory	Highly Unsatis- factory	Never Used Willow Run Expressway	Total
I very much prefer expressway driving	64	27	1	1	-	93
I somewhat prefer expressway driving	15	19	1	-	1	36
I have no particular preference	3	9	1	-	1	14
I somewhat prefer city street driving	4	7	1	-	2	14
I very much prefer city street driving	4	2	4	4	1	15
No answer	-	-	1	-	-	1
Total	90	64	9	5	5	173

TABLE 9
EFFECT OF PREFERENCE AND SATISFACTION UPON USE OF THE EXPRESSWAY, SHOWN BY CONTROLLING THE DISTANCE RATIO

Distance Ratio	Percent Using the Expressway	
	High Preference High Satisfaction	Low Preference Low Satisfaction
.75 - .84	100	-
.85 - .94	100	-
.95 - 1.04	79	67
1.05 - 1.14	33	33
1.15 - 1.24	50	40
1.25 - 1.34	30	15
1.35 - 1.44	25	14
1.45 - 1.54	0	0
1.55 - 1.64	0	-
1.65 or more	0	0

TABLE 10
EFFECT OF PREFERENCE AND SATISFACTION UPON USE OF EXPRESSWAY, SHOWN BY CONTROLLING THE TIME RATIO

Time Ratio	Percent Using the Expressway	
	High Preference High Satisfaction	Low Preference Low Satisfaction
.45 - .54	100	-
.55 - .64	100	100
.65 - .74	100	50
.75 - .84	53	44
.85 - .94	29	25
.95 - 1.04	25	25
1.05 - 1.14	0	0
1.15 - 1.24	0	-
1.25 or more	0	0

Expressway users report time-oriented advantages more than they do distance-oriented advantages, while for nonusers this relationship is reversed. This result, of course, reflects the objective situation. In our sample, most persons who use the expressway gain time and lose distance, while nonusers tend to lose time and save distance by taking city street routes.

The question arises whether people who use the expressway place a higher value on time saving over distance saving than do those who do not use the expressway or whether they are merely in a different objective situation. There is some evidence that the result is not due entirely to the objective situation. Although not shown here, among those who gain both time and distance on the route chosen, expressway users give time-oriented advantages more than nonusers, who typically express the advantage in terms of distance.

A second free-answer question directed at those who did not use the expressway specifically asked why they did not use it. Since this question taps about the same content area, the results also show distance to be the primary consideration for the nonusers; however, the other responses differ somewhat from those given to the previous questions (Table 5). Fear responses came out more strongly (about 13 percent). The responses under "traffic" are actually generated not so much by the expressway itself as the roads which must be used in conjunction with the expressway.

TABLE 11

EFFECT OF THE PERCEPTION OF GAIN OR LOSS OF TIME ON THE PERCENT USING THE EXPRESSWAY

	Percent Using the Expressway	
	Perceive Time Gain	Perceive Time Loss
Objective Gain in Time	68	4
Objective Loss in Time	25[a]	9
Total	65	5

[a] based on only 5 cases.

TABLE 12

EFFECT OF THE PERCEPTION OF GAIN OR LOSS OF DISTANCE ON THE PERCENT USING THE EXPRESSWAY

	Percent Using the Expressway	
	Perceive Distance Gain	Perceive Distance Loss
Objective Gain in Distance	91	100[a]
Objective Loss in Distance	70	19
Total	77	23

[a] based on only 3 cases.

In addition to the free-answer question, two fixed alternative questions were used covering the advantages and disadvantages of expressway driving. The particular advantages and disadvantages given in the questionnaire were chosen on the basis of a pretest. The most-striking difference between Table 6 and those presented previously is the relative importance of the frustration factor, which appears to be of equal importance as time saving. Variations by frequency of use are not significant, although they support the contention that time saving is more important for expressway users independent of their objective situation.

The most-important disadvantage is concerned with safety (Table 7). Of the 98 giving at least one disadvantage, 40 mentioned this factor as being most important. Distance loss is rated as second in importance, while the condition of the driving surface relative to other roads is rated as the third-most-important disadvantage.

Comparing the advantages and disadvantages, 132 out of 168 named three advantages, but only 29 of the 168 gave three disadvantages. When asked to rate the degree of importance of the first advantage and first disadvantage, respondents gave the disadvantages a much-more-minor role than the advantages. It is not surprising, then, that when respondents were asked to say whether the advantages of expressway driving outweigh the disadvantages, or vice versa, 87 percent felt that the advantages are more important than the disadvantages. When broken down by frequency of use, even the low-frequency-user group show 65 percent saying that the advantages outweigh the disadvantages. The middle group in terms of frequency of use showed 95 percent saying the advantages outweighed the disadvantages, while the high-frequency-user group showed 98 percent saying the advantages outweighed the disadvantages.

Satisfaction and Preference

A high positive feeling for expressways was also revealed in questions dealing with satisfaction and preference (Table 8). When asked to say how well satisfied they were with their experience in driving on the Willow Run Expressway, 90 of the 168 persons who had driven on the expressway reported the experience "highly satisfactory," while 64 persons reported it "fairly satisfactory." Only 14 persons reported it "fairly unsatisfactory" or "highly unsatisfactory."

When asked which they preferred, driving on expressways or driving on city streets, strong preference was reported in favor of expressway driving. Out of the 172 persons answering the question, 93 said they "very much prefer expressway driving" and 36 said they "somewhat prefer" it. Fourteen had no preference, and 14 and 15 respectively "somewhat" or "very much prefer" city street driving. As would be expected, the higher the preference or satisfaction, the greater the use of the expressway.

To see what effect satisfaction and preference have upon diversion, the sample was divided into two groups: a high-preference, high-satisfaction group and a low-preference, low-satisfaction group. The percent diversion was then calculated for the various time and distance ratios. Results are presented in Tables 9 and 10. It will be noted that the high-preference, high-satisfaction group shows a relatively higher percentage of diversion for a given time ratio, or distance ratio, than the low-preference, low-satisfaction group.

Perceived Time and Distance

Drivers could not be expected to have perfect information about the routes they use. To what extent are they aware of losses and gains as a result of taking a particular route? And secondly, what effect do perceptual errors have upon their behavior.

With regard to gains or losses in distance, 73 of 107 drivers (68 percent) were correct when they said they either lost or gained distance. Twenty-eight were incorrect. Expressway users were less accurate in their perceptions of distance than nonusers, tending to say that the expressway distance was shorter than it really was relative to the best city-street route.

The drivers showed about the same degree of accuracy in judging time. Of the 107 drivers, 67 (63 percent) were correct when they said they either lost or gained time. Thirty-five were incorrect. Expressway users were more accurate in their perceptions of time than the nonuser, who tended to overestimate time on the expressway.

Combining the perceptions of time and distance, 41 out of 107 (38 percent) were correct in their perceptions of both time and distance. In addition, 58 (54 percent) were correct on at least one dimension. Only one person was wrong on both, while seven cases were indeterminate.

The significance of these errors in perception is revealed by an analysis of their effect upon behavior. It makes a great deal of difference whether or not the individual is aware that he has a time advantage or disadvantage. For instance, of those who could have gained time by using the expressway and knew it, 68 percent actually used it (Table 11). But among those who could have gained time, but did not know it, only 4 percent used the expressway. Of those who actually would lose time by using the expressway, 25 percent used the expressway when they thought it was quicker, but when they were aware of the loss of time, only 9 percent used the expressway.

Awareness of distance loss shows a similar type of relationship (Table 12). Among those actually losing distance, 70 percent divert when they think they are gaining distance, and only 19 percent who know that they are losing distance use the expressway. Among those actually gaining distance, the percent diverting who are not aware of the gain is somewhat higher than when they know it. The latter result, based on only three cases, is unreliable.

Since driver perceptions do influence behavior, a diversion curve based on the drivers' perceptions might be quite a bit different than one based upon objective data. Probably it would more closely resemble the all-or-nothing curve than those based upon objective measurements.

Speed and Diversion

One often hears that people drive like maniacs on the expressways. While this type of driving does not seem to be restricted to the expressways, it is possible that persons who drive faster are more inclined to use the expressways. To test this hypothesis, drivers were asked what speed they preferred to drive when traffic conditions on an open highway permitted them to go at any speed. Persons who reported using the expressway 30 or more times in the last 6 months reported speeds which averaged 55.2 mph. Those who used the expressway 5 to 29 times in the last six months named apeeds which averaged 53.3 mph. The low-frequency-user groups, reported speeds averaged 51.8 mph. Similarly, persons who used the expressway on the last trip to downtown reported a slightly higher speed than those who did not use the expressway and those who had no downtown trip. Respective speeds averaged 54.9, 53.7, and 52.1.

On the basis of the above findings, it is probable that faster drivers make fuller use of the expressway. Since they stand to gain a larger amount of time per unit of distance travelled, this is, of course, understandable.

SUMMARY

Many different factors enter into the choice of a route. Some of these are advantages of time and distance freedom of movement, concern for personal safety, comfort in driving. These factors may be considered as forces acting on an individual and tending to move him along one route or another. When all forces are operating in the same direction, the choice of a route presents little problem to the driver. However, forces frequently act in opposite directions so that an individual might, for example have to travel a greater distance to save time, thus making route choice more difficult.

Some of these factors can be measured objectively and related to the behavior of people in mass movements. Other factors are subjective in nature and are difficult to measure. Nevertheless, these subjective factors have an influence on the behavior of people and help to explain some of the variations in their behavior. For example, concern for personal safety may be such a strong force that it will overcome the effect of both time and distance advantage. Drivers' perceptions of time and distance also have an effect on their choice of routes. This study has shown that drivers are not completely accurate in judging which of two routes is longer or shorter in distance or time. Even if they intended to save time, it would require a large difference between the two routes before 100 percent were aware of it.

Thus, the question must be asked whether or not these subjective factors which influence behavior are sufficiently strong that they must be measured and used in predicting expressway usage. Or to put it another way, can objectively measured factors be used to predict diversion, with reasonable assurance that they are accounting for most of the variation in behavior? Since time and distance savings or losses came out strongly as reasons for route choice and since objective measures of time, distance, and speed correlate highly with diversion behavior, it appears that there is no need for including subjective factors in a traffic-assignment formula. The effects of perception, preference, attitude, and other subjective factors apparently cancel one another in group behavior; so their inclusion in an assignment model would not significantly increase the accuracy of assignment.

If subjective factors are not necessary in an assignment formula, which objective factor or factors should be used in assigning traffic to expressways? It is apparent that a curve employing only one variable must be used with extreme caution in an assignment problem. The single variable curves developed from the expressway studies reviewed in this paper are a result of the combinations of speed, distances, times, and trip lengths found in each particular city or on each particular facility. These curves, particularly ones based on time ratio and time differential, varied quite a bit for the different expressways, indicating that the curves have application only in assigning to facilities similar to the facility from which a particular curve was developed. If the facility being appraised can be classified and the proper curve selected, then a reasonably accurate assignment would be possible using a single variable curve based on time ratio or time differential.

The distance ratio curves did not vary as much for the various expressways as did the ones based on time. Traffic was assigned to the various facilities within ± 5 percent of the total observed volumes by using a curve which was an average of the distance ratio curves for all six expressways. It appears that an average distance-ratio curve would give an assignment within tolerable limits to any single urban expressway having average trip length, time ratio, distance ratio, and speed ratio within the values found for the six expressways studied in this report. However, for single expressways, particularily for an expressway network where longer trips are possible than on one expressway and resulting in higher average speeds, the average distance-ratio curve would not be adequate. The single variable curves, since they classify trip transfers on only one dimension, necessarily group many transfers together, resulting in a wide range of variation around the mean value of expressway usage for individual groupings. This is apparently a normal distribution around the mean, so an assignment based on a single variable gives a close approximation of the total vehicles assigned, even though some individual transfers are assigned high and some low. An accurate assignment of individual zone-to-zone transfers is more important than an accurate total assignment, because ramp and expressway section loads are a result of summing individual zone-to-zone transfer assignments.

The use of a two-variable curve produces a more-accurate assignment of individual zone-to-zone transfers. The reason for this is that two-variable curves based on time, distance, or speed, relate two dimensions of the trip to expressway usage and, through their interrelation, automatically control the third. The addition of a second variable helps to explain some of the variation around the mean occurring in single variable groupings. By establishing more groups with narrower limits, the range of variation around the mean value is reduced.

Two families of curves, each employing two variables, were presented. The first related time and distance differential to expressway usage and the second showed the relation between distance ratio, speed ratio, and expressway usage. The latter is clearly superior, because of the ease with which measurements can be made and the ratios computed and because of adaptability to machine assignment procedures.

CONCLUSIONS

From the data analyzed in this study, the following is concluded:

1. Time and distance savings are the most important considerations in the choice of a rate. Expressway users consider time savings to be more important than distance savings.

2. Drivers' attitudes and perceptions effect their choice of a route, but objective factors account for most of the variation in behavior. In dealing with groups of people there apparently is no need for including the influence of subjective factors in the assignment of traffic to a proposed expressway.

3. An assignment of traffic to an expressway based on time ratios necessitates a classification of the expressway being appraised and selection of an appropriate time-ratio curve. Volumes assigned to an expressway by a time-ratio curve could vary almost 100 percent, depending on which curves were selected.

4. An assignment based on time-differentials would vary even more than assignment by time-ratios. Thus, to assign by time differentials involves an even-more-careful appraisal and curve selection than for time-ratio method. In addition to the difficulty of selecting a curve for either time ratio or time differential, it would be difficult to estimate travel times on expressways and city streets some 20 years in the future.

5. Distance differential has little application as a predictor of expressway usage.

6. Distance ratio appears to be better adapted to universal assignment than any other single variable curve. A curve made from averaging distance-ratio curves from six expressways, assigned to five out of six expressways within ± 5 percent of observed total volume. However, individual zone-to-zone transfers may vary widely in assignment. While distance ratio might work in assigning to an expressway with speed, dis-

tance, and time characteristics similar to expressways used in this study, it obviously would not work for an expressway or expressway network which might accommodate different combinations of trip speeds, distances, and times.

7. Assignment to a single expressway which does or does not have the same characteristics of the ones studied or assignment to a network of expressways which would have a whole variety of combinations of time, distance, and speed suggests the use of a family of curves employing two variables. The two-variable curves are suggested, because they offer many more groupings into which zone-to-zone movements can be classified and also narrow the range of variation around mean values. A family of such curves would facilitate a more-accurate assignment of zone-to-zone transfers.

8. The distance-ratio-and-speed-ratio curves appear to offer a simple, fast, and accurate method of assignment.

These speed-distance-ratio curves were used satisfactorily in assignments to an expressway network in Detroit. Through a mechanical procedure developed by the study staff, an assignment of 25,000 zone-to-zone movements to a network of 260 miles of expressways was completed in less than three weeks. This mechanical assignment procedure is the subject of a paper to be presented at the annual meeting of the Highway Research Board in January of 1956.

ACKNOWLEDGMENTS

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Induced Traffic on Chesapeake Bay Bridge

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All persons in the traffic field are familiar with the estimates of traffic potential to a proposed new facility by various methods of traffic assignment to the several sections of a new route. In many instances these estimates have a tendency to be on the conservative side; in fact, recent openings of several major facilities have revealed traffic volumes greatly in excess of the estimates prepared prior to construction of the facilities. The Chesapeake Bay Bridge was one of these.

It was immediately apparent that the traffic volumes on the bridge were far greater than those recorded previously on the ferry it replaced. Through a series of origin-and-destination studies made annually at the ferry and bridge termini a considerable amount of factual data was obtained. From these data it was determined that the increases in traffic volumes were not confined to any particular origin-and-destination pattern, nor to any month or season of the year but was quite general. Also indicated was the fact that the total number of trips to the Eastern Shore of Maryland by both the bridge crossing and routes around the head of the bay had each increased materially. It is evident that the bridge, in addition to providing a more efficient route, has contributed to the development of the Eastern Shore, thus generating more traffic than ever before. It was also ascertained that the number of trips moving between the south and the north, particularly trips in the 250 miles and over category are increasing annually on the bridge but were almost negligible on the ferry.

It is believed that the study definitely proves that there was a great deal of diversion of traffic from other major north-south routes.

● THE subject of this discussion is the amount of traffic induced to use a new traffic-carrying facility. This so-called induced traffic is in addition to the potential traffic which may be expected to use the new facility by virtue of its travel on existing parallel routes and including the old route, if any, replaced by the new facility.

We are probably all familiar with the estimates of the traffic potential to a proposed new facility. By various methods of traffic assignment to various sections of the new route, we are able to determine approximate traffic volumes for design purposes and for estimating revenues in the case of proposed toll facilities.

In many instances these estimates have a tendency to be on the conservative side. Recent openings of several major facilities have revealed traffic volumes greatly in excess of the estimates prepared prior to construction of the facilities.

The Chesapeake Bay Bridge, which replaced a ferry system operating between approximately the same termini and with an unchanged toll rate, was one of these. I shall not attempt to describe the detailed engineering aspects of the bridge construction, because this subject has been thoroughly covered in previous treatises and published widely in engineering periodicals.

In order to better understand the position of the Chesapeake Bay Bridge as a traffic facility, it is necessary that we place it in its proper perspective.

First we must visualize the geographical location of Maryland in relation to the coastal states of the Eastern Seaboard. Any traffic movement by highway from the populous centers of the North, in fact, any east of the Hudson River, must travel down along the State of New Jersey and cross a section of Delaware and Maryland in order to proceed to a destination south of Maryland. This is shown in Figure 1.

Nearest to the coast is US 13, which runs from the Delaware Memorial Bridge, connecting with New Jersey at that point, through the State of Delaware, and thence through the Eastern Shore of Maryland, and the Eastern Shore of Virginia to connect with the Little Creek—Kiptopeke Ferry, which takes it across the lower Chesapeake Bay to Norfolk, and beyond. Also beginning at the Delaware Memorial Bridge is US 40, which runs concurrently with US 13 to a point in Delaware where it takes off southeasterly, staying west of the Chesapeake Bay, crossing the Susquehanna River, and connecting with southern routes in Baltimore. The continuation of US 40 from Baltimore runs westward throughout the state, connecting with US 40 in Pennsylvania, and thence continuing across the country to the Pacific Ocean.

There are now three major southern routes with which connections are made by US 40 in Baltimore. Us 1, which is a four-lane, undivided highway running through Washington to connect with Richmond and other points south. Another of these is the Baltimore-Washington Expressway, the federal portion of which is known as the Baltimore-Washington Parkway; since no trucks are permitted on this section, this new route, opened to traffic as recently as October of 1954, is expected to take a great majority of the passenger-car traffic off the old route, US 1. The third of these routes is US 301, which has its beginning in Baltimore and connects with all other arterial routes in the city, running in a southerly direction, bypassing the City of Washington, and crossing the Potomac River by means of a high-level toll bridge to Dahlgren, Virginia, and thence to Richmond and the South.

The opening of the Chesapeake Bay Bridge created another north-south route which utilizes portions of several just mentioned. From US 301, US 1, or the Baltimore-Washington Expressway, traffic can now proceed on a direct connection via US 50 to the bridge, across the Chesapeake Bay and thence, in a general northeasterly direction to connect with US 13 near Smyrna, Delaware, thence to connect with the Delaware Memorial Bridge. Portions of this route leave much to be desired in the way of alignment and sight distance. Under construction at this time and scheduled for completion by 1956 is one roadway of an ultimate dual highway, on entirely new relocation, of a route to connect the end of the present divided highway which now ends about 6 miles east of the bridge on a straight line with US 13 in Delaware. What effect this improvement will have on future traffic patterns is almost as difficult to estimate as were the tremendous traffic increases experienced in the postwar years.

TABLE 1

COMPARISON OF ESTIMATED AND ACTUAL TRAFFIC VOLUMES ON SEVERAL TOLL FACILITIES IN MARYLAND

Facility	Estimated 1953	Actual 1953	Actual 1954[a]	Estimated 1970
Susquehanna River bridge	4,980,000	8,400,011	8,425,000	7,580,000
Potomac River bridge	1,070,000	1,841,166	1,870,000	1,920,000
Chesapeake Bay bridge	1,150,000	1,932,741	2,058,000	2,000,000

[a] Based on first 10 months volumes.

Prior to the erection of the Chesapeake Bay Bridge, service across the bay was provided by four ferry boats operating on a schedule which provided service every 20 minutes when traffic conditions warranted the maximum possible. Even with this, on summer weekends, especially Sunday afternoons and evenings, traffic was subjected to long waits and, frequently, vehicles were lined up more than 2 miles on the Eastern Shore awaiting passage. I often wonder what happened to the itinerant vendors who sold hot dogs, soda pop, and ice cream to the waiting motorists. They are probably retired and living off their income. Also gone are the early morning bull sessions among various personnel of the state roads commission who had business on the Eastern Shore; there seemed to be an unwritten directive that the 8 a. m. boat would be taken.

Along each of these routes, with the exception of the Baltimore-Washington Boulevard, now replaced by the expressway or parkway, there is a toll facility on which it was necessary to predict future revenues in connection with the proposed construction of the Chesapeake Bay Bridge. By act of the Maryland legislature, the revenues of each of these toll facilities were dedicated one to each other and then to the cost of the Chesapeake Bay Bridge. All of them are now part and parcel of a revenue-toll-trust agreement which includes, other than those mentioned, the Baltimore Harbor Crossing, a twin-tube underwater tunnel now under construction.

Estimates made in 1948 to determine the revenues which could be expected indicated the number of vehicles which would use each of the three toll facilities for future years. Shown on Table 1 are the estimated volumes for 1953 and for 1970, the actual volumes for 1953 and the 1954 volumes based on the first 10 months of 1954.

From this tabulation it can easily be seen that the traffic volumes on each of these facilities have, in 1954, equalled or exceeded the estimated volumes for the year 1970, except the Potomac River Bridge which is just short of the 1970 estimated volume of 1,920,000 vehicles annually. Figure 2, shows diagrammatically the average daily traffic, by months, for the period from January 1, 1950, to October of 1954 for each of the toll facilities on the major north-south routes through Maryland. Through the courtesy of the Delaware State Highway Department, the Delaware Memorial Bridge is included in this chart. The actual traffic volumes may be found in Table 2.

A first glance at the chart indicates the continuous annual increases in traffic at each of the toll facilities shown. While the seasonal changes reflect the falling off of traffic in the fall and winter months of each year, a month-by-month comparison with the corresponding month of the previous year shows that this steady increase is not confined to any particular season. There are a few exceptions to this statement, the most pronounced of which is the decrease in traffic volumes shown for January 1954 as compared with January 1953. This decrease, which ranged from ½ percent on the Delaware Memorial Bridge to 7 percent on the Susquehanna River Bridge, is attributable to the fact that unusual snow and ice conditions throughout the area made driving hazardous during January 1954. This same decrease was noted at all the permanent automatic traffic-counter stations in Maryland for the month. Another decrease is shown for the Chesapeake Bay Bridge in August 1953 as compared with August 1952. This was due to the fact that the bridge was first opened to traffic on July 30, 1952, and attracted a tremendous number of sightseers during its first full month of operation. It is worth noting, however, that the decrease was only 3 percent, and the following August the average daily traffic lacked 61 vehicles of equalling the August 1952 volumes and exceeded the August 1953 volumes by 2 percent.

Further reference to Figure 2 shows that, with the exception of the period immediately subsequent to the opening of the Chesapeake Bay Bridge, the same general pattern appears for each of the facilities and for each of the years. The low points in January, the peaks in July, and the tapering off in traffic in the fall until the December traffic nears the low of January appear to be representative of the traffic pattern in Maryland.

Immediately following the opening of the Chesapeake Bay Bridge, the monthly reports on traffic volumes were eagerly awaited. The average daily traffic for the first month of operation was 8,900 vehicles per day, an increase of 127 percent over the previous year's ferry volumes, which averaged 4,000 per day during August. During the following month, September, the increase over the previous year dropped to 60 percent; but from then until the completion of a full year of the operation of the bridge, the increase over the ferry traffic of the previous year ranged from 84 percent to 109 percent.

An interesting comparison of weekday and week-end volumes was made by averaging all the traffic for each Monday, Tuesday, Wednesday, etc. in January, February, March, and so on through the year. This was done for the ferry traffic in 1951 and the bridge traffic in 1953, and the results are shown in Figure 3. Reference to this figure indicates a similar pattern for each day of the week and, also, for each month of the year on both the ferry and bridge volumes, although the increases in traffic of the bridge over the ferry are clearly shown to extend for each day of the week throughout the entire year period.

Reference to traffic data on file in the offices of the traffic division showed increases along the feeder routes of the bridge and the assumption was made that these increases were due wholly to the traffic attractiveness of the bridge route. A more-careful study indicated that elsewhere traffic volumes were increasing, at locations where the bridge traffic could not possibly influence it. It was also determined that the overall traffic volume increase of 1953 over 1951 was approximately 15 percent.

Starting with this known fact, Figure 4 was prepared. The base of the bars, which are solid black, indicate the average daily traffic volumes at these locations for 1951, the last full year of operation of the Chesapeake Bay Ferry. The upper line of the rectangle, which normally encloses a blank space, indicates the volume of traffic which,

TABLE 2

MONTHLY TRAFFIC VOLUMES AT VARIOUS TOLL FACILITIES ON MAJOR NORTH-SOUTH ROUTES IN OR NEAR MARYLAND

YEAR	1950	%	1951	%	1952	%	1953	%	1954	%	1955	%
MONTH	ADT	Chge.	ADT	Chge	ADT	Chge	ADT	Chge.	ADT	Chge.	ADT	Chge
CHESAPEAKE BAY BRIDGE (Ferry Prior to July 30, 1952)												
January	1,425	+14	1,565	+10	1,634	+4	3,284	+101	3,098	-6		
February	1,446	+17	1,549	+ 7	1,928	+24	3,777	+ 96	4,156	+10		
March	1,470	+ 4	1,913	+31	1,894	- 1	3,958	+109	4,152	+ 5		
April	1,943	+15	2,122	+ 9	2,330	+10	4,825	+107	5,250	+ 9		
May	2,196	+ 9	2,411	+10	2,724	+13	5,261	+ 93	5,677	+ 8		
June	2,827	+19	3,197	+13	3,621	+13	6,663	+ 84	6,941	+ 4		
July	3,340	+ 9	3,770	+13	4,787	+27	8,178	+ 86	9,162	+12		
August	3,511	+15	4,050	+15	8,912	+127	8,647	- 3	8,851	+ 2		
September	2,665	+11	3,061	+15	4,910	+60	5,899	+ 20	6,477	+10		
October	2,159	+12	2,382	+10	4,697	+97	4,851	+ 3	5,176	+ 7		
November	1,962	+13	2,134	+ 9	4,136	+93	4,152	+ 0	4,682	+13		
December	1,749	+ 6	1,825	+ 4	3,640	+99	3,913	+ 8				
Annual ADT	2,226	+12	2,494	+12	3,744	+51	5,295	+ 41				
Year Total	810,259		910,226		1,370,382		1,932,741					
POTOMAC RIVER BRIDGE												
January	2,174	+15	2,708	+25	3,145	+16	4,192	+ 33	3,937	- 6		
February	2,262	+10	2,945	+30	4,099	+39	4,700	+ 15	4,888	+ 4		
March	2,430	+12	3,529	+45	3,614	+ 2	4,555	+ 26	4,595	+ 1		
April	2,860	+18	3,343	+17	4,282	+28	5,163	+ 21	5,256	+ 2		
May	2,593	+ 8	3,211	+24	4,014	+25	4,824	+ 20	5,023	+ 4		
June	2,825	+14	4,337	+53	4,763	+10	5,298	+ 11	5,185	- 2		
July	3,643	+16	4,821	+32	5,372	+11	6,557	+ 22	7,009	+ 7		
August	3,502	+22	4,424	+26	5,789	+35	6,457	+ 12	6,289	- 3		
September	3,066	+18	3,715	+21	4,518	+22	5,135	+ 14	5,432	+ 6		
October	2,593	+22	2,991	+15	4,318	+44	4,526	+ 5	4,628	+ 2		
November	2,769	+28	2,987	+ 8	4,241	+42	4,279	+ 1	4,287	+ 0		
December	2,983	+33	3,160	+ 6	4,576	+45	4,803	+ 5				
Annual ADT	2,802	+18	3,506	+25	4,395	+26	5,044	+ 15				
Year Total	1,022,833		1,279,678		1,608,702		1,841,166					
SUSQUEHANNA RIVER BRIDGE												
January	11,732	+23	13,658	+17	17,158	+26	18,116	+ 6	16,908	- 7		
February	11,963	+19	14,721	+23	20,057	+36	20,179	+ 1	20,493	+ 4		
March	12,574	+18	17,494	+39	19,653	+12	20,086	+ 2	20,199	+ 1		
April	17,121	+18	18,888	+10	23,444	+24	23,829	+ 2	24,047	+ 1		
May	14,861	+12	18,624	+25	22,611	+21	23,354	+ 3	23,522	+ 1		
June	17,096	+21	22,513	+32	25,591	+13	25,638	+ 0	25,059	- 2		
July	18,935	+20	24,006	+27	26,680	+11	27,332	+ 2	28,294	+ 4		
August	19,542	+23	24,932	+27	27,771	+11	28,538	+ 3	28,113	- 2		
September	17,951	+18	22,892	+28	24,298	+ 6	24,574	+ 1	25,328	+ 3		
October	15,652	+20	19,727	+26	22,057	+12	22,180	+ 1	22,587	+ 2		
November	15,427	+16	19,730	+28	21,365	+ 8	20,931	- 2	22,464	+ 7		
December	14,806	+21	17,696	+20	20,017	+13	21,229	+ 6				
Annual ADT	15,654	+19	19,598	+25	22,560	+15	23,014	+ 2				
Year Total	5,714,022		7,153,147		8,257,052		8,400,011					
DELAWARE MEMORIAL BRIDGE (Newcastle - Pennsville Ferry Prior to Aug. 16, 1951)												
January	6,148		7,007	+14	11,974	+71	14,302	+19	14,245	+ 0		
February	6,341		7,509	+18	14,932	+106	16,519	+11	17,640	+ 7		
March	6,616		8,802	+33	14,177	+61	16,435	+16	17,084	+ 4		
April	8,647		9,133	+ 6	17,869	+96	20,178	+13	21,011	+ 4		
May	7,877		8,814	+12	17,401	+97	19,576	+12	20,602	+ 5		
June	9,965		11,342	+14	21,574	+90	23,668	+10	23,765	+ 0		
July	11,698		12,402	+ 6	23,476	+89	26,973	+14	28,566	+ 6		
August	11,832		17,199	+45	26,167	+52	28,141	+ 8	28,231	+ 0		
September	10,259		16,616	+62	20,527	+24	22,607	+10	23,576	+ 4		
October	8,483		12,801	+51	17,951	+40	19,293	+ 7	19,850	+ 3		
November	7,809		13,055	+67	17,126	+31	17,474	+ 2				
December	7,529		12,182	+62	15,985	+31	17,584	+10				
Annual ADT	8,613		11,425	+33	18,269	+60	20,251	+11				
Year Total	3,143,663		4,170,138		6,686,938		7,391,512					

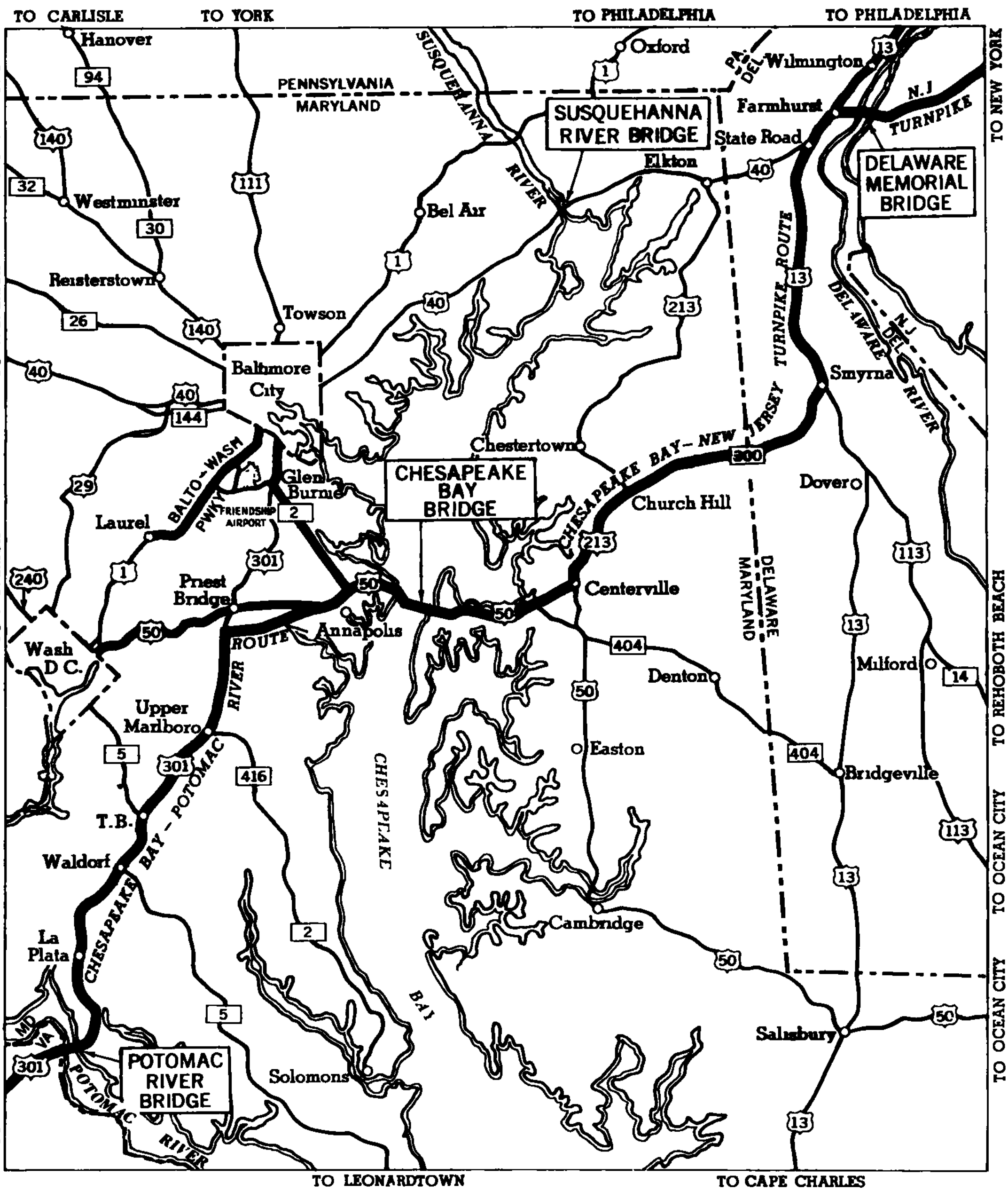


Figure 1. North-south route between the New Jersey Turnpike and the south via the Chesapeake Bay Bridge.

based on a normal 15 percent increase for the period, is the estimated average daily traffic for 1953, the first full year of the operation of the Chesapeake Bay Bridge. The apex of the speckled triangle indicates the actual average daily traffic for 1953, which reflects an increase (upright triangle) or decrease (inverted triangle). By following with the eye the routes acting as feeders for the Chesapeake Bay Bridge and the bridge itself, it may be noted that there are substantial increases along these lines. Conversely, the parallel north-south routes (US 40 and US 13), while showing traffic increases over 1951, do not, in many instances, equal the estimated 1953 volumes. It is our thought that this map proves beyond a reasonable doubt that the bridge route had diverted traffic from other major north-south routes.

The next step was to determine if possible, some information regarding this diverted traffic. Were they long trips, short trips, sightseers out for a look at the bridge? Or were we wrong in assuming that the traffic increases shown in Figure 2 were being diverted from other routes?

Fortunately we had some basic data with which to work. In the summer of 1952, a comprehensive study was made to determine the feasibility of operating the ferryboats between several points in the lower Chesapeake Bay. In connection with this study, a number of origin-and-destination studies were made, which included one at the ferry toll booths prior to the opening of the bridge and another at the toll plaza of the bridge approximately a month later. Realization that this significant material was available for comparative purposes resulted in the preparation of a short report and the hope that it would be possible to continue these origin-and-destination studies each year on approximately the same weekday as the first two studies.

We were most fortunate in that there have been three origin-and-destination studies on the Chesapeake Bay Bridge in addition to the one from which the pattern of the ferry traffic was obtained.

The volume of traffic, by type of vehicle, for each of these studies is shown in the tabulation at the top of page 45, in addition to the date and day of week the interviews were obtained:

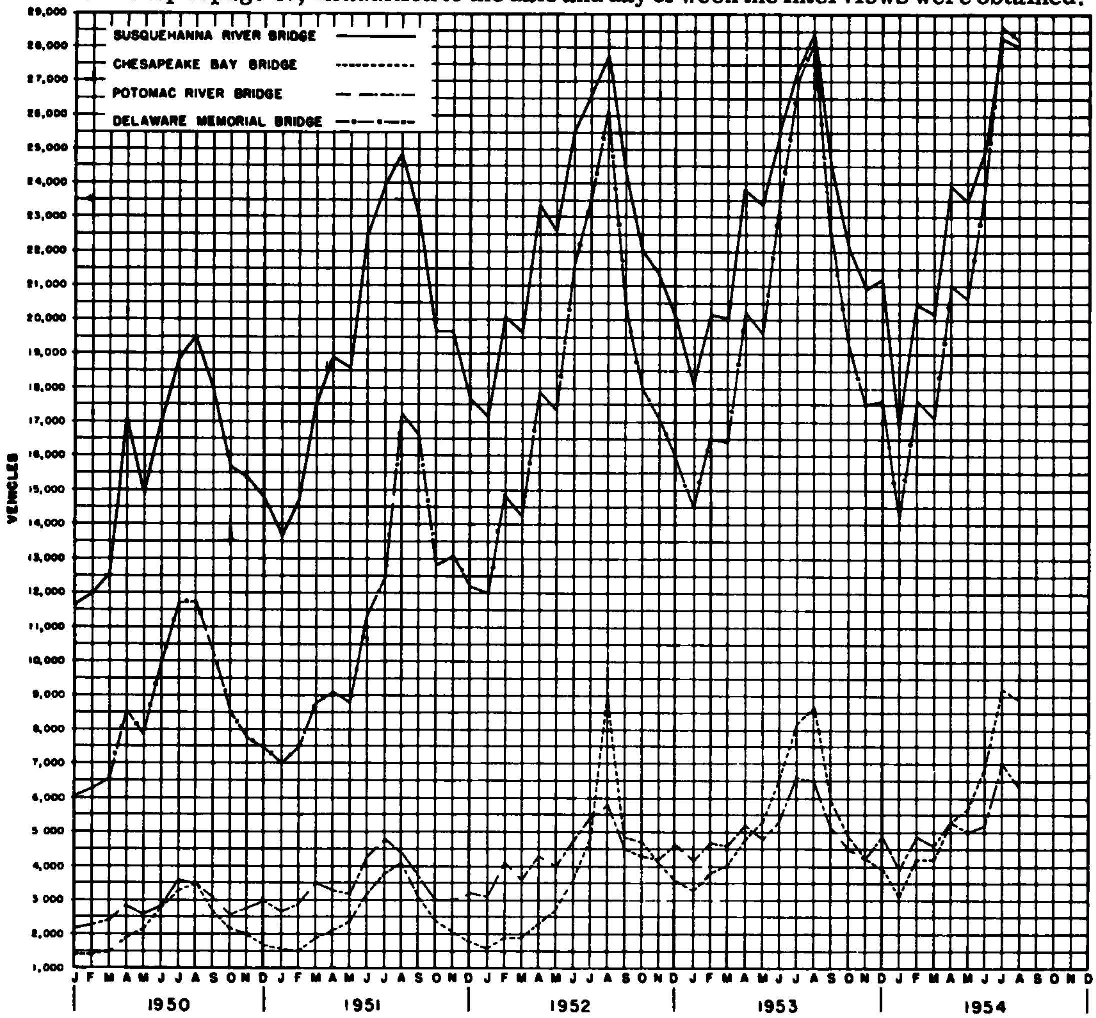


Figure 2. Comparison of monthly traffic 1950-1954 toll facilities on major north-south routes through Maryland.

Facility	Day of Week and Date	Pass. Cars		Comm. Vehicles		Total	
		No.	%	No.	%	No.	%
Ferry	Thursday July 24, 1952	2,547	79	670	21	3,217	100
Bridge	Wednesday Aug. 26, 1952	5,953	87	864	13	6,817	100
Bridge	Wednesday Aug. 28, 1953	5,080	84	955	16	6,035	100
Bridge	Wednesday Aug. 25, 1954	5,618	83	1120	17	6,738	100

Your attention is directed to the total volume figure for the bridge in 1952, which is higher than the volumes for the two subsequent years. The date was chosen for the study four weeks after the opening of the bridge to traffic with the hope that the bulk of the sightseeing traffic would be over and the Labor Day traffic would not have started to move. Unfortunately, some portions of each of these types of traffic were encountered, which resulted in a higher volume of traffic for the 1952 study than was present in the two subsequent bridge studies.

During the 1953 origin-and-destination study, a separate record was made of the license plates of the cars to determine the state in which the vehicles were registered. The results indicated that 42 percent of the passenger cars were foreign, and 58 percent were native Marylanders. In May of 1954, a similar record was made for a full week period, which showed 45 percent foreign and 55 percent local (see Table 3).

From the origin-and-destination data, Table 4 was prepared, showing a detailed comparison of the number of origins and destinations generated by various significant locations on either side of the bridge, (see Figure 5). The metropolitan areas of Baltimore and Washington, which account for approximately 70 percent of the traffic generation on the west side of the bay in both the ferry and bridge studies, showed gains of 65 percent and 77 percent, respectively, in the number of origins and destinations for 1954 as compared with the ferry traffic in 1952. The traffic generated by Virginia increased 364 percent in 1952, 247 percent in 1953 and 756 percent in 1954. The Virginia trips in 1954 amounted to 10 percent of the total, as compared with 1.3 percent of the ferry traffic in 1952.

On the eastern side of the bridge the origins and destinations were spread over a larger area, with Ocean City leading with better than 20 percent of the total for each period under study. The trips generated by the entire Eastern Shore area, including Ocean City, Delaware, and the Eastern Shore of Virginia, which represented 96 percent of the total ferry trips in 1952, increased from 3,090 to 5,877 in 1952 and dropped to 4,976 in 1953, but rose again to 5,284, 78 percent of the total in 1954. It is entirely possible that the decrease of Eastern Shore trips in 1953 reflects the number of sightseers who crossed the bridge during its first month of operation in 1952. An interesting fact is indicated by the number of trips generated by the area north of Wilmington, Delaware, including New York, New Jersey, and New England, which amounted to only 122, or 4 percent of the total ferry trips in 1952, increased immediately during the first bridge study in 1952 to 1,023 trips, amounted in 1953 to 993 trips, and increased to 1,454 trips, representing 22 percent of the total bridge trips, in 1954. These gains were, percentagewise: 739, 714, and 1,092 over similar trips on the ferry.

The increase in the trips from the north and from Virginia and farther south led to the desire to learn something about the trip lengths. Accordingly, Table 5 and Figure 6 were prepared. Reference to the figure indicates, by the large initial increases in trips of shorter length in 1952, that a number of persons wished to cross the bridge and return after seeing it. The steady increases year to year of the trips in the 100-to-200-mile range reflects the previous findings of this report. The tabulation also indicates by volume and percentage increase the fact that a large portion of the induced traffic is in the trips with higher mileages, 200 to 300 miles and 300 miles or over, which latter category

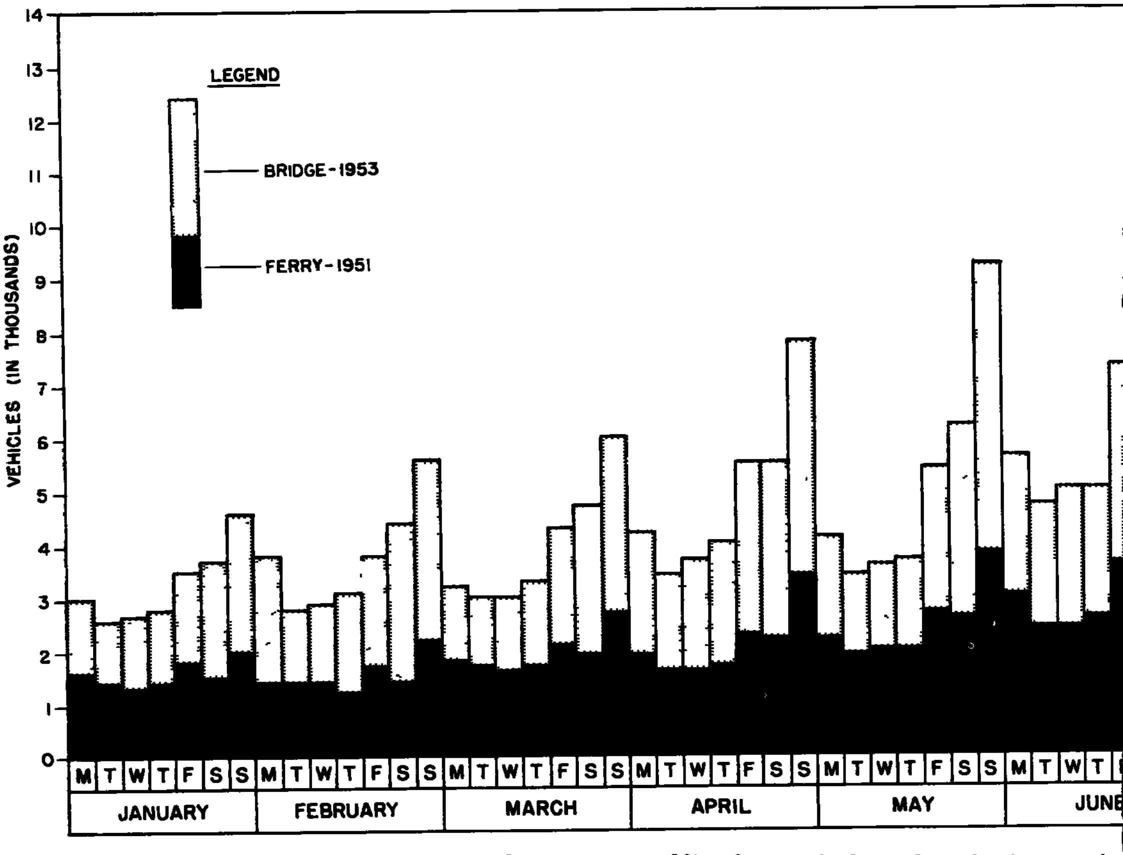


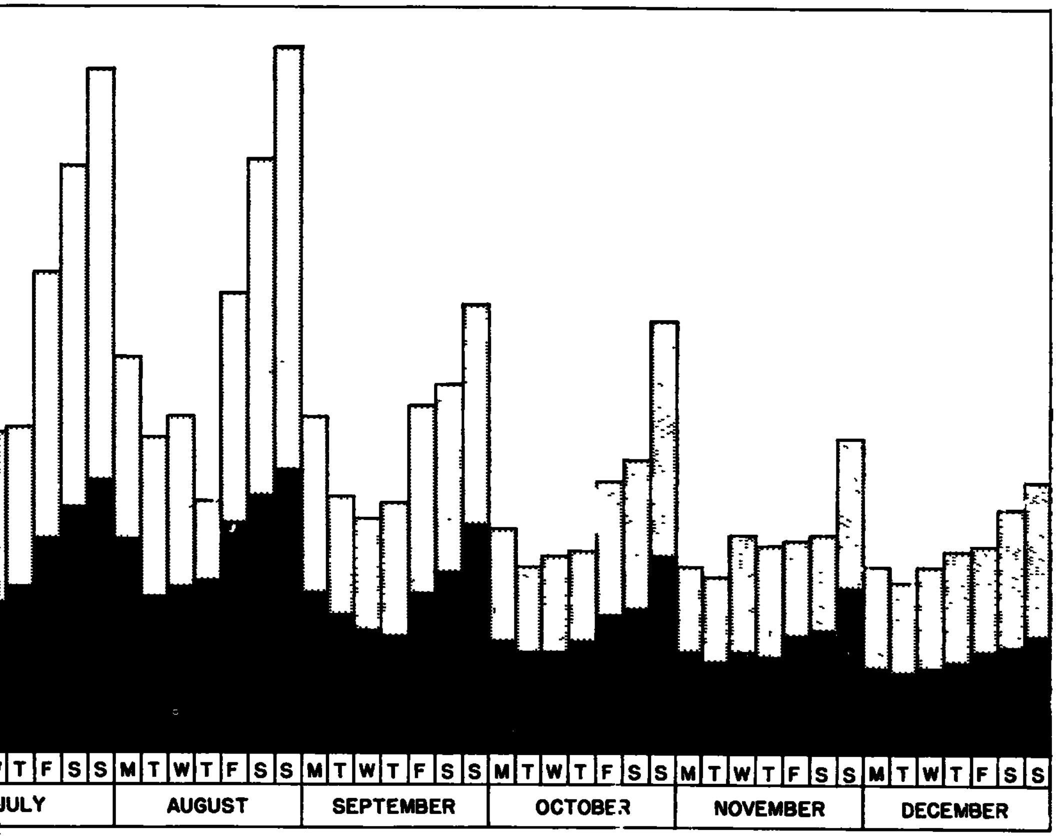
Figure 3. Comparison of average traffic for each day of week, by month,

TABLE 3

CHESAPEAKE BAY BRIDGE

Number of passenger cars, and panel or pick-up trucks crossing by day of week and state of registration - May 23-29, 1954

State of Registration	Sunday No.	%	Monday No.	%	Tuesday No.	%	Wednesday No.	%	Thursday No	%	Friday No.	%	Saturday No.	%	Total No.	%
Virginia	550	6	240	7	164	5	158	5	209	6	581	8	671	7	2573	7
District of Columbia	520	6	157	4	134	4	127	4	131	4	462	7	773	9	2304	6
New York	236	3	178	5	133	4	171	5	219	6	487	7	620	7	2044	5
New Jersey	276	3	145	4	120	4	159	5	191	6	433	6	635	7	1959	5
Pennsylvania	371	4	168	5	103	4	151	5	174	5	398	6	574	6	1939	5
Delaware	411	5	175	5	157	5	166	5	175	5	325	5	356	4	1765	5
Florida	126	2	152	4	146	5	150	5	150	4	154	2	131	1	1009	3
Connecticut	70	1	64	2	45	1	39	1	69	2	111	2	106	1	504	1
Massachusetts	52	1	55	2	52	2	43	1	61	2	94	1	121	1	478	1
North Carolina	55	1	28	1	30	1	32	1	46	1	80	1	75	1	346	1
Ohio	31	-	29	1	21	1	27	1	26	1	41	1	53	1	228	1
Sub-total	2698	32	1391	40	1105	36	1223	38	1451	42	3166	46	4115	45	15149	40
Other Foreign	353	4	226	6	210	7	154	4	219	6	339	5	387	4	1888	5
Total Foreign	3051	36	1617	46	1315	43	1377	42	1670	48	3505	51	4502	49	17037	45
Maryland	5496	64	1897	54	1738	57	1872	58	1817	52	3350	49	4588	51	20758	55
Grand Total	8547	100	3514	100	3053	100	3249	100	3487	100	6855	100	9090	100	37795	100



apeake Bay Ferry, year of 1951, and Chesapeake Bay Bridge, year of 1953.

totalled 1,249 trips in 1954, or an increase of 554 percent over similar trips via the ferry in 1952.

From the pattern developed during the previous part of this study, it is obvious that there is additional traffic on the Chesapeake Bay Bridge far over and above that anticipated at the time of its opening to traffic. It is not so obvious whether this traffic has been diverted from a particular route, since several complications make this practically impossible to determine without a series of similar repeated studies on all other parallel routes timed to coincide with the bridge origin-and-destination studies. Localized increases in traffic volumes, added attractiveness of vacation resorts, new housing developments, and other variable factors are all difficult to estimate without comprehensive factual data.

In support of the theory that the entire Eastern Shore area has grown as a traffic generator, we have two studies on US 40, one made at the Delaware line in 1952 and another near North East in 1954, which indicated that the number of vehicles proceeding around the head of the Chesapeake Bay to Eastern Shore destinations has actually increased over the 1952 volumes. It has already been demonstrated that the number of trips to the Eastern Shore by bridge have almost doubled. Much of these two increases can be attributed to the traffic attractiveness of the bridge and to the development on the Eastern Shore, which has resulted from the fact that the bridge has made it less time consuming and more worthwhile to do business and visit socially or recreationally across the bay.

During another study made on US 301, south of US 50, where traffic must turn off US 301 to cross the bay bridge, motorists were questioned as to whether or not they used the Chesapeake Bay Bridge in proceeding from origins to destinations. Of the total 8,000 interviews, 2,100 were potential bridge users, and 1,200, or 56 percent of this potential, reported using the bridge. Since the ferry study indicated a low volume of trips

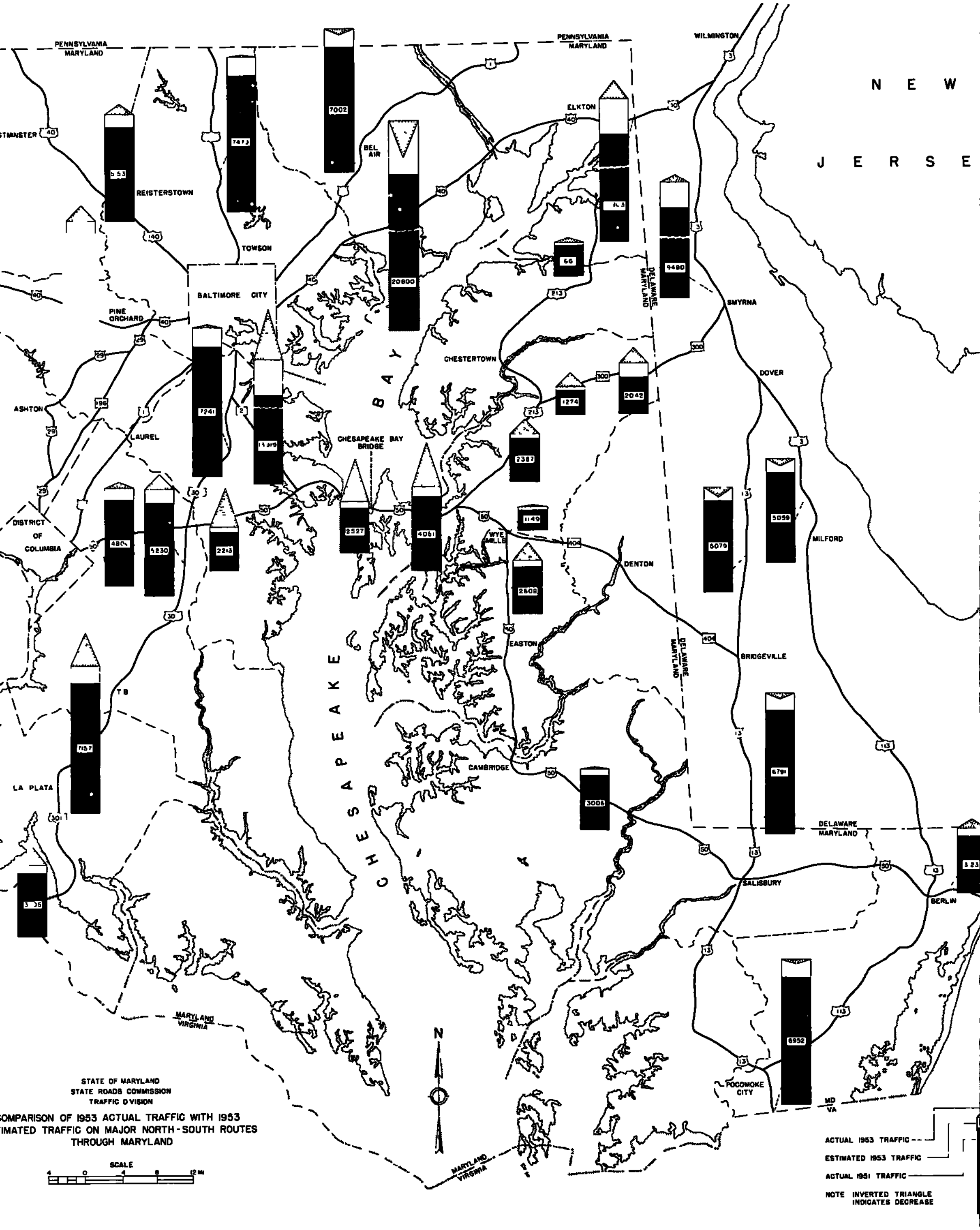

PENNSYLVANIA
MARYLAND
NEW
JERSEY
WILMINGTON
ELKTON
BEL AIR
REISTERSTOWN
TOWSON
BALTIMORE CITY
PINE ORCHARD
ASHTON
LAUREL
DISTRICT OF COLUMBIA
LA PLATA
CHESTERTOWN
CHESAPEAKE BAY BRIDGE
WYE MILLS
EASTON
DENTON
CAMBRIDGE
SMYRNA
DOVER
MILFORD
BRIDGEVILLE
SALISBURY
BERLIN
POCOMOKE CITY
DELAWARE
MARYLAND
MD
VA
MARYLAND
VIRGINIA
CHESAPEAKE BAY
7002
7473
20800
9480
66
1274
2042
7241
14319
2387
1149
2527
4061
2608
4804
5230
2213
5079
5059
7157
3006
6791
6952
STATE OF MARYLAND
STATE ROADS COMMISSION
TRAFFIC DIVISION
COMPARISON OF 1953 ACTUAL TRAFFIC WITH 1953 ESTIMATED TRAFFIC ON MAJOR NORTH-SOUTH ROUTES THROUGH MARYLAND
SCALE
ACTUAL 1953 TRAFFIC
ESTIMATED 1953 TRAFFIC
ACTUAL 1951 TRAFFIC
NOTE INVERTED TRIANGLE INDICATES DECREASE

Figure 4.

TABLE 4

CHESAPEAKE BAY BRIDGE AND FERRY STUDIES
COMPARISON OF ORIGINS AND DESTINATIONS

	ORIGINS AND DESTINATIONS	FERRY - 1952 Number	FERRY - 1952 Percent	BRIDGE - 1952 Number	BRIDGE - 1952 Percent	BRIDGE - 1952 Bridge/Ferry	BRIDGE - 1953 Number	BRIDGE - 1953 Percent	BRIDGE - 1953 Bridge/Ferry	BRIDGE - 1954 Number	BRIDGE - 1954 Percent	BRIDGE - 1954 Bridge/Ferry
West Side	Baltimore	1909	59.4	3522	48.7	+74	2977	49 3	+56	3143	46 6	+65
	Washington	822	25.6	1672	24 5	+103	1495	24 8	+82	1459	21.7	+77
	Annapolis	130	4.0	673	9.9	+418	464	7 7	+257	390	5.9	+200
	Southern Maryland	16	0.5	46	0 7	+188	41	0.7	+156	30	0.4	+88
	Western Maryland	59	1 8	92	1 4	+56	127	2.1	+115	88	1.3	+49
	Virginia	78	1 3	362	5 3	+364	271	4 5	+247	668	9.9	+756
	Other Southern States	83	3.7	375	5 5	+352	406	6 7	+389	675	10.0	+713
	Philadelphia	6	0 2	10	0.1	+67						
	New York	4	0.1	17	0 2	+325	5	0.1	+25			
	Other Northern States	4	0 1	6	0.1	+50						
	Other Western States	106	3 3	242	3.6	+128	249	4.1	+135	285	4.2	+169
	Total	3217	100 0	6817	100 0	+112	6035	100.0	+88	6738	100.0	+109
East Side	Kent Island	279	8.7	626	9 2	+124	661	10.9	+137	535	7.9	+92
	Centreville	57	1 8	439	6 4	+670	170	2.8	+198	255	3 8	+347
	Chestertown	84	2 6	221	3 3	+163	196	3 2	+133	200	3.0	+138
	Dover, Delaware	215	6 7	175	2 6	-19	107	1 8	-50	321	4.8	+49
	Easton	427	13 3	783	11.5	+83	651	10.8	+52	636	9.4	+149
	Denton	87	2.7	124	1.8	+41	110	1.8	+26	171	2 5	+20
	Federalsburg	27	0.8	121	1.8	+348	138	2.3	+41	127	1 9	+47
	Cambridge	247	7.7	412	6.0	+67	366	6 1	+48	387	5.7	+57
	Salisbury	441	13.7	555	8.1	+26	488	8.1	+11	521	7.7	+18
	Crisfield	66	2.1	69	1.0	+5	113	1.9	+71	92	1.4	+39
	Southern Delaware	247	7.7	532	7 8	+115	503	8.3	+104	550	8.2	+123
	Eastern Shore - Virginia	76	2.1	142	2 1	+110	83	1 4	+9	178	2.6	+134
	Ocean City	837	26.2	1578	23 2	+89	1390	23.0	+1560	1311	19.5	+1466
	Philadelphia	17	0.5	131	1 9	+670	156	2.6	+817	233	3 5	+1270
	New Jersey	35	1 1	310	4.6	+786	269	4.5	+669	431	6.4	+1131
	New York	49	1 5	327	4.8	+567	310	5.1	+533	494	7.3	+908
	Other Northern States	13	0 4	201	3 0	+1446	217	3.6	+1569	262	3.9	+1015
	Virginia	3	0 1	7		+133	26	0.4	+767			
	Other Southern States	2	0 1	10	0.1	+400	40	0.7	+1900			
	Elkton	4	0.1							4	0.1	
	Wilmington, Delaware	4	0 1	54	0.8	+1250	41	0.7	+925	30	0.4	+650
	Total	3217	100.0	6817	100.0	+112	6035	100.0	+88	6738	100.0	+109
	Passenger Cars	2547	79.0	5953	87.0	+134	5080	84.0	+99	5618	83.0	+121
	Trucks and Buses	670	21.0	864	13.0	+29	955	16.0	+43	1120	17.0	+67

TABLE 5

CHESAPEAKE BAY BRIDGE ORIGIN AND DESTINATION STUDIES
Number of trips by length of trips using Chesapeake Bay Ferry or Chesapeake Bay Bridge

TRIP MILEAGES	FERRY - 1952 Number	FERRY - 1952 Percent	BRIDGE - 1952 Number	BRIDGE - 1952 Percent	BRIDGE - 1952 Bridge/Ferry	BRIDGE - 1953 Number	BRIDGE - 1953 Percent	BRIDGE - 1953 Bridge/Ferry	BRIDGE - 1954 Number	BRIDGE - 1954 Percent	BRIDGE - 1954 Bridge/Ferry
Under 25	25	0.8	149	2.2	+496	123	2 0	+392	79	1 2	+216
25-50	308	9 6	887	13 0	+188	719	11.9	+133	670	9.9	+118
50 - 100	1,124	34.9	1,858	27.2	+ 65	1,571	26 0	+ 40	1,804	26 8	+ 60
100 - 150	996	31.0	1,818	26 7	+ 83	1,603	26 6	+ 61	1,559	23.1	+ 57
150 - 200	442	13.7	876	12.9	+ 98	794	13 2	+ 80	814	12 1	+ 84
200 - 250	93	2.9	289	4.2	+211	264	4.4	+184	364	5 4	+291
250 - 300	38	1 2	99	1.5	+161	74	1 2	+ 95	199	3.0	+424
300 and over	191	5.9	841	12.3	+340	887	14 7	+364	1,249	18.5	+554
Total	3,217	100 0	6,817	100.0	+112	6,035	100.0	+ 88	6,738	100.0	+109

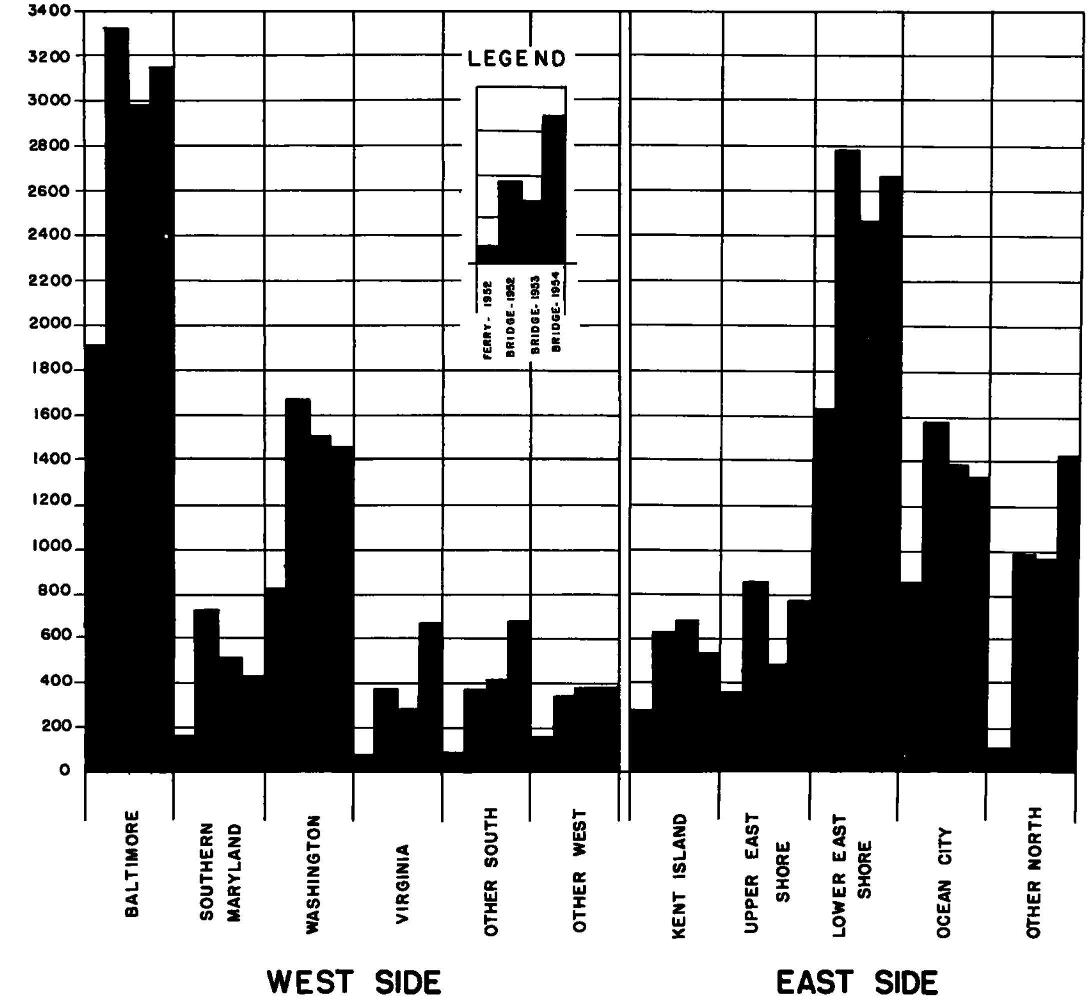


Figure 5. Comparison of origins and destinations Chesapeake Bay Bridge studies.

from the area served by the lower portion of US 301 and the subsequent bridge studies showed much higher volumes for this category, it can be assumed that at least 50 percent of the potential US 301 traffic was diverted to the Chesapeake Bay Bridge from the combined US 301 and US 40 north-south route. While not conclusive, considerable support of this contention may be found in Table 4. Reference to this table indicates that the total number of trips generated by southern Maryland, Virginia, and other Southern states, a great many of which would normally traverse US 301, amounted to 177 in 1952 via the ferry, and 1,373 in 1954 via the bridge. The increase of 1,196 is approximately the same as the 1,200 bridge trips reported in the US 301 origin-and-destination study. Allowances for seasonal changes in volumes and travel habits would probably widen the gap between these two figures but not enough to contradict the fact thtat most of these 1,200 trips are now using the Chesapeake Bay Bridge instead of US 40 north.

In line with this thought, a 15-percent increase in traffic has been applied to the total 3,217 trips recorded on the 1952 ferry study, making an estimated total of 3,700 trips which could be expected on the bay bridge in 1954. The difference, approximately, 3,000 trips, is more than likely induced traffic and amounts to 45 percent of the total traffic on the bridge at the time of the study. A similar rate of increase has been added to the several trip categories, with the result that the estimated induced traffic of 3,000 trips can be broken down into 1,200, between the South and the Eastern Shore and other northern points, 1,400 between the Eastern Shore and all points except the south, 300 between the North all all other points south of Maryland. The remaining 100 trips are made up of a number of different origin-and-destination groups, none of which is large enough to mention separately. The comparative flow of traffic by direction of travel is shown in Figure 7.

It is felt that this study has indicated a few rather significant facts regarding induced traffic on the Chesapeake Bay Bridge. Among these are:

1. The traffic volumes on the Chesapeake Bay Bridge include a considerable volume of induced traffic approximately 45 percent of the total traffic.

2. This induced traffic is of two kinds: that which formerly traversed longer routes and that which is due to the expansion of commercial and recreational facilities on the Eastern Shore which are believed to have developed because of the bridge.

3. The induced traffic attracted from other routes in addition to the estimated diverted traffic prefers the shorter time and distance involved, even though a considerable portion of the new route leaves much to be desired in the way of alignment and width.

4. The greater the overall trip length the more likely traffic will be attracted to a new route.

5. The traffic pattern, while varying seasonally, continues to reflect the higher volumes, including the induced traffic, throughout the week and for each month of the year.

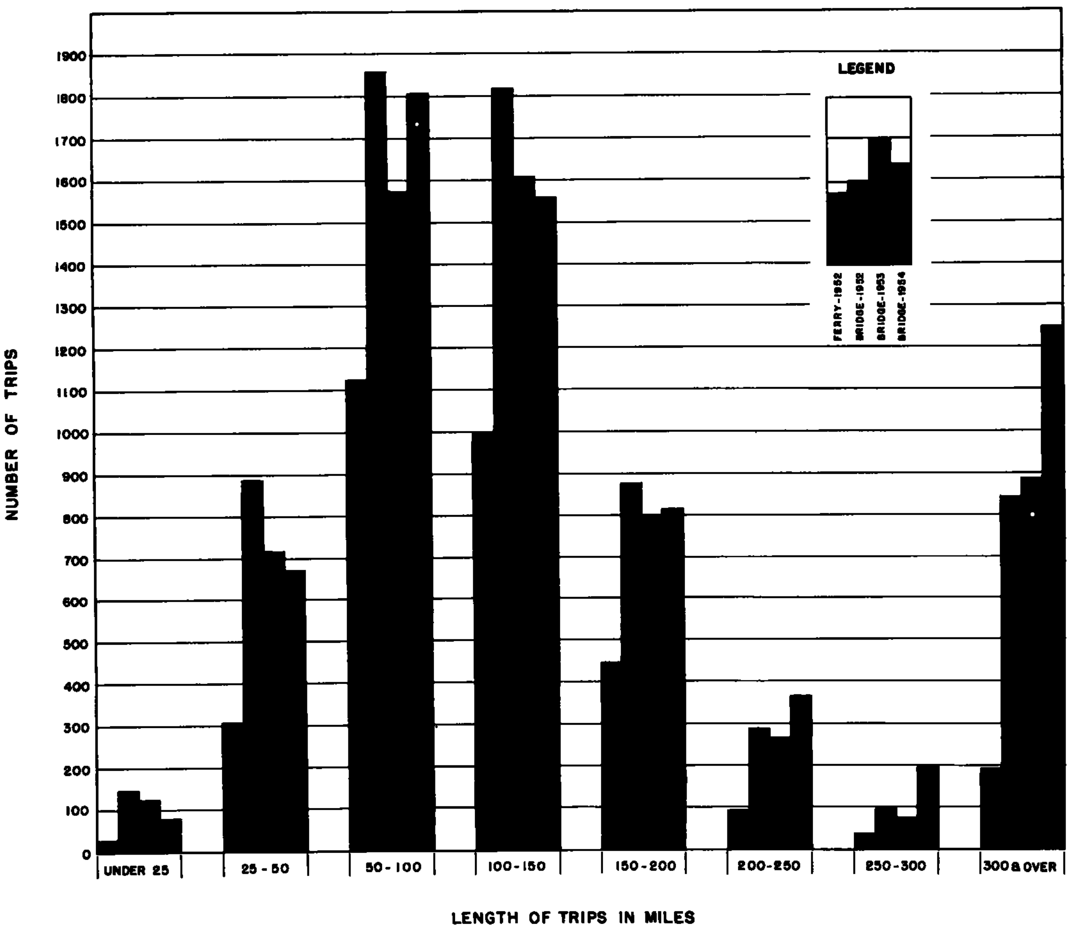
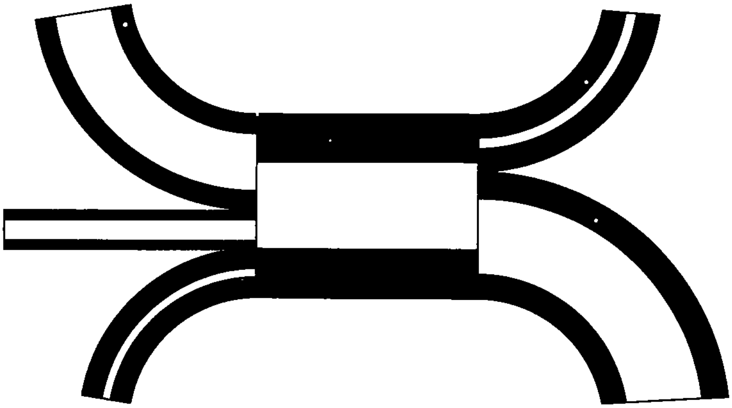


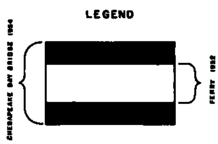
Figure 6. Number of trips by length of trip using Chesapeake Bay Ferry or Chesapeake Bay Bridge.

TRIPS BETWEEN BALTIMORE AND BEYOND AND	Ferry 1952	Bridge 1954	Percent Change
Lower Eastern Shore	1889	2915	+ 54
Upper Eastern Shore	179	446	+ 149
Other North	20	155	+ 675
TOTAL	2088	3516	+ 68

TRIPS BETWEEN UPPER EASTERN SHORE AND THE NORTH AND	Ferry 1952	Bridge 1954	Percent Change
Baltimore	194	527	+ 172
Washington, D C.	193	484	+ 151
Southern Maryland	35	137	+ 291
Virginia	14	389	+2679
Other South	37	619	+1573
Other West	5	74	+1380
TOTAL	478	2230	+ 367

TRIPS BETWEEN WASHINGTON, D C AND VICINITY AND	Ferry 1952	Bridge 1954	Percent Change
Lower Eastern Shore	629	975	+ 55
Upper Eastern Shore	140	169	+ 21
Other North	53	315	+ 494
TOTAL	822	1459	+ 77





TRIPS BETWEEN SOUTHERN MARYLAND AND BEYOND AND	Ferry 1952	Bridge 1954	Percent Change
Lower Eastern Shore	221	618	+ 180
Upper Eastern Shore	37	161	+ 335
Other North	49	984	+1908
TOTAL	307	1763	+ 474

TRIPS BETWEEN LOWER EASTERN SHORE AND BEYOND AND	Ferry 1952	Bridge 1954	Percent Change
Baltimore	1774	2704	+ 52
Washington, D C.	629	975	+ 55
Southern Maryland	111	283	+ 155
Virginia	64	279	+ 336
Other South	46	56	+ 22
Other West	101	211	+ 109
Other North	14	-	-
TOTAL	2739	4508	+ 65

Figure 7. Comparative traffic flow map, 24 hour traffic.

While this study was made for the primary purpose of determining how the Chesapeake Bay Bridge has affected the traffic pattern and travel habits in Maryland, it is hoped that the material contained herein will be of use to others who would like to explore more deeply into this question of induced traffic.

Until similar studies have been made in the several sections of the country, (both urban and rural areas and with varying conditions of terrain and traffic) and a broad sample has been obtained, the problem of estimating the amount of induced traffic will continue to be a baffling one.

Intracity Traffic Movements

F. HOUSTON WYNN, Assistant Professor
Bureau of Highway Traffic, Yale

● WITHIN the past decade, the daily travel habits of urban populations have been intensively studied by a host of investigators. Sociologists, economists, engineers, politicians, and many others have all found reasons to investigate specific aspects of intracity travel and the problems of street and terminal capacity which it creates. Much serious work has been done by persons seeking solutions to specific problems or making intensive study of a particular urban community. Few researchers have attempted to discover the characteristics of urban travel that are common to all communities.

About 5 years ago, a research project was set up at the Yale Bureau of Highway Traffic to investigate the fundamental nature of urban travel and to devise practical techniques for the measurement of characteristics which might be identified. Since this research was begun, a great deal has been learned about some aspects of intracity travel. Needless to say, a great deal still remains to be found out. The Yale Bureau studies, soon to be published, constitute a voluminous and detailed report. This paper constitutes a synopsis of the studies on automobile travel within the urban limits of modern American cities.

The principal source materials for these investigations have come from the home-interview origin-destination surveys cosponsored by the Bureau of Public Roads and various state and city agencies since 1944. About a hundred such studies have been made throughout the United States within the past 10 years.

Considerable time and effort was devoted to an evaluation of these home-interview data prior to using them for an analysis of urban-travel characteristics. Trip tabulations and other home-interview materials were obtained from about 60 cities, and studies which appeared to be most complete and which required the least adjustment were selected for further analysis. Twenty post-war studies were picked for the initial investigations.

TOTAL INTERNAL TRAVEL

Initial stages of the urban travel studies were based on the broadest possible investigations. The gross number of internal trips performed by all members of each urban community was determined, disregarding travel mode, and the overall trip volumes for all 20 cities plotted against community size (Fig. 1). Total internal travel in all cities appears to be directly proportional to urban population without regard to the geographic location of the community or the year of study, although the correlation found is far from perfect.

INTERNAL WORK TRIPS

At the second level of investigation, work trips were segregated from trips made for other purposes. The argument for doing so was based on the finding that work trips were more-completely reported in the home interviews than trips for other purposes. Work trips also constitute the largest category of trips by purpose. Furthermore, the labor force in an urban population constitutes about 40 percent of the residents in most census tracts and is, therefore, distributed throughout most of the area in direct proportion to population distribution. If about the same proportion of the labor force in each city can be expected to report to work each day, it would seem that work trips should be made in direct proportion to the size of the population pool. Investigation of the twenty cities show that such is indeed the case (Fig. 2). Work trip volume is found to be more consistently related to city size than is the over-all volume of internal travel generated by urban populations (Fig. 1).

INTERNAL AUTO-DRIVER WORK TRIPS

Work trips were next related to mode of travel to and from place of employment (auto driver or transit rider). When the total daily volume of internal work trips was plotted against city size, a rather wide variation in average per capita trips was found for auto

TABLE 1

TWENTY HOME-INTERVIEW ORIGIN-DESTINATION STUDIES

Population, Dwelling Unit Occupany, Vehicle Registration

No.	City and State	Year of Study	Pop. of Study Area (thous.)	Av. No. Persons Per Dwg. Unit	Private Autos Owned per 1000 pop.
1.	Minneapolis, Minn.	1949	585	3.0	255
2.	Seattle, Washington	1946	519	2.8	288
3.	Portland, Oregon	1946	453	3.0	231
4.	St. Paul, Minnesota	1949	331	3.1	235
5.	Grand Rapids, Mich.	1947	221	3.4	239
6.	Salt Lake City, Utah	1946	197	3.4	194
7.	Tacoma, Washington	1948	139	2.9	253
8.	Spokane, Washington	1946	138	2.9	215
9.	Tucson, Arizona	1948	127	3.3	260
10.	Lansing, Michigan	1946	123	3.4	247
11.	Albuquerque, N.M.	1949	116	3.3	237
12.	Saginaw, Michigan	1948	113	3.5	239
13.	Madison, Wisconsin	1949	104	3.1	243
14.	Duluth, Minnesota	1948	97	3.0	204
15.	Johnstown, Pa.	1949	88	3.8	158
16.	Muskegon, Mich.	1946	84	3.6	226
17.	Kalamazoo, Mich.	1946	72	3.2	238
18.	Bay City, Mich.	1948	69	3.5	229
19.	Sharon-Farrell, Pa.	1949	48	3.6	195
20.	Superior, Wisconsin	1948	34	3.2	172

driver travel (Fig. 3). Similar variation was found for the ratio of transit work trips to population in cities under 200,000 (Fig. 5). A remarkable correlation of transit work-trip-ratio to city size was found for cities larger than 200,000. The apparent stability of the curve shown is based on so few data, however, (only six cities) that it should be viewed with caution.

An attempt was next made to find the principal cause of work-trip deviations by mode. Inasmuch as total work trips (Fig. 2) are generated in direct proportion to population, variations by mode must be due to differences in the relative attractiveness of transit and auto travel in different cities. This could mean poor terminal facilities, relatively low auto ownership, especially convenient and attractive mass transportation, or a combination of these and other factors.

Since car-ownership data were available for each city, the effect of car ownership was tested against variations from the curves fitted to data in Figures 3 and 5.[1] From

[1] This is a graphic correlation technique suggested by Ezekiel. Deviations from the freehand lines of estimate in Figures 3 and 5 have been computed as a percentage of the value represented by the line, and the percentage deviations plotted against the ratio of cars to people in each city. If that ratio is the most-important cause of deviation from the original curve, the new series of points should line up in such a way that a curve can be fitted to them which will materially reduce the total amount of deviation found in the first instance. Such freehand curves have been fitted to plotted variations in Figures 4 and 6. The broken lines of Figure 4 represent a range of 10 percent above and below the values represented by the fitted curve. See: Ezekiel, Mordecai, "Short-Cut Methods of Determining Net Regression Lines and Curves," Chapter 16, Methods of Correlation Analysis, John Wiley and Sons, New York, 1930, pp. 229-241.

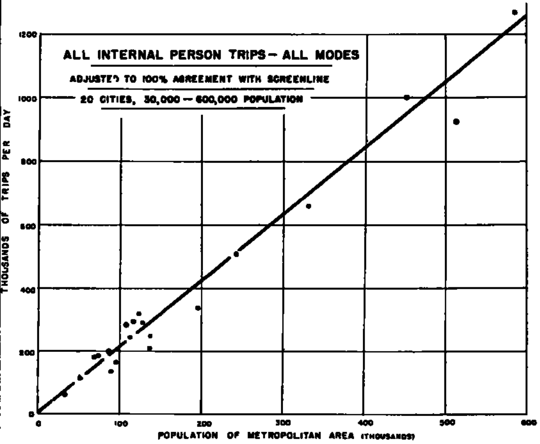


Figure 1.

these tests, it was clearly shown that the ratio of cars to population is indeed an important factor in the choice of travel mode to and from work. Figure 4 shows that most of the variation in auto trips to work is a function of car ownership. The deviations plotted in Figure 6 represent transit riders for only those cities under 200,000 population. High vehicle ownership is seen to be an important negative factor in the generation of work trips but is clearly not the only factor, aside from city size, which influences work trips by transit.

ALL INTERNAL CENTRAL BUSINESS DISTRICT TRIPS

Thus far, the studies have shown that city size has a consistent effect on the generation of travel within a city, being directly related to volume of trips generated by purpose (work) and by mode of travel (auto or transit). Another area worth investigating is that of land use.

Figure 7 shows the attractive power of the central business district in each of the 20 cities for all modes and purposes of travel.[2] A remarkably uniform pattern of central-business-district trip generation is shown for the 20 cities. A free-hand curve fitted to the data appears to show that the central business district attracts visitors from within the city at an increasing rate as cities increase in size. The data do not include walking trips, however, which are of considerable importance in small cities but lose importance as cities become larger and more spread out. It is also likely that the small number of cities in the range 200,000 to 600,000 are not a fair sample, since investigations of still larger cities (not shown) show that the central business district attracts internal trips at a decreasing rate as metropolitan area populations become very large.

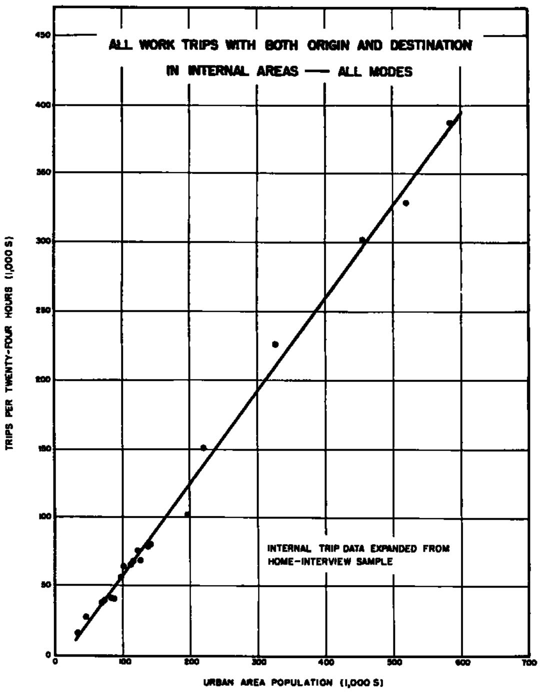


Figure 2.

[2] Initial investigations of central-business-district travel were based on trips generated in the business districts described in each city survey report. Wide discrepancies in relative trip attraction in some cities were traced to overzoning the central business district to include several times the area of greatest trip attraction. An effort was then made to identify the "core" area in each downtown business district. The core, as defined for the parking surveys and as used here, consists of a unified grouping of blocks, nearly all of which generate more auto trips than can be accommodated by parking spaces at curbs or offstreet in the blocks. Since trip data are available for study on a "zone" basis, it has been necessary to include small amounts of excess area where zone limits did not coincide with core area limits. The generation of trips in these marginal blocks is so low per unit of area, when compared to the core, that relatively little discrepancy should be expected from this source.

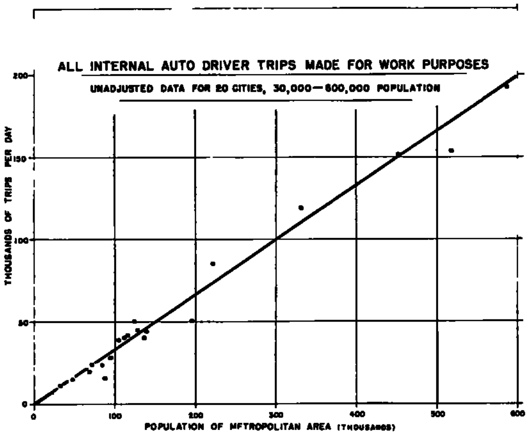


Figure 3.

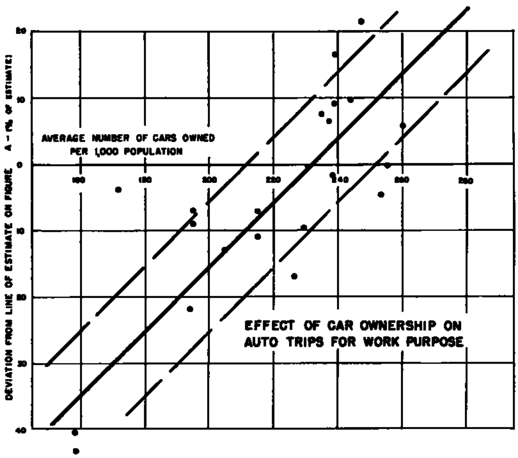


Figure 4.

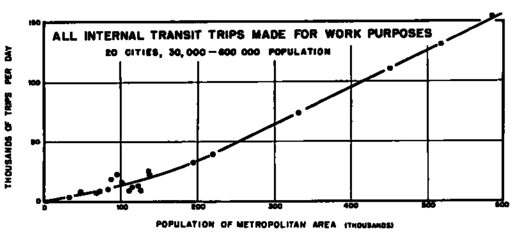


Figure 5.

DETAILED EXAMINATION OF CENTRAL BUSINESS DISTRICT TRIP DATA

At this point in the investigations, it became necessary to make a much-more-detailed analysis of the origin-destination data. Because the analyses are very involved when areas are studied by zones instead of on an overall basis, it was found desirable to reduce the number of cities studied. In doing so, however, the range of city size has been increased by adding

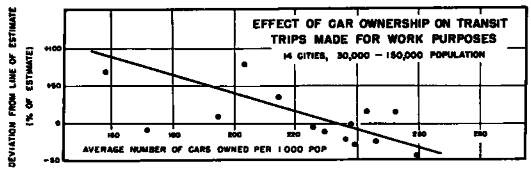


Figure 6.

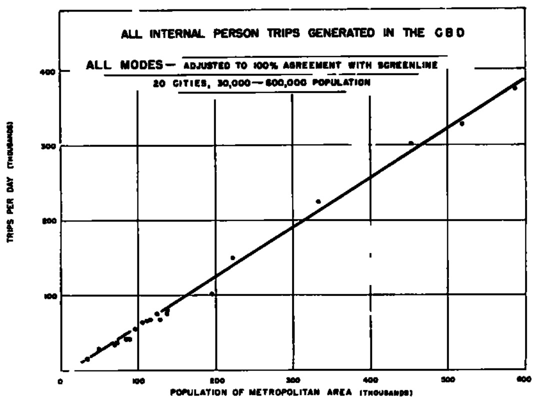


Figure 7.

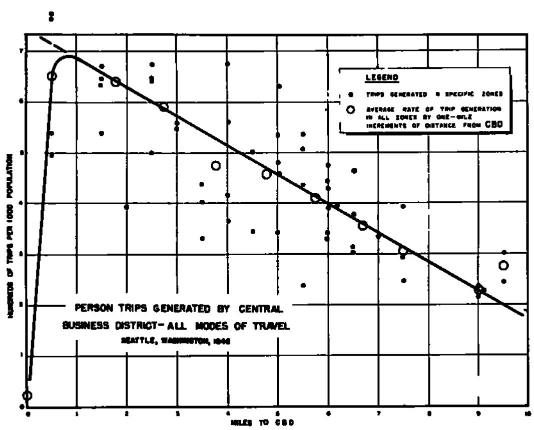


Figure 8.

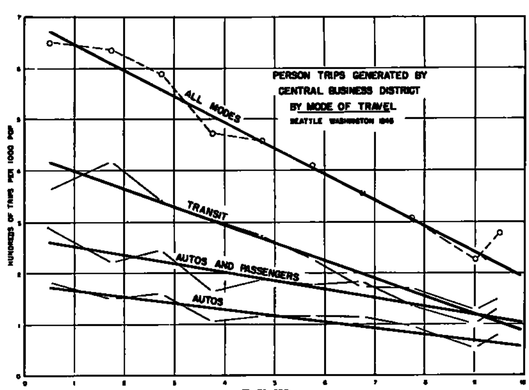


Figure 9.

TABLE 2

ORIGIN-DESTINATION STUDIES OF THE CENTRAL BUSINESS DISTRICT

City	Year of Survey	Met. Area pop. (thous.)	CBD Core	Trips Generated			
				Auto Dr.	Auto and Taxi Pass.	Transit	Total
Washington, D. C.[a]	1948	1,110	Sector 0	101,120	(Taxi 24,013) 93,278	302,608	497,006
Seattle, Wash.	1946	519	District 5 and 6-Zones 002-005, 007	50,948	(Taxi 13,085) 47,500	177,670	275,118
			012-017	72,073	36,288	146,538	254,899
Portland, Oregon	1946	453	Zones 023, 031-036, 041, 042, 053	71,173	34,044[3])	120,083	225,300
Honolulu, T. H.	1947	214	Zones 001, 002, 011, 012, 021, 022	33,429	16,714[3])	42,853	92,996
Wilmington, Del	1948	181	Zones 015, 021-025	26,939	17,006	41,707	85,652
Tacoma, Wash.	1948	139	District 00	27,194	11,127	27,818	66,139
Albuquerque, N. M.	1949	116	Zones 000, 001	26,433	15,939	16,984	59,410
Bay City, Mich.	1948	69	Zone 144	23,784	12,687	8,922	45,393
Kenosha, Wis.	1950	56	Zones 111 and 121	16,107	7,610	7,720	31,437

[a] Data for all of Sector "0" have been used to represent the District of Columbia. Districts "5" and "6" within the sector represent the principle retail areas and generate a little more than half of Sector "0" volume. Government offices are the principle generators in the rest of the sector and while they may or may not represent a normal central business district function, the lumping of all sector "0" trip generation results in a trip volume that is approximately the amount expected from extrapolation of the line of estimate on Figure 7. Figure 7 was prepared from data limited to cities under 600,000 pop. - none of them more than half the size of Washington at the time of its study and can only be applied experimentally to Washington data. Data from other large cities will have to be tested before this extension of the curve can be evaluated.

a larger city (Washington, D. C.) and a smaller city (Kenosha, Wisconsin) to the list.

Another consideration which came to mind at this time related to the shape of a city's pattern of growth. If the study was restricted to cities which were so located that they had developed equally in all directions from the central business district, would travel characteristics and other relationships which might be derived from study of those cities apply to communities of less regular shape? To avoid this uncertainty, a diverse group of cities was selected for study with the hope that any characteristics common to the group would be representative of all cities within a similar range of size. The cities selected for these studies are listed in Table 2.

CENTRAL-BUSINESS-DISTRICT TRIPS RELATED TO LENGTH OF TRIP

Since the central business district seems to attract trips from within the metropolitan area in direct proportion to the size of the population pool, it might be expected that such trips are uniformly distributed throughout the urban populace. Such is not the case, however. Figure 8 is a plot of trips generated in the central business district.[3]

The daily rate of central-business-district trip generation per 1,000 population in Seattle is shown to deteriorate rapidly as distance from the central business district increases. Populations 9 miles from the central business district generate travel at only a third of the rate for populations at 1 mile. The rate of trip generation appears to depreciate uniformly with distance between those points.

Investigations of central business district trips versus distance from central business

[3] Distances were measured along the shortest route by existing streets between the approximate center of the central business district and the center of population in each zone. Distances were rounded to the nearest ½ mile and plotted as shown. Data were then combined for travel between central business district and all zones at each increment of distance. Average rates of trip generation were computed by 1-mile increments, and these averages were plotted. A free-hand regression curve was then fitted to the plot of 1-mile averages, and the deviations from this line subject to statistical examination. All points are within acceptable range of the regression curve, considering the number of trips and size of sample involved in each case. Within a mile of the central business district, walking trips account fot the decline in rate of trip generation by car and transit.

district for a number of other cities (not illustrated) disclose similar behavior patterns. In every case the rate of trip generation decreases with distance. Even so, it is difficult to reconcile the curve shown in Figure 7 with such a variable rate of trip generation related to travel distance as is shown here.

CENTRAL-BUSINESS-DISTRICT TRIPS RELATED TO LENGTH AND MODE OF TRAVEL

When trips generated in the central business district for all purposes are plotted by mode against length, several interesting relationships appear. First, trips by each mode

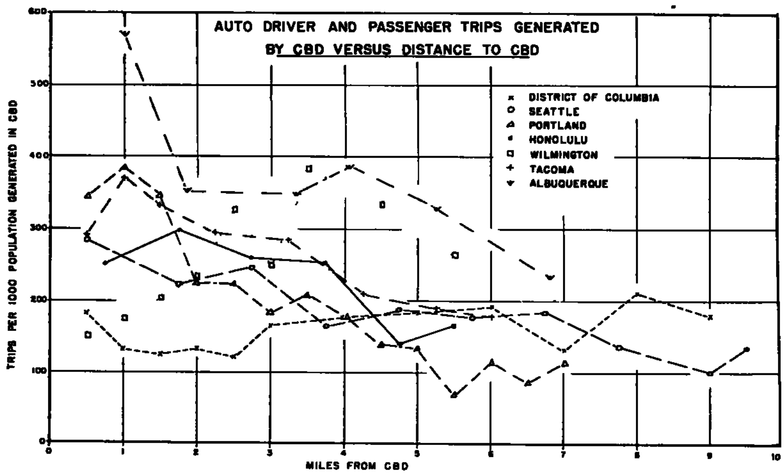


Figure 10.

tend to be generated at a lower rate as distance from the central business district increases. However, trips by transit drop off much-more rapidly than auto-driver trips. There are several reasons why this is so. Study of the population-vehicle ownership ratio zone by zone shows that fewer cars are owned per thousand population near the central business district than in areas further out. Furthermore, transit lines do not give the same amount of service at the outskirts of urban population that they provide near the center, making a higher proportion of the population dependent on cars as distance from the central business district increases. Also, the travel time required by bus or streetcar is less important for short trips originating near the central business district than for longer trips from the outskirts where the rider experiences longer walking distances, longer headways, and many more stops between points of boarding and alighting.

Figure 9 illustrates the patterns of central-business-district trip generation by transit, auto drivers, and drivers and passengers in Seattle, Washington. At 9½ miles, transit riders are generated at only a fourth the rate at which they are generated a mile from the central business district. On the other hand, at 9 miles auto drivers and auto drivers and passengers are generated at half the rate experienced at 1 mile. However, auto drivers and passengers amounted to only two thirds of the volume of transit traffic at a mile, and transit riders were still equal in numbers to drivers and passengers at 9 miles.

In other cities the ratio of auto riders to transit riders is different than that shown for Seattle, but the principles of trip generation are similar. In large cities, transit trips generated near the central business district may be several times the volume of auto riders. In smaller cities, the automobile may be much-more important than transit. In fact, the auto is much more important in the city of Seattle now than at the time of the origin-destination survey in 1946, due to a considerable increase in auto ownership throughout the city.

Figure 10 shows auto-driver-and-passenger data for seven metropolitan areas, ranging in size from 116,000 to more than a million in population. The cities represent a wide variety of geographic locations and city types. Yet, with the exception of Wilmington, Delaware, auto driver and passenger trips are generated by the central business district according to a fairly consistent pattern. At all distances from the central business district, the smallest community (Albuquerque) generates the highest ratio of central-business-district auto trips per unit of population. There is a tendency for auto travel per unit population generated in the central business district to decline as cities become bigger, especially in zones near the central business district. It is clear, though, that other conditions modify this tendency, especially in the case of Wilmington.

RATIO OF POPULATIONS TO CARS VERSUS DISTANCE FROM CENTRAL BUSINESS DISTRICT

Much of the apparent discrepancy in Figure 10 may be explained by a study of car ownership ratios shown for nine cities in Figure 11. Residents of Wilmington, Honolulu, and the Washington, D.C., metropolitan areas are shown to possess few cars in zones close to the central business district, accounting, in part, for the low rate of auto travel generated in those zones. Car ownership increases rapidly with distance. This pattern of car ownership provides a quality of auto-travel service just the reverse of that made available by mass-transportation facilities which are focused on the central business district and give most-efficient service to nearby zones.

The population-vehicle ratio tends to level off at about 4 miles, ownership increasing at a slow rate beyond that distance. Most of the data shown were collected from 1946 through 1949. Despite a considerable increase in automobile registration throughout the country during these years, there is remarkably close agreement between the curves

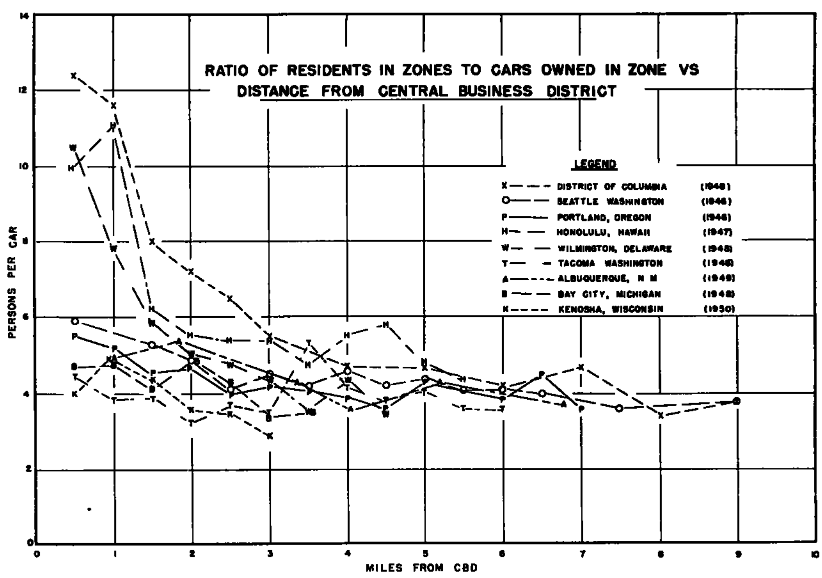


Figure 11.

beyond 4 miles (3.5 to 4.5 persons per car). An even-greater increase in registration has taken place in the 5 years, 1949-1954, and the ratios shown in Figure 11 have undoubtedly been modified.

Registration in the peripheral areas beyond 4 miles are generally as high or higher than registrations for the state as a whole, excepting in those locations where the urban area itself constitutes a large proportion of the state's total population. Data for all cities except Washington are shown in Table 3.

Note that outlying Seattle had a lower population-vehicle ratio than the State of Washington in 1946. Since then the ratio of persons to cars in the state has dropped about 50 percent. Seattle residents have undoubtedly contributed to the drop by acquiring more cars. Other states have increased registrations at about the rate shown for Washington.

TABLE 3

City	Year of Study	[a]Pers/car 4 mi. and beyond	Persons per car in State Year of Study	1952
Seattle, Washington	1946	4.00	4.45	3.50
Portland, Oregon	1946	4.20	3.90	2.45
Honolulu, Hawaii	1947	5.35	6.60	4.10
Wilmington, Delaware	1948	3.95	4.65	3.30
Tacoma, Washington	1948	3.85	3.75	3.00
Albuquerque, New Mexico	1949	3.70	4.30	3.70
[a] Bay City, Michigan	1948	3.76	3.53	2.96
[a] Kanosha, Wisconsin	1950	3.33	3.57	3.43

[a] The peripheral area for Bay City and Kenosha begins at 2.5 miles.

CENTRAL - BUSINESS - DISTRICT TRIPS PER CAR VERSUS DISTANCE FROM CENTRAL BUSINESS DISTRICT

A series of smoothed curves for nine cities, drawn over plotted data, are shown in Figure 12 to illustrate the rate at which the average automobile generates trips in the central business district at various distances.

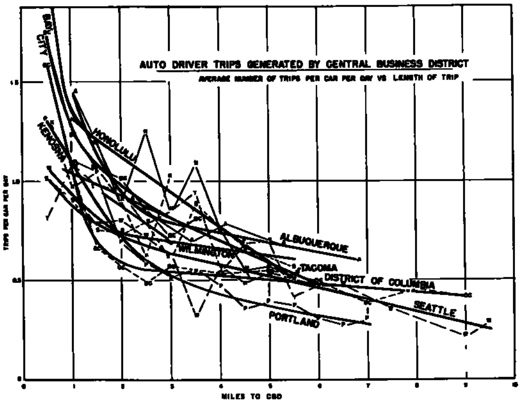


Figure 12.

Note that cars garaged near the central business district in nearly all of these cities generate a much-higher average volume of trips than do cars from more remote zones. The rate of trip generation declines precipitately to a distance of 1½ to 2 miles and then assumes a more gradual rate of decrease. This transition requires special study to determine how its effect on trip generation can be measured.

In some respects these curves reflect the car ownership ratios illustrated in Figure 11. Where the number of cars owned is small in proportion to the number of residents, there is unusual pressure on car owners to make use of their vehicles. Under these conditions the average car may make twice as many trips into the central business district as vehicles in other cities where ownership is greater.

Furthermore, if transit service is relatively poor, such as is likely in communities not yet large enough to support a well integrated transit system, the auto is called on to perform a higher proportion of the daily travel. This would account for a high rate of trip generation even when car ownership is high, as in Bay City and Kenosha.

RELATION OF CENTRAL BUSINESS DISTRICT TO METROPOLITAN AREA POPULATION

The ratio of persons to cars, to length of trip, and to trips per car account for much of the variability of auto-trip attraction to the central business district. Data for cities like Wilmington and Honolulu are still not explained in a satisfactory manner, however. In seeking another measure to explain the remaining discrepancies, it was noted that the relative concentration of population with regard to the central business district in each of the nine metropolitan areas was extremely variable.

Figure 13 shows the relative amount of metropolitan-area population living at any distance from the central business district. In cities which have been able to develop symmetrically around the central business district, such as Wilmington and Washington, D. C., populations are quite compact. In cities forced to develop in a lopsided fashion because of topographical restrictions, such as Honolulu and Seattle, population is spread over a greater distance and is not concentrated so heavily around the central business district. This characteristic of population concentration is not necessarily related to density. There are simply more acres available for development at each range of distance in symmetrical cities than are usable in asymmetrical areas. Since the volume of travel generated between the central business district and residential zones is modified by travel distance, it is clear that population concentration is an important factor in trip generation.

CORRELATION OF VARIABLES AFFECTING AUTO TRAVEL TO AND FROM CENTRAL BUSINESS DISTRICTS

Four important independent variables have been identified which relate to the generation of internal auto trips in the central business districts of cities under ½ million population. The average number of trips made to and from the central business district each day by each car garaged in the metropolitan area is related to the average distance of travel (trip length), the number of persons per car in each area (population-vehicle ratio), the proportion of the urban area population that is concentrated within various increments of distance from the central business district (population compactness), and the total number of people resident in the metropolitan area (city size).

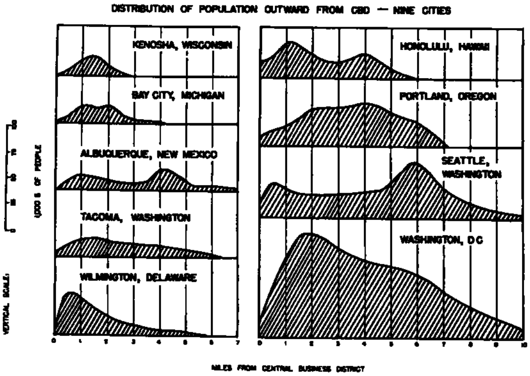


Figure 13.

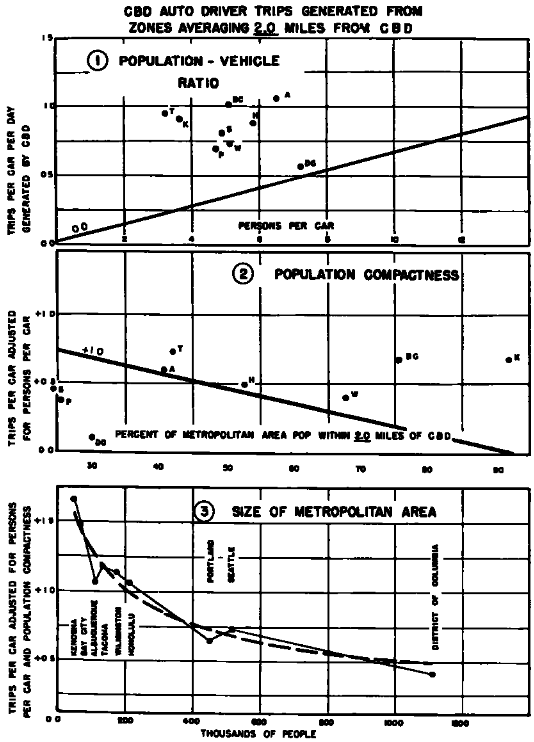


Figure 14.

The graphic-correlation technique previously mentioned has been employed to assess simultaneously the significance of each variable. By a process of cut and try, the several sets of data for each of the nine cities were related to one another, and a series of curves were developed from which a pattern of auto travel generated in the central business district can be determined for any city within the population range 50,000 to 600,000. One step in the graphic solution of this problem is shown in Figure 14.

The effects of the distance variable have been determined by studying the remaining variables by mile or ½-mile increments of distance from the central business district. Trip volumes produced in all zones at the prescribed distance in each city have been reduced to the average number of trips performed by each car registered in those zones on an average day. In Step 1 of the correlation study (Fig. 14) the average number of trips per car per day have been plotted against the average population-vehicle ownership ratio in those zones which generated the trips.

Ezekiel's method of graphic multiple correlation has been employed in succeeding stages of the correlation. A line is fitted to the data plotted in Step 1 and the variations from that line plotted, Step 2, against the cumulative proportion of the metropolitan-area

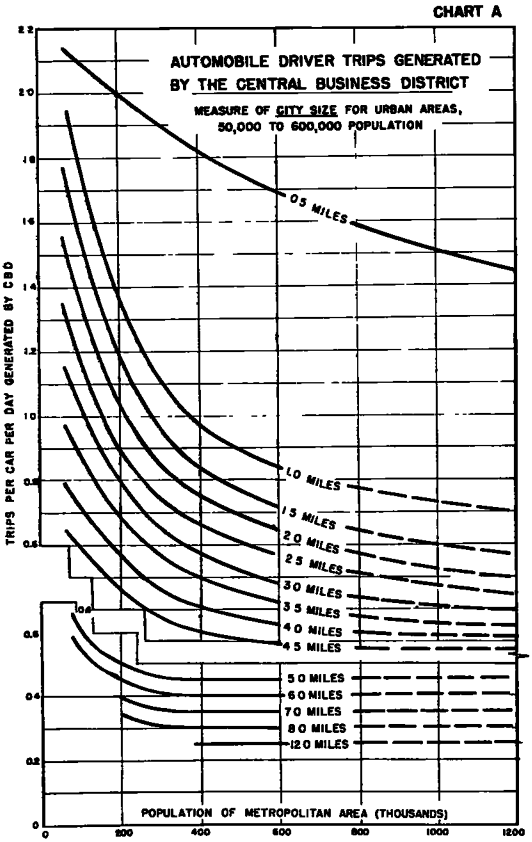


Figure 15.

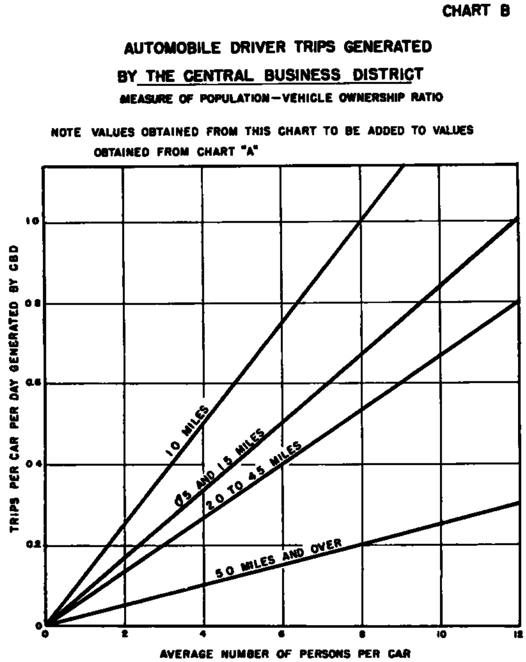


Figure 16.

population living within the prescribed distance (within 2 miles in this illustration). A line is then fitted to these data and the deviations from this line plotted, Step 3, against a scale representing metropolitan area population. A line is fitted to this last plot (in this case, a curved line), and the data examined to determine how well the variables tested have explained the generation of travel to the central business district.

If the curve drawn in the final step cannot be made to fit the data well, the process is repeated, trying different slopes of line in the initial comparisons which will effect the relationships of points plotted in succeeding stages. The curves shown in Figure 14 are a result of numerous trials which are related not only to the data shown on the drawing but also to data for shorter and longer distances from the central business district as well. The final step in Figure 14, fitting a curve to account for city size, results in a good correlation.

Correlations similar to Figure 14 were made for each ½-mile increment of distance from 0.5 miles to 4.0 miles from the central business district. Beyond 4 miles, population compactness ceases to be a factor and has been omitted. Data have been correlated to city size and car ownership by 1-mile increments from 4 miles to 7 miles and for trips generated at 9 miles (drawings not shown).

ESTIMATING INTERNAL AUTO DRIVER TRIPS GENERATED BY CENTRAL BUSINESS DISTRICT

Three charts have been prepared to show the relative effects of each of the three independent variables tested in the series of studies represented by Figure 14. These charts are illustrated in Figure 15 (effect of city size), Figure 16 (effect of ratio of population to vehicle ownership) and Figure 17 (effect of population compactness). The fourth variable, distance from central business district, is represented by a series of curves in each drawing.

In order to separate the several series of curves in a logical sequence (by increments of distance from the business district), an arbitrary series of scales have been worked

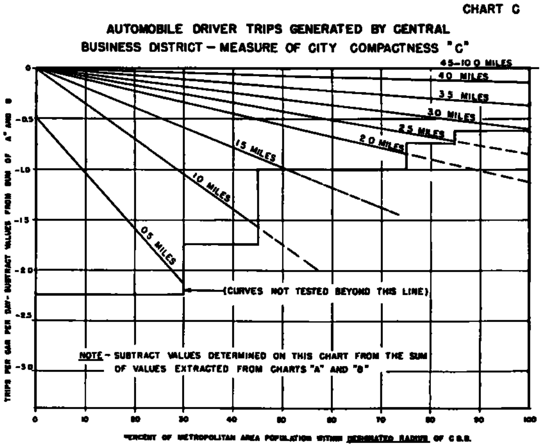
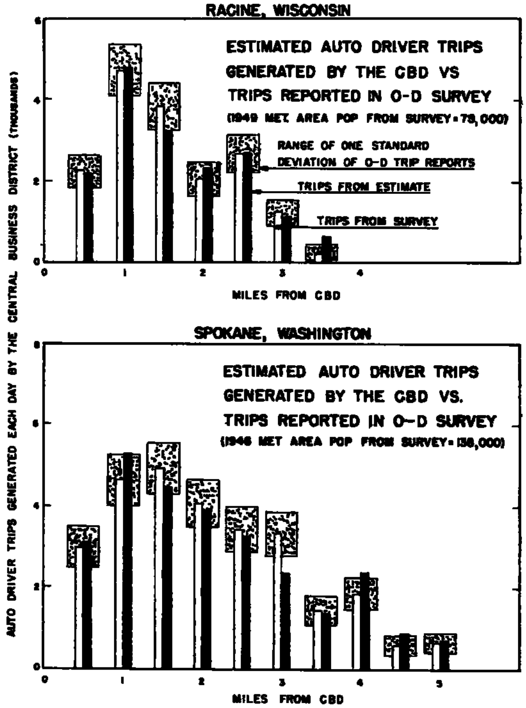


Figure 17.



Figures 18 and 19.

out for the dependent variable (trips per car per day) which give positive values to city size (Chart A) and population-vehicle ratios (Chart B), but make population compactness a negative value (Chart C). These arbitrary scales are convenient for use in making estimates of trip generation, but by no means reflect the relative importance of each variable.

Data for any city in the population range 50,000 to 600,000 may be evaluated by these three charts (values based on data from the only city larger than 600,000 are regarded as tentative). Readings from Charts A and B are simply added together and their sum reduced by the value determined from Chart C. The result is the average daily volume of trips generated in the central business district by each motor vehicle regularly garaged in the particular zone or group of zones at the designated distance.

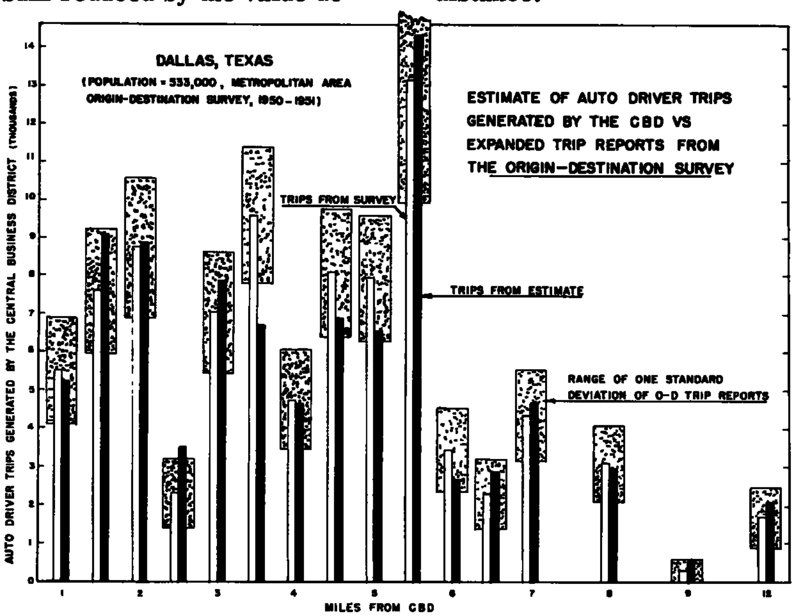


Figure 20.

DATA REQUIRED FOR ESTIMATES OF CENTRAL BUSINESS DISTRICT TRIP GENERATION

The information needed to measure the internal generation of automobiles by the central business district consists essentially of population and vehicle-ownership data. Evaluated by the set of charts just described, the pattern of residential termini can be quickly established. If this information is to be of most value to the traffic or planning analyst, a complex breakdown of the residential community is desirable—perhaps as many as 50 or 60 zones or tracts of nearly equal size or population. The population and vehicle ownership in each zone should be carefully determined (for this reason census tracts may prove to be a convenient base). The centroid of population distribution should then be established in each zone and the shortest distance between that centroid and the center of the central business district determined, as measured along existing streets. Population compactness and the ratio of population to vehicle ownership for each zone must also be computed. These data are sufficient to make the estimates already described.

A better estimate of residential termini can be made if the total number of central-business-district auto trips generated by metropolitan-area residents is known. A parking-turnover study conducted at curb and off-street facilities can supply this information, provided care is taken to ascertain the proportion of trips generated beyond the metropolitan-area limits. The known volume of internal central-business-district auto trips thus obtained may be compared with the total estimate derived from the graphic formula and the volume of movement ascribed to each zone raised or lowered in direct proportion to the difference between estimated overall volume and actual volume.

TESTING RELIABILITY OF CENTRAL BUSINESS DISTRICT TRIP ESTIMATES

Reliability of the estimating process described above can be determined by making estimates of central-business-district generation in cities for which O-D information is available as a check. Three cities were selected for this purpose, none of which was used in deriving the estimating formula. These cities, and their metropolitan area populations at the time of study, were Racine, Wisconsin, (78,000 in 1949); Spokane, Wash-

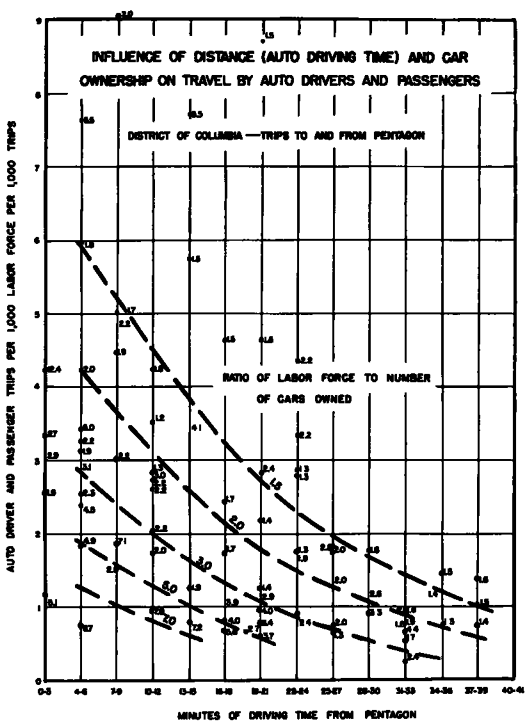


Figure 21.

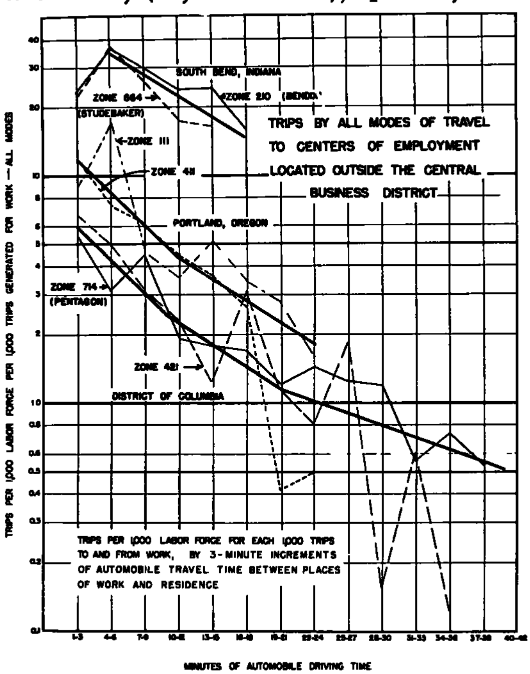


Figure 22.

ington, (138,000 in 1946); and Dallas, Texas, (533,000 in 1950-51).

Tests were carried out for estimating the average number of central business district trips performed by each car at each increment of distance from the central business district. An approximate standard deviation was established for the O-D trip reports at each distance and the difference between estimate and O-D reports computed in terms of standard deviation units.[4] These data are shown graphically in Figures 18, 19, and 20, where sample data and estimated volume have been plotted against a shaded area representing a range of one standard deviation. Estimates for all three cities appear to be about as reliable as the data obtained from home interview samples.

AUTO TRIPS TO WORK

The investigation of trips generated in the central business district has been subject to more attention in this study than has been devoted to trips with origins and destinations outside that area. The central-business-district study was undertaken earliest and was well developed before other land uses were investigated in any detail. The investigations of industrial and residential areas have been principally devoted to the application of variables similar to those used in the central-business-district study. On the whole, this approach seems to have been justified. Studies of individual cities show that the variables of distance (or travel time), car registration, population distribution, and city size are important factors in the generation of all internal auto travel.

Four broad land-use categories were considered when these studies were designed, and three of them were investigated. Auto trips which originate in residential areas may terminate in other residential zones, in the central business district, in a recreational area, or in industrial areas. Trips to recreational areas were not investigated specifically, although trips to neighborhood playgrounds, schools, etc., would generally be included in the residential-area category.

The term "industrial area" is an ambiguous one. Trips to factories, institutions and other large establishments are included in this designation, as used here. Most of such trips are generated by places of employment.

Figure 21 shows a family of curves fitted to data representing the ratio of population (labor force)[5] to vehicle ownership, plotted in terms of trips per unit of population against driving time to the Pentagon in Washington, D. C., and describe the approximate rate of trip generation from zones of various car ownership levels. The Pentagon attracts a larger volume of workers each day than any other area studied (about 40,000 trips per day). Although many discrepancies from the fitted curves are evident, the relationships shown are quite real. Many of the widest discrepancies are due to very small, unstable samples.

The data shown in Figure 21 are a rough measure of two of the four variables studied for central-business-district auto generation. A third variable, city size, has been examined in Figure 22 for travel by all modes.

Data for two industrial zones in each of three cities have been plotted here against minutes of travel time. A free-hand curve has been fitted to data for each pair of industrial zones to show the approximate rate of trip generation in each city. In every case the field data deviate considerably from the line of estimate. Such deviations are

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[4] A principal deficiency of the estimating technique described above, and the reliability checks made for three cities, is the lack of an adequate statistical measure of dependability. At this time it does not seem possible to make a correct evaluation of 0-D sample data, due to the decided bias introduced when underreported samples must be adjusted upwards. Without such a measure, assumption that the Gaussian law applies sets up an arbitrary scale for the comparison of synthesized data with the more conventional samples. This scale must serve for the present as a guide to the relative similarity of estimate and sample and should not be construed to define more precise values than that.

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[5] "Labor force" appears to be a more reliable basis for work trip generation than total population. Investigation of census data for Portland, Oregon, shows labor force to range from less than 40 percent to more than 60 percent of census-tract population.

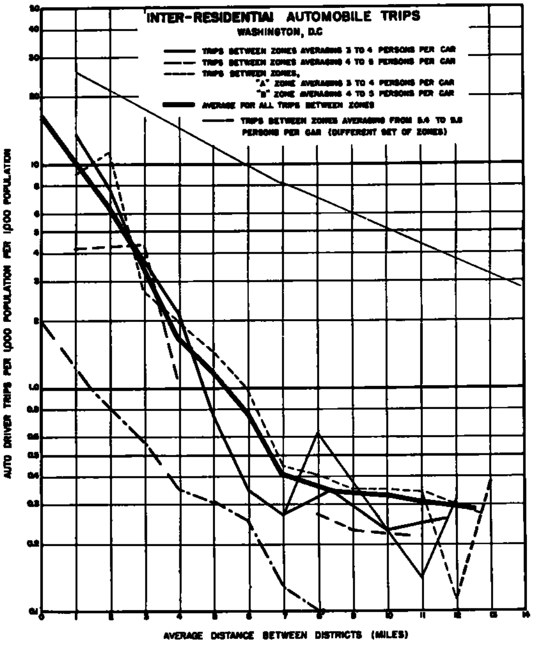

Figure 23.

generally of smaller magnitude near the industrial zone, where trip volumes are large and samples stable. In Washington, data for the Pentagon fit rather closely throughout the city, due to the large sample represented by the Pentagon. Data for Zone 421 lose stability at about 25 minutes distance.

In Portland the data for Zone 111 show a wide range of variation but shift above and below the line of estimate, the most extreme deviation occurring at 4 to 6 minutes from the zone. On the other hand, Zone 411 shows a steady rate of trip generation out to 18 minutes, when the sample becomes very small and unreliable.

In South Bend both sets of data fit rather well, considering the size of the community. Generation is measured in trips per 1,000 labor force per 1,000 trips made to the zone.

Washington, with twice the population of Portland, has twice as large a labor force and, therefore, generates from it at half the rate to provide each thousand workers to the Pentagon. South Bend with a fourth the population of Portland must generate at four times the Portland rate to provide a thousand workers at the plant.

The consistency with which this takes place is most impressive. The same degree of stability was not achieved when auto driver trips were examined alone, however, and it appears likely that another variable may have to be investigated. The population-compactness variable has been studied but does not appear to hold the entire answer.

Inter-Residential Auto Travel

Trips generated between residential zones have been subjected to a series of investigations similar to those applied to industrial work travel.

Two selected groups of districts in the Washington, D. C., metropolitan area were chosen for analysis. Twenty districts in which car ownership ranged from three persons per car to five persons per car were carefully selected to represent a cross-section of the metropolitan area. Another set of ten districts was selected in which ownership ranged from a low of 9. 6 persons per car to a high of 5. 4 persons per car. Most of these districts are within the District of Columbia.

In Figure 23, data from the 20 zones of high car ownership have been segregated into three categories. These are districts of high ownership ratio (three to four persons per car), relatively low ownership (four to five persons per car), and mixed areas (one of high and one of low registra-

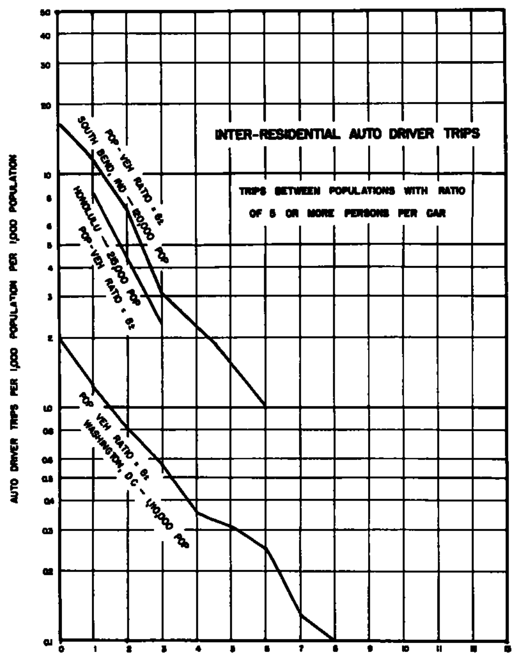

Figure 24.

tion). Trips in the latter category constitute the majority of movements and show the most consistent trend. In fact, they show a slightly higher rate of trip generation than trips between areas of high registration, but here again the sample is small and this difference is not significant. Travel between districts of low car ownership are generated at a lower rate.

When trip interchanges between the group of districts with very-low registrations are plotted, there can be no mistaking the importance of the ownership ratio. The slope of this line indicates an exponential decay pattern similar to the curve for all trips generated between the districts of high registration but at a rate very-much lower.

Although the rate of interresidential auto travel declines rapidly as trip length increases, the rate of decrease flattens abruptly at about 7 miles. There is no ready explanation for this, other than the possibility that this is a characteristic of the Washington area, since trips for all three categories exhibit the same tendency. Data are weak beyond 7 miles, in any event.

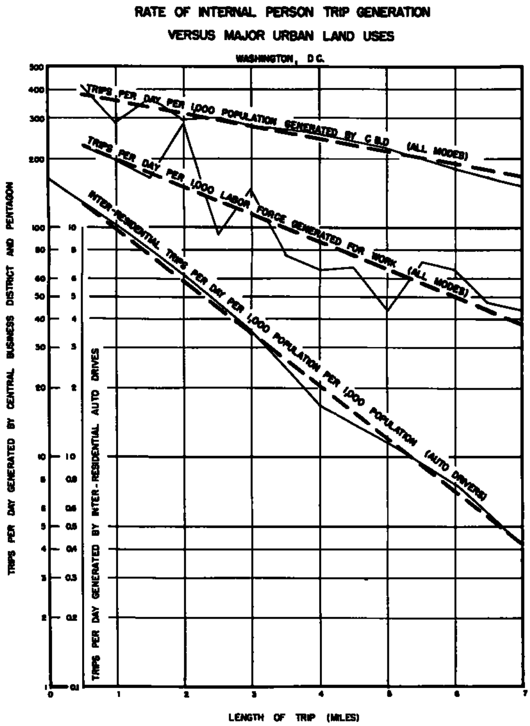

Figure 25.

In Figure 24, data for trip interchanges between zones of low car registration have been plotted for three metropolitan areas. In South Bend it was possible to study trips up to 6 miles in length. In Honolulu the zones of low registration are located near the center of the city, and study was limited to interchanges 1 to 3 miles in length (intrazone data were not evaluated). Trips in Washington extend up to 8 miles in length.

The rate of car ownership in all of the areas studied here is roughly the same. Note that the pattern of trip generation is quite consistent from one city to the next. Variable rate of trip generation appears to be closely related to city size. Since the trip opportunities of a population increase directly with population increase as discussed in the evaluation of work trips, it would seem that the pattern produced is a reasonable one.

Range of Trip Attraction Related to Land Use

One of the most-interesting results of the trip studies is the comparison of ranges of influence by land use types. Figure 25 shows the relative strength of trip attraction for each of the three land use categories studied in Washington, D. C. Trips by all modes of travel form the basis for these comparisons (inter-residential transit use is negligible).[6]

Travel to the central business district is maintained at a relatively high rate for many miles out from the center of the city. This is due, of course, to the unique quality of the central business district. Many types of service, trade, employment, and other features cannot be duplicated elsewhere in the community. In order to avail themselves of these unique qualities, the resident must go to the city center, regardless of his distance from it. He can postpone his visits and accumulate his errands if the trip is long, but he has no more convenient alternate. Trips by all modes to the Washington, D. C., central

[6] The contrasts would have been even greater if auto travel only had been shown since the curve for auto trips to central business district (Figure 10) is practically level, and the curve for work trip generation is probably flatter than the one for all modes. The latter has not been drawn, however.

business district are generated from 7 miles at about half the 1-mile rate.

Travel to places of work is not so restrictive as travel to the central business district. Most large centers of employment are still located near the city center, however, and there is need to travel several miles to reach any of them from outlying suburbs. Since many of the same skills are required in all large employment centers and since competition in the same labor market tends to stabilize levels of compensation, it is likely that many workers attach themselves to one of the more-convenient work centers. This would account for a more-rapid decline in work trips from the more-remote areas as against trips generated in the central business district. Industrial area work trips at 7 miles are generated at only a fifth the rate at 1 mile in Washington, D. C.

Interresidential trips greater than a mile in length are usually performed by car, because of relatively poor transit service between residential districts. Most interresidential trips are short, and the range of attraction to other residential areas drops off fast. This may be explained by the fact that each residential area is immediately adjacent to similar areas on one or more sides.

The opportunities for neighborhood services, amusement, recreation, visiting, school, church, etc., are numerous within a short range. More-remote areas offer virtually the same attractions, so that there is relatively little demand for interresidential travel of any length. The rate of interresidential trip generation at 7 miles in Washington, D. C., was found to be only one twenty-fifth of that at 1 mile.

Perhaps the most striking feature in Figure 25 is the consistency of the slope of the lines, each of which appears to conform to an exponential-decay pattern throughout its length.

Discussion

J. D. CARROLL, JR.—Wynn is to be congratulated for tackling such a difficult task. This is one of the most-meaningful papers yet presented on basic urban-travel patterns and their predictability. Reading, interpreting, and correcting various O-D surveys to a common base is a difficult job and one that has long been needed.

Wynn provides evidence of a reliable prediction of the number of trips, especially work trips that will be made in any urban area, and explores factors which can be used to predict trips between the central business district and other points in the urban area. This analysis is helpful in that it indicates variables associated with auto-driver trips. It is too bad multiple correlation was not used, instead of the nomograph-estimating procedure, to provide more-precise evidence of the effect of the variables used.

A test of Wynn's formulation interpolating from his charts to get the central business district auto driver trips in an area of 3 million population (Detroit) discloses that his estimates will be almost 1,000 percent high in such a large city. Therefore the ranges apply only to the cities studied.

Wynn has generally used the premise that residential characteristics can be the basis for predicting zone-to-zone movements. This presents a problem, since only 80 percent of all trips are to or from home (zone of residence). The other 20 percent cannot always be logically predicted on the basis of residential characteristics of the tract or zone of trip origin. For example, where he finds more CBD origins and destinations proportionately at the closer zones, proof should be developed that these are not due to intermediate stops by residents of the outer suburbs who are only performing some errand enroute to or from the central business district. In brief, all trip origins from a residential zone are not made by residents and, therefore, cannot all be predicted on basis of the characteristics of those residents.

A comment is offered, not in criticism of this paper (the best material so far presented), but in hope for the future. These facts should be synthesized into a theoretical explanation as to why these patterns are predictable. Only with this further synthesis can these numerous facts be organized into a body of tools to forecast the traffic effects of land-use change. Ultimately, it is possible that traffic flows can be approximated from population and land-use data. This paper represents a first step. Wynn is to be congratulated.

F. HOUSTON WYNN, Closure—Carroll is exceptionally well informed on urban traffic characteristics, and I appreciate the kind words he has to say about my paper. He is somewhat critical of my use of the nomographic technique and perhaps a few words of explanation are called for. In my opinion the data used were too few to definitely establish the precise effect of the different variables used, or even their order of importance. When more data are at hand, I expect to develop more-precise evaluations.

One cannot caution too strongly against the misapplication of the CBD trip charts. In addition to the hazard of city size that Carroll points out, there is also the problem of defining the limits of the CBD to which trip estimates will apply. Caution must also be exercised in applying these curves to areas of lower population-vehicle ratios than were found in the cities from which they have been developed. The curves have been prepared to illustrate the consistencies of traffic behavior among a diverse group of cities; the fact that they can be used to estimate traffic behavior in other cities must be regarded, for the time being, as incidental. The relationships encourage me to believe a practical predictive formula will soon be developed.

The paper is entirely too brief to cover all of the many aspects of urban travel which have been investigated by our studies at Yale. We have found, as Carroll suggests, that about a fifth of all internal trips cannot be directly related to the residential units. We have developed some measures of this travel, but there is much yet to be done before we can describe all of this travel with confidence. Carroll gets to the basic problem whe[n] he points out the need for a theoretical explanation upon which the entire pattern of urban travel can be based. I am confident that this overall concept is not far off.

Evaluation of Intercity-Travel Desire

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This paper covers the development, use, and limitations of a mathematical formula for measuring the relative desire for travel between cities in the state of Washington.

The need for such a formula grew out of the efforts, eventually successful, to develop a quantitative yardstick for measuring the state's interest in highways. This formula was used as one of six factors in the yardstick as developed for classifying, as state or county, all the rural roads of Washington.

Factors developed by others to measure the variation in interaction between different-sized groups varying distances apart are reviewed. Basically, this concept as applied to highways can be stated in general terms as follows: (1) the larger a population center the more traffic it generates and attracts; (2) the greater the distance between two population centers the less the travel between them; (3) the mathematical form of the law of attraction between physical masses. Included is a discussion of these basic concepts, a description of the general statistical procedures used for four formulas considered for measuring the concepts, and graphic presentation of the results of their correlation with minimum traffic counts between cities on seven representative cross-state routes.

The method of application of the formula to the roads of Washington is described and illustrated. Other possible applications and certain limitations of such formulas are also discussed. A bibliography of publications on related material is included.

A single method of attack is seldom the answer to any problem. An intercity-travel-desire formula is one of the devices available for indicating the total amount of travel desire generated by separated population centers. It can be used as a reliable mathematical tool for estimating intercity origin-and-destination data for determining how many people want to go where.

● THE need for a factor for measuring intercity-travel desire became apparent when methods were being considered for classifying the highways in the State of Washington. Classification of highways is the grouping of highways according to their functional use and to their predominant interest to the several units of government.

Highway classification is needed to stabilize the basic framework of highways in the state, so the assignment of the responsibility over various classes of roads may be made to the most appropriate agency of government on a lasting basis and to form a basis for establishing a definite and equitable financial policy and an efficient management and cooperation between government levels (1). The object of the highway-classification study in Washington was to find methods for defining a system of highways that would include those roads which primarily benefit the state as a whole and that would have the same total mileage as the present state system.

Highways that would primarily benefit the state as a whole would provide traffic communication with other states; transportation among population, agricultural, and industrial centers in different counties within the state; and access to all recreational and governmental centers of more than local use and interest. In order to determine the amount of state interest in the highways, a set of definite requirements and a numerical yardstick were developed. This yardstick, to be complete, needed a component for measuring the desire for travel between population centers. This measure includes both the desire for personal travel between these centers and, to a degree, the desire to move goods from one center to another.

With this need for a quantitative measure for interurban travel desire in mind, investigation of possible methods of measurement was begun. Work done by others along similar lines was studied.

As early as 1885, E. G. Ravenstein (2) observed that a population center attracts migrants from other centers in relation to its population size and its distance away and that migrants leave according to the same principle. This is called the $^{P}/D$ relationship.

Starting with the $^{P}/D$ relationship, George K. Zipf (3) a sociologist, proposed the theory that "the number of persons that move between any two communities in the United States whose respective populations are P_1 and P_2 and which are separated by the shortest transportation distance, D, will be proportionate to the ratio, $\frac{P_1P_2}{D}$, subject to the effect of modifying factors."

Highway, railway and airway data were used for an arbitrary set of cities during intervals of measurement in 1933-34 to support this proposition. Conditions in the United States in the fourth decade closely approximated those that were anticipated by the above theory. Movement of materials by freight and parcel post was also tested on the basis of this hypothesis with apparently good correlation. In this connection Zipf (2) states:

> Before discussing the possibility of other kinds of data it is perhaps wise to point out at once that our theory calls for the movement of all goods and services by all means of transportation; the theory will not necessarily hold for each kind of transportation since we know that for some commodities, one type of transportation is cheaper than another. The fact that our theory holds so well for Railway Express suggests that the service of Railway Express is of equal value to persons, regardless of the size of the cities or of their locations; the same may well be true of parcel post for which, unfortunately data are lacking. Nevertheless in the case of mining communities or agricultural centers, we may suspect that they ship out great values of bulky materials by railway freight while receiving payment in terms of less bulky materials that are not all sent by freight. To repeat, our theory calls for all shipments by all means; hence we may expect a certain amount of variation in the data for one particular means of shipment.

Bus passenger travel, newspaper circulation and the amount of news about a city, P_2, reported in a city, P_1, a distance, D, away all followed this hypothesis.

TABLE I

INDIVIDUAL TRAVEL DESIRE FACTOR

ROUTE H

Location	Colville	Chewelah	Deer Park	Spokane	Colfax	Pullman	Clarkston &Lewiston	Mileage
Mileage	0	22	57	80	139	156	178	
√Pop Pop	54.772 3,000	41.231 1,700	34.161 1,167	402.12 161,700	55.678 3,100	109.545 12,000	122.474 15,000	
Colville		102.65 4.666	32.82 0.576	275.31 3.441	21.94 0.158	38.46 0.246	37.69 0.212	F3 F4
Chewelah			35 40.24 1.150	58 285.86 4.928	117 19.62 0.168	134 33.71 0.252	156 32.37 0.208	F3 F4
Deer Park				23 597.25 25.968	82 23.20 0.283	99 37.80 0.382	121 34.58 0.286	F3 F4
Spokane					59 379.48 6.432	76 579.61 7.626	98 502.54 5.128	F3 F4
Colfax						17 358.78 21.105	39 174.85 4.483	F3 F4
Pullman							22 609.84 27.720	F3 F4

$$F_3 = \frac{\sqrt{(Pop\ 1)\ (Pop\ 2)}}{D} \qquad F_4 = \frac{\sqrt{(Pop\ 1)\ (Pop\ 2)}}{D^2}$$

John A. Cavanaugh, in his doctor's dissertation (4), corroborated the hypothesis of George K. Zipf with studies correlating actual data with predictions from the $\frac{P_1 P_2}{D}$ hypothesis on the number of telephone calls between cities; number of automobiles from the different states entering Mt. Rainier, Glacier, Yosemite and Yellowstone National Parks; moving household goods by moving van from city to city; transporting passengers by airline from city to city; number of tourists from the different states entering the state of Washington; number of passenger automobiles entering Seattle by Washington counties and states; travel by all methods into the city of Seattle; number of students attending the University of Washington by state of residence; number of postal money orders sent between Seattle and arbitrarily selected cities; and registration of guests at two Seattle hotels.

A correlation of 0.8 or better was obtained for 70 percent of the 27 sets of interaction data used. The correlation for the remainder of the data ranged from 0.5 to 0.8. Some of the lower correlation was attributed to the small size of some of the samples and, perhaps, sampling error in a few cases.

John Q. Stewart (5), in a study made about the same time George K. Zipf was making his studies, observed that older national universities (i.e., Princeton, Harvard, and M.I.T.) tended to attract numbers of students from states according to their population and their distance from the university in question.

Stuart C. Dodd (6), of the University of Washington Sociology faculty, has proposed that human interactance quite possibly follows the same law as does the attractive force between physical masses, that is $\frac{m_1 m_2}{D^2}$. He states that weighting factors may need to be introduced to equate the heterogeneity of the groups. These weighting factors would correspond in the human mass to the specific weights of molecules in the physical masses.

> In generalizing the concept and definitive formula for gravity from physics to sociology to all sciences, the number of interacting yet statistically independent particles clustered in each group seems to a sociologist the essential variable whether the particles are molecules or persons or any other entities that fulfill the preconditions....
>
> The hypothesis of interactance predicts the number of interactions, of any one specific kind, among people when observed in groups, from their basic dimensions of time, space, population and per capita activity.... Groups of people interact more as they become faster, nearer, larger, and leveled up in activity. Conversely, people will interact less in proportion as their groups (a) have fewer actions per period (b) are further apart (c) are smaller in population, and (d) are more unlike each other in average activity....
>
> This hypothesis includes the $\frac{'PP'}{L}$ hypothesis (i.e., population product over distance) and the population potential ("P/L") hypothesis as special cases. They are the cases where the remaining factors are unities in effect by being controlled or neglected or irrelevant....
>
> It suggests that a condition for the interactance hypothesis to hold is that of uniform density or an even distribution of the population over the area studied. This uniform density may hold even though the population may be clustered among human groups, such as cities of varying sizes, as long as all the groups of any one size tend to be evenly dispersed in the area studied. If the density is not uniform, then some function of the distance other than its first power may give a better fit between the model and the data....
>
> This law, it should be reiterated lest some readers misinterpret it, tells nothing about the nature of the interaction or why it occurs. It only states how much interacting is to be expected from aggregates of particles, given that those particles interact and are statistically independent.

Michigan based its highway classification study on a hypothesis philosophically similar to the $\frac{"PP"}{L}$ hypothesis. Excerpts from the Michigan Report (7) define the basic hypothesis used.

> The Michigan method is founded on a functional concept of highway service and operation; it classifies roads and streets on the basis of traffic attraction....
>
> The traffic attraction of any specific place is indicated by the manner in which the average frequency of trips to the place varies according to the distance of the trips. When the trip frequencies were plotted against their corresponding distances, it was found that the attraction of the place in terms of trip frequencies varied inversely as the distance. It was also found that for any given distance, the attraction to the more important places was greater than to places of less importance....
>
> This experience led to the hypothesis that the attraction of a place measured in terms of trip frequencies is directly proportional to the importance of the place and inversely proportional to the length of the trips.

Building upon this hypothesis an economic analysis of the towns in Michigan was made on the basis of the population of the immediate retail trade area, assessed valuation, banking resources and newspaper circulation. On the basis of this economic analysis and the relative traffic attraction, these towns were grouped into five classes: (1) metropolitan centers, (2) regional centers, (3) intermediate market centers, (4) minor market centers, and (5) neighborhood centers. A network of roads connecting the places falling within the first three classes of places was classified as the primary road system. The Class 4 and Class 5 places were then points of reference for the selection and classifying of the secondary roads which were of widest transportation importance.

The highway classification study made in Illinois followed closely the pattern used by Michigan. The basic philosophy of their method is epitomized in the following excerpts from their report (8).

> Highway classification may be defined as the grouping or identification of those segments of highway that have similar functional usage and render comparable service....
>
> The development of the standards and criteria upon which to select the highways for the primary system is based on the concept that the importance and functional use of a section of highway may be measured and classified by the relative importance of the points of traffic attraction connected by the highway....
>
> The functional usage of a segment of highway may be measured by the economic importance or traffic attraction of the populated places connected by the highway....
>
> Population of an Immediate Trade Area is made up of the people whose everyday needs are served directly by the community trade center. It is this population that determines to a great extent the amount of retail trade and industrial development in the trade area. (1940 Federal Census enumeration.)...
>
> The proportion that the traffic passing from one center to the other is of the total traffic on the road increases as the importance of the centers increases and as the distance between them decreases.

In the Illinois report, the towns were classified as (1) regional centers, (2) major market centers, (3) Market Centers A, (4) Market Centers B, or (5) minor market centers. This report states that highways connecting places in all the classifications except minor market centers met the requirements for primary highways and the highways connecting minor market centers were qualified for inclusion in the secondary system. These secondary roads were considered as primarily collector or local service roads of county interest.

The several trade center classifications fall, generally, into similar population groups as shown in Figure 1. Ordinarily the greater the economic importance of the trade center the larger its population. In this case some exceptions and some overlapping of population sizes into two trade center classifications do occur. However, the population of a town is a strong indicator if its economic importance. The size of a town will not indicate whether it is primarily industrial, or a rural trade center, but it will indicate within limits its relative economic importance.

Work done by others in developing methods for predicting the amount of interchange of people, services and goods from one population center to another, points to three general rules: (1) the larger the population center the greater its influence; (2) the greater the distance from a population center the less its influence; and (3) the population of a city is a strong index of its economic importance.

DEVELOPMENT OF A QUANTITATIVE MEASURE OF INTERCITY TRAVEL DESIRE

When quantitative methods for measuring intercity travel desire were being weighed, the following facts seemed to be of special significance:

1. The larger a population center is the more traffic it generates and the more traffic it attracts.
2. The farther apart two population centers are the less travel there is between them.
3. The population of a city is a strong index of its economic importance and thus a measure of its traffic attraction. The more mature the population center the more true this would be.
4. According to the 1944 Interregional Highway Report to Congress 90 percent of the travel on main highways originates or terminates in a population center.
5. In the State of Washington, population figures can be used to measure travel as well as motor-vehicle-registration figures, because of the uniformity of the per-capita motor-vehicle registration for all counties in the state.
6. The mathematical form of the law of attraction between physical masses, $F = \frac{m_1 m_2}{D^2}$, might be applicable to social masses in the form of $\frac{(\text{Pop } 1)\ (\text{Pop } 2)}{D^2}$ where "Pop" stands for population and "D" stands for the shortest highway distance.

A logical mathematical relationship that would include the first three items listed above seemed to be $\frac{(\text{Pop } 1)\ (\text{Pop } 2)}{D}$ where "Pop" represents town population taken from 1950 census figures and "D" represents the shortest highway distance between two towns.

This hypothesis states that the desire for travel between towns is directly proportional to the size of the towns and indirectly proportional to their distances apart. It seemed reasonable that if this travel desire factor would correlate with the minimum AAD (annual average daily traffic) for any given stretch of road it could be used as a measure of intercity travel desire or through traffic interest on any road. The minimum AAD between population centers was chosen because it would more nearly reflect through traffic than the higher AAD nearer the town limits or road junctions.

This desire-for-travel factor is computed so as to reflect all desire for travel between two population centers whether the travel will be (1) between the two centers only, (2) from beyond the first center to or through the second center, or (3) from beyond the second center to or through the first center. Any of these cases would necessitate travel from the one population center to the other.

The larger percentage of the local-travel desire was eliminated in this travel-desire factor, because rural population not gathered into incorporated or unincorporated centers over 1,000 was not considered and the metropolitan district population rather than the population within the political boundaries was used for towns over 50,000, thus eliminating the local suburban travel desire in the vicinity of the larger towns. Contingent towns such as Chehalis and Centralia were treated as a single population center.

Seven representative roads, were chosen as samples for the correlation study (Figure 2). All the towns of 1,000 population or more on the route being studied were tabulated. The populations of the towns and the mileages were also recorded on the tabulation sheets. Tabulation for Route H is shown in Table 1.

Next, cumulative travel desire between any two towns was obtained by adding all the numbers above and to the right of the lines in the tabulation that separate the two towns being considered. The cumulative travel desire for Route H is shown in Table 2. This method, when applied to travel interchange among all cities over 1,000 in the state became unmanageable, and a cross-tabulation method was developed for this purpose.

TABLE 2

CUMULATIVE TRAVEL DESIRE FACTOR

ROUTE H FROM	TO	F_1 x 10^6	F_2 x 10^6	F_3	F_4	AAD Min.
Colville	Chewelah	6.92	0.09	508.87	9.299	800
Chewelah	Deer Park	11.93	0.16	818.02	11.339	800
Deer Park	Spokane	20.62	0.53	1437.79	36.532	2200
Spokane	Colfax	59.85	0.74	1741.00	21.381	1400
Colfax	Pullman	54.57	0.75	1830.39	39.928	1800
Pullman	Clarkston + Lewiston	34.74	0.65	1391.87	38.037	900

TABLE 3

TABLE OF STATISTICAL INDICES

FACTOR	Index of correlation ρ (log data)	Correlation coefficient r (raw data)	Standard errors of estimate (log)
$\sum \frac{\sqrt{(Pop\ 1)\ (Pop\ 2)}}{D}$	0.74	0.79	0.24
$\sqrt{\sum \frac{(Pop\ 1)\ (Pop\ 2)}{D^2}}$	0.66	0.83	0.27
$\sum \frac{\sqrt{(Pop\ 1)\ (Pop\ 2)}}{D^2}$	0.88	0.93	0.17
$\sqrt{\sum \frac{(Pop\ 1)\ (Pop\ 2)}{D^4}}$	0.89	0.90	0.17

In cases where parallel routes, loop routes, or nonparallel routes connected two given population centers, the travel-desire factor was apportioned to the roads in question on the basis of voltage or current distribution in parallel power lines of varying lengths.

$$\text{If } F = \frac{P_a P_c}{D_{abc}}, \text{ then } F_1 = \frac{P_a P_c}{D_{abc}} \left\{ \frac{D_{adc}}{D_{adc} + D_{abc}} \right\} \text{ and } F_2 = \frac{P_a P_c}{D_{adc}} \left\{ \frac{D_{abc}}{D_{adc} + D_{abc}} \right\}$$

In cases where the road under consideration was joined by another route, the desire-for-travel factor from towns on the second route to towns on the first route was added to the desire-for-travel factor already figured on the first route in the same manner as traffic from two routes is added on a traffic-flow map.

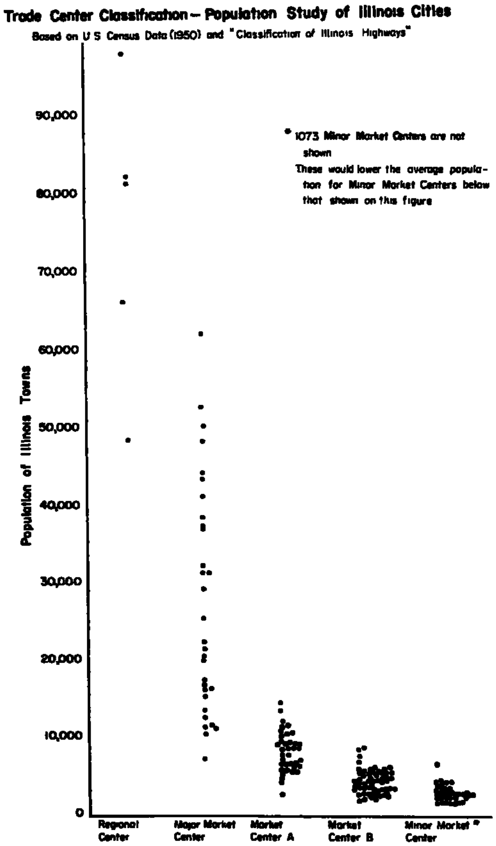


Figure 1.

Generally the distance between towns in Washington is more or less constant, except for the towns separated by the Cascades, but the differences in the total populations of the towns is large. It was found that the factor $\frac{(\text{Pop 1})\,(\text{Pop 2})}{\text{D}}$ gave a correlation ratio, computed from raw data, of 0.68 with the minimum AAD. In an endeavor to decrease the scatter (increase the correlation) of the travel desire factor with the AAD, three other combinations of Populations 1 and 2 and the distance between them were tried:

$$\frac{(\text{Pop 1})\,(\text{Pop 2})}{\text{D}^2}, \quad \frac{\sqrt{(\text{Pop 1})\,(\text{Pop 2})}}{\text{D}}, \text{ and } \frac{\sqrt{(\text{Pop 1})\,(\text{Pop 2})}}{\text{D}^2}.$$

All four of these factors, in the cumulative form, were computed for each section of the seven sample roads and plotted on log-log paper against the minimum 1950 AAD for each respective section of road.

In plotting the data the X axis was used to represent the cumulative travel desire factor and the Y axis to represent the minimum AAD. The original computed values for the travel desire factor and the minimum AAD from the state-highway-department traffic-flow maps were plotted directly on the log-log paper. Plotting data on log-log paper tends to condense the points of the scattergram into a smaller area than they would occupy on arithmetic squared paper and is equivalent to plotting the logarithms of the X value and the Y value on arithmetic paper.

Next a straight estimating or regression line was computed for two of the factors. The normal log-equations for plotting a line of regression on double-log paper from the original values are:

$$\Sigma \log y = n \log a + b \, \Sigma \log X$$
$$\Sigma \log x \log y = \log a \, \Sigma \log x + b \, \Sigma (\log x)^2$$

where b is the slope of the line of regression, log a is the point where the line of regression crosses the Y-axis and n is the number of items used in plotting the scattergram (the number of points). The values of a and b are obtained by solving the two regression equations simultaneously. These equations give a straight estimating line in terms of logarithms from which the squares of the deviations of the logarithms are at a minimum. Since the equations are in terms of logarithms, the line of regression is not a least square fit to the original data, although the discrepancy is usually not large.

To check the possible difference in correlation that might be attributed to the line of regression not being a least square fit with the original data, the index of correlation was computed for the logs of the raw data. The normal equation for computing the index of correlation using logarithms of the x and y observations is:

$$p \log Y \log X = \frac{N \Sigma \log X \log Y - (\Sigma \log X)\,(\Sigma \log Y)}{\sqrt{[N \Sigma (\log X)^2 - (\Sigma \log X)^2]\,[N \Sigma (\log Y)^2 - (\Sigma \log Y)^2]}}$$

when there are two or less constants in the equation.

Also the same data that was used for computing the $\Sigma \frac{\sqrt{\text{Pop 1 Pop 2}}}{\text{D}}$ and

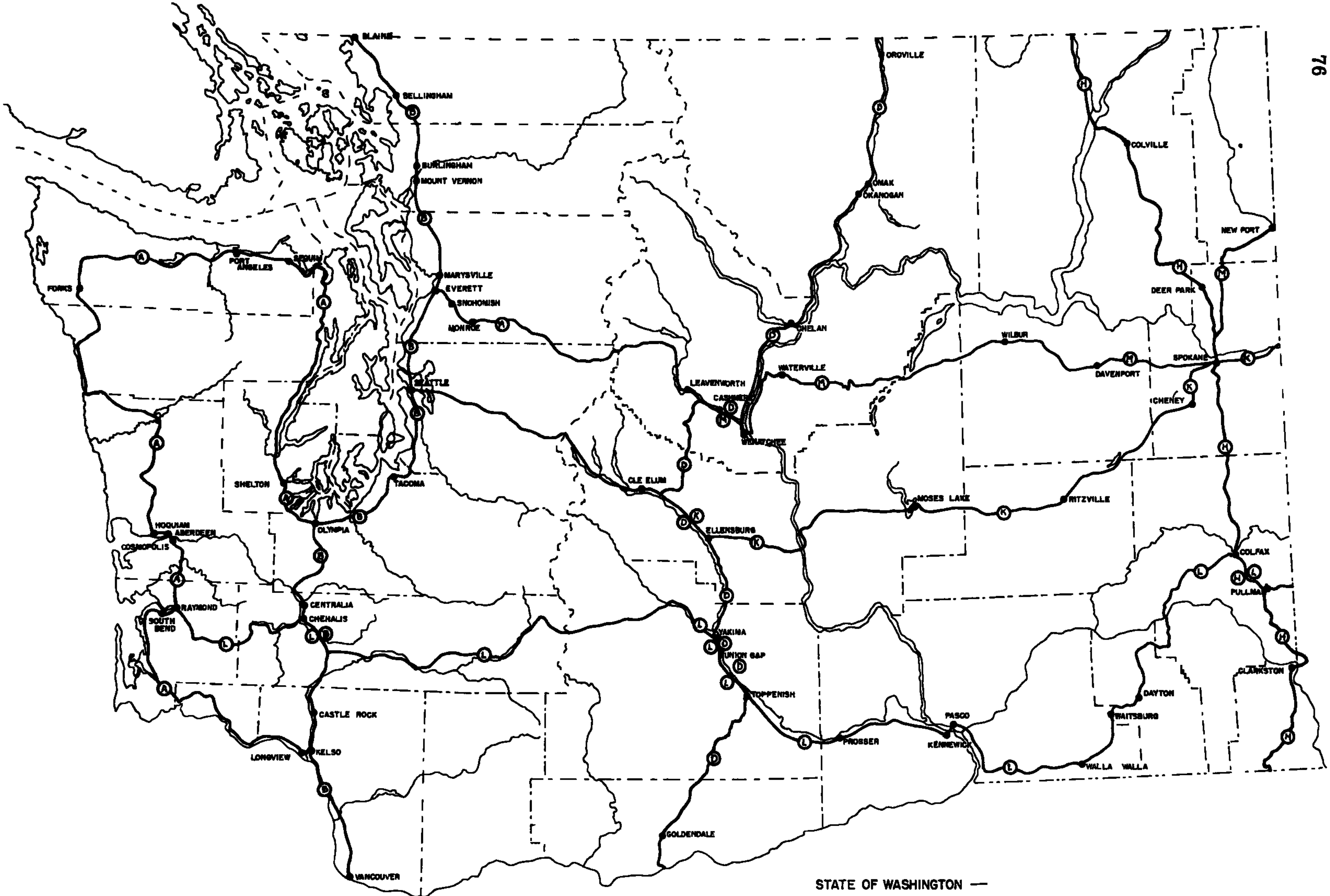


Figure 2.

STATE OF WASHINGTON —
SEVEN REPRESENTATIVE CROSS-STATE ROADS
USED IN CORRELATION STUDY OF POPULATION FACTOR AND 1950

$\Sigma \sqrt{\frac{\text{Pop 1 Pop 2}}{D^2}}$ cumulative factors were recomputed summing the individual factors before taking the square root giving the cumulative factors $\sqrt{\frac{\Sigma \text{ Pop 1 and Pop 2}}{D^2}}$ and $\sqrt{\frac{\Sigma \text{ Pop 1 and Pop 2}}{D^4}}$

The plots of the factors tried are shown in Figures 3, 4, 5, and 6. Regression line equations were computed for the cumulative combinations of the $\sqrt{\frac{\text{Pop 1 Pop 2}}{D}}$ and $\sqrt{\frac{\text{Pop 1 Pop 2}}{D^2}}$ factors and are shown on the respective plots.

TABLE 4

INDIVIDUAL INTERCITY TRAVEL DESIRE FACTOR AND ORIGIN AND DESTINATION DATA (1950 Equivalent) FROM WASHINGTON STATE HIGHWAY DEPARTMENT

U. S. 99	Mt. Vernon	Ever-ett	Seattle	Tacoma	Olympia	Chehalis-C	Kelso-L	Vanc-Port	
Bellingham	19.7 512 394	7.1 492 160	16.1 1558 1048	5.5 704 45	0.9 146 14	0.6 114 2		2.04 577 113	F4 F3 O&D
Seattle				392.8 12,568 6216	26.7 1658 422	10.6 1019 218	7.03 978 179	21 3892 566	F4 F3 O&D
Tacoma					68.7 2060 1156	14.4 919 243	7.1 763 44	18.5 2830 216	F4 F3 O&D
Olympia						13 442 227		7.3 900 122	F4 F3 O&D
Longview-K					3.5 271 29	10.7 462 101			F4 F3 O&D

	Yakima	Prosser	Spokane	
Seattle	14.7 1855 364	7	3.99 1146 296	F4 F3 O&D

	Aberdeen	Port Angeles	
Olympia	7.98 375 207	727 39	F4 F3 O&D

$$F3 = \frac{\sqrt{\text{Pop 1} \times \text{Pop 2}}}{D} \qquad F4 = \frac{\sqrt{\text{Pop 1} \times \text{Pop 2}}}{D^2}$$

Origin and destination data of less than 10 were not used in the correlation computations.

In the linear log regression equation. log y = log a + b (log x), the relationship is interpreted as straight line on log-log or squared paper if the b factor is 1.00 ± 0.2. Slopes with a value greater or less than 1.00 ± 0.2 will appear linear on log-log paper and curvilinear on ordinary squared paper (9).

For example, the regression line equation for the correlation of $\Sigma \sqrt{\frac{(\text{Pop } 1)(\text{Pop } 2)}{D}}$ with minimum AAD is log y = 1.4188 + 0.5400 log x. In this case the value of b is 0.54 showing that the relationship is not linear. The type of equation that would fit the raw data in all cases tried would be $y = ax^b$.

The computed correlation coefficient, r, between the expected and observed travel indicates the relationship of the actual observed minimum AAD and that expected by the intercity travel desire factor.

The coefficient of determination, r^2, explains what proportion of the variance of the Y values is determined by the X values. In the case of the $\Sigma \sqrt{\frac{(\text{Pop } 1)(\text{Pop } 2)}{D^2}}$ factor, r^2 = 86 percent. This means that 86 percent of the variance of the Y values is associated with the variability of the X values. If r^2 is more than 50 percent, the determining factors are more known than unknown and the predictability of the Y values from the X values is more than just probability.

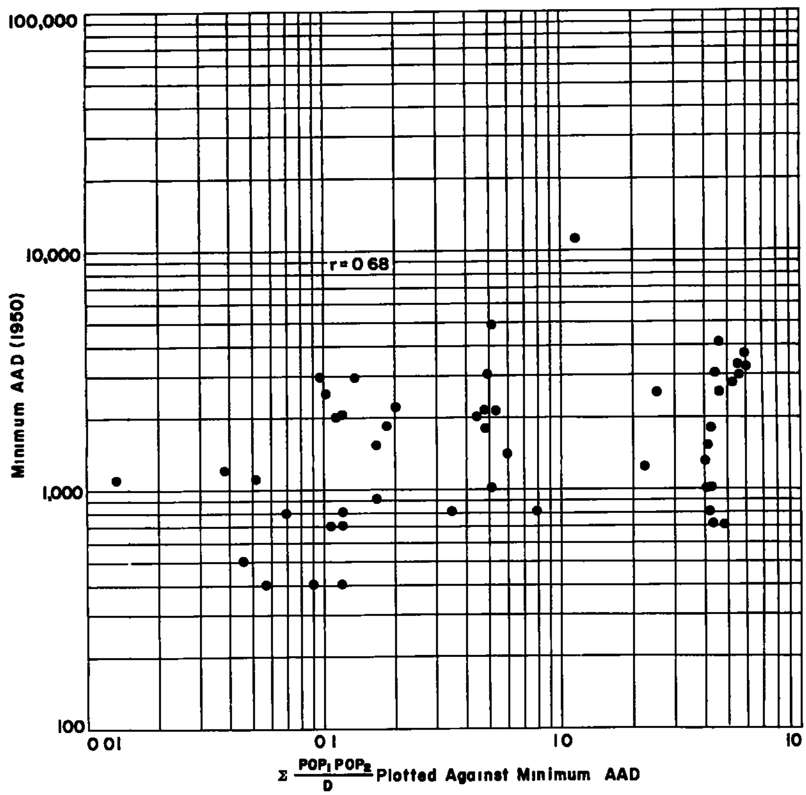


Figure 3.

Table 3 shows the correlation coefficients, indices of correlation and standard errors of estimate for the cumulative combinations of the square root factors.

The choice of a factor to be used to measure intercity travel desire for the Washington State Highway Classification Study was based on the following:

1. Of the factors tried the $\sqrt{\frac{(\text{Pop } 1)(\text{Pop } 2)}{D^2}}$ form gave the best correlation with the minimum AAD. This factor was called the intercity travel desire factor.

2. The longer a trip the more overall state interest exists in the trip. For example, a 200-mile trip would be of greater value to the economy of the state than an 100-mile trip. In order to weight the longer trip to emphasize the state interest in the trip, it was decided to multiply the $\sqrt{\frac{(\text{Pop 1})\ (\text{Pop 2})}{D^2}}$ factor by the distance between the two towns being considered. This procedure netted the weighted factor $\sqrt{\frac{(\text{Pop 1})\ (\text{Pop 2})}{D}}$, which was then used to evaluate state interest in the cumulative intercity travel desire for each section of highway under consideration in the classification study.

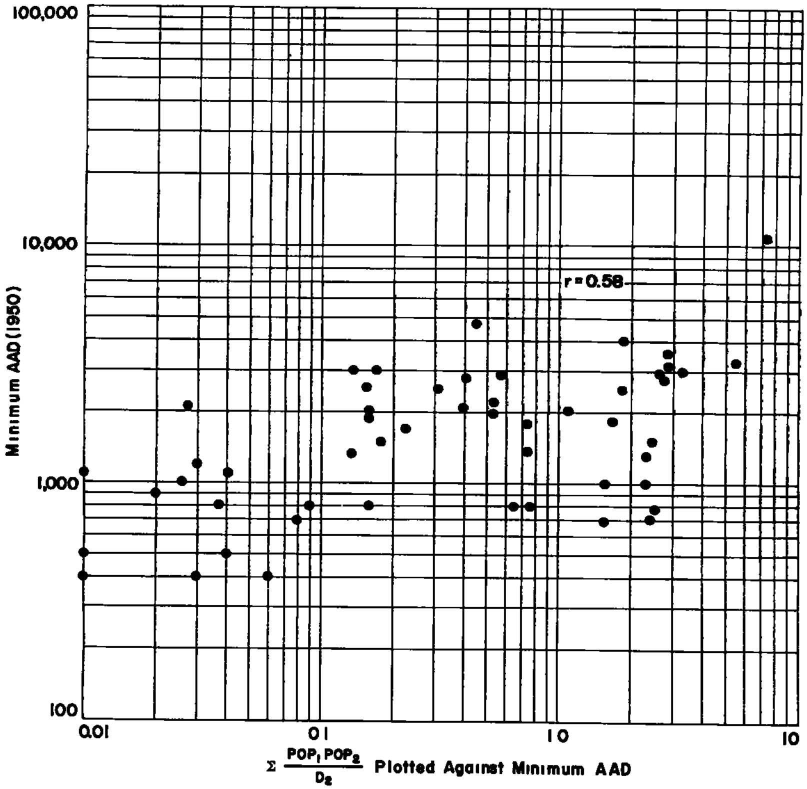


Figure 4.

A correlation check was made with the origin-and-destination data available from the Washington State Highway Planning Survey. Because the sample is small, 22 items, the results cannot be considered conclusive; however, the correlation of the raw data for these 22 figures with the individual $\sqrt{\frac{(\text{Pop 1})\ (\text{Pop 2})}{D}}$ factors was 0.95 and with the individual $\sqrt{\frac{(\text{Pop 1})(\text{Pop 2})}{D^2}}$ was 0.99. There was not enough origin-and-destination data available to check the cumulative factor which would be more representative of total intercity-travel desire. This data is shown in Table 4 and Figures 7 and 8. When more data becomes available, it would undoubtedly be of value to run a more thorough correlation study along this line.

Some of the variance in the relationship between the intercity-travel-desire factor and either the minimum AAD or origin-and-destination data can be attributed to the influence of the condition and adequacy of road on the amount of traffic using the road. The intercity-travel-desire factor is entirely independent of road condition and adequacy.

Figures 9 and 10 show a traffic-flow map and a travel-desire-factor map for the state highways in Spokane County drawn up from the sample data and data computed for other state roads in Spokane County. The bulges in the traffic-flow map indicate local traffic conditions. These bulges tend to disappear on the travel-desire-factor map, since local-travel desire was minimized to a considerable degree. Weighting of the travel desire factor by the distance between the towns also tends to smooth out the bulges due to local traffic.

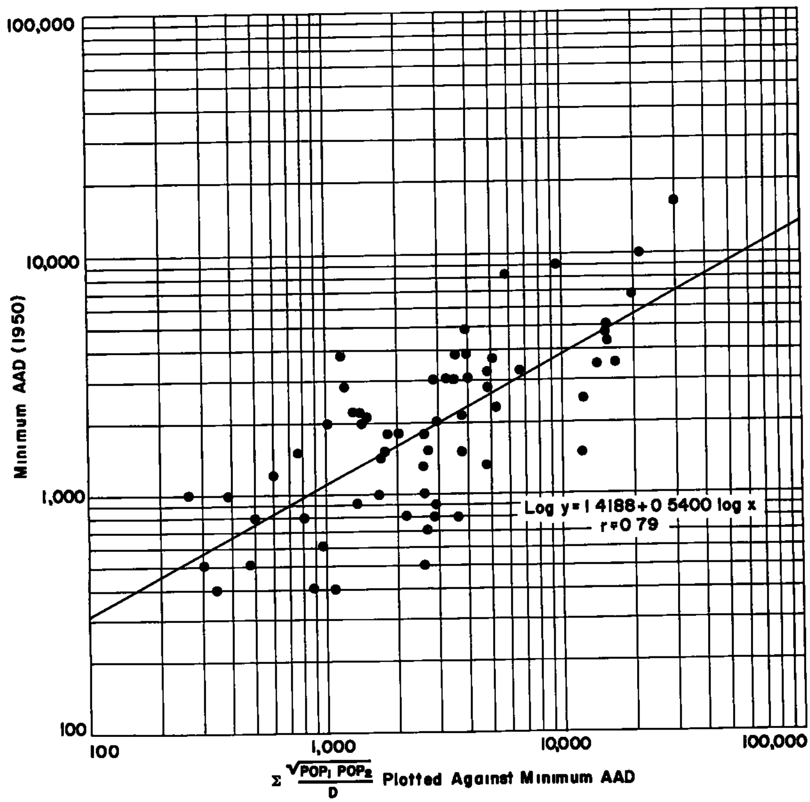


Figure 5.

The travel-desire bands correspond in width with the minimum traffic-flow bands within tolerable limits. Travel desire from eastern Washington cities to Washington perimeter cities in Idaho more than 20 miles from the state border were not considered in computing the data for Figure 10. It may be that cities more than 20 miles from the state border should be included as perimeter cities for computing travel desire from the Idaho-Washington border to the Idaho perimeter cities in Washington.

It is possible that cities within a radius of 300 or 400 miles of a city being studied should be included in computing the intercity-travel-desire to that city, regardless of political boundaries. In this correlation study, Portland and Vancouver were the only two cities outside the state that were considered. Perimeter cities within approximately 20 miles of the state border were used in the computations for the weighted intercity-travel-desire factor used in the classification study.

APPLICATION OF THE INTERCITY-TRAVEL-DESIRE FACTORS

In order to insure consistent application of the weighted intercity-travel-desire factor to the highways throughout the state several arbitrary but rational policies were established.

1. All incorporated or unincorporated towns of 1,000 or more population would be considered. This minimum limit would probably vary from one state to another.

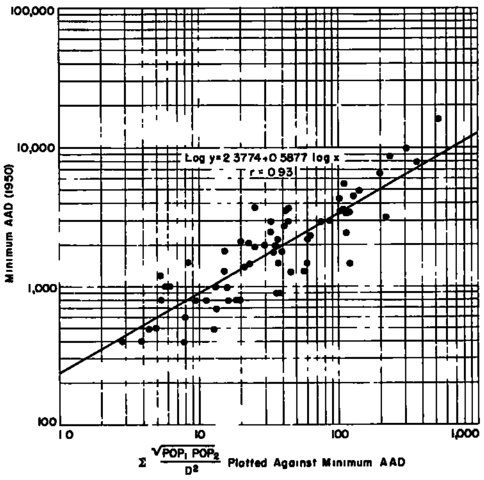


Figure 6.

2. Population figures would be taken from those of the United States Census Bureau.

3. The population to be used for all cities over 50,000 would not be that of the political boundaries of the city but that of the metropolitan area of the city as established by the United States Census Bureau.

4. Contingent cities which were approximately five miles or less apart and had much the same characteristics of a single town were to be considered as one population unit instead of two. The boundaries of most of these cities cannot be clearly defined by appearance because of the dense suburban population between them.

5. The populations of contingent towns would be added before taking the square root in the mathematical procedure $\sqrt{(\text{Pop 1})(\text{Pop 2})}$.

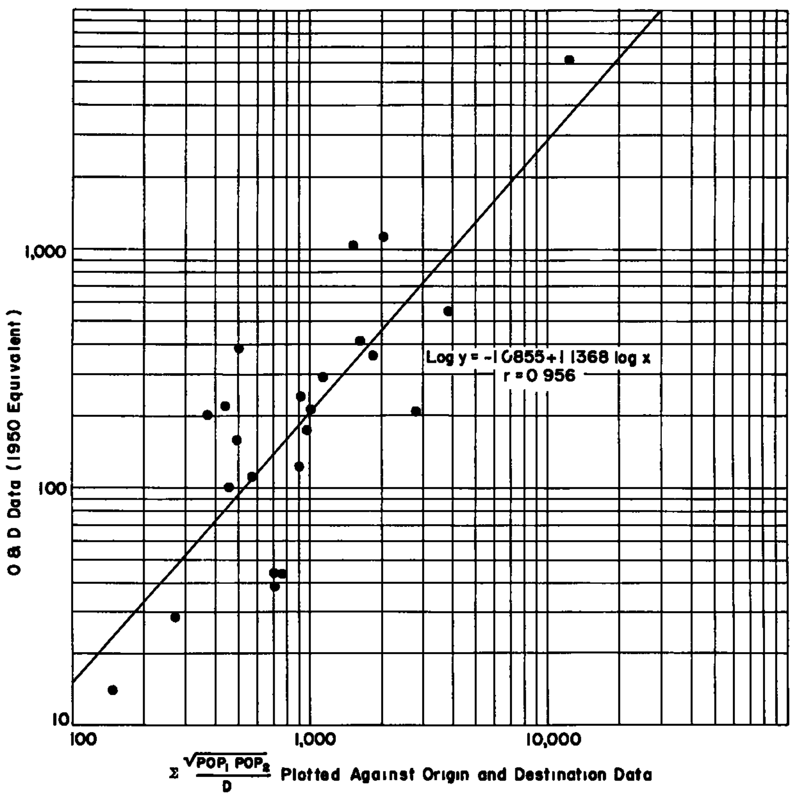


Figure 7.

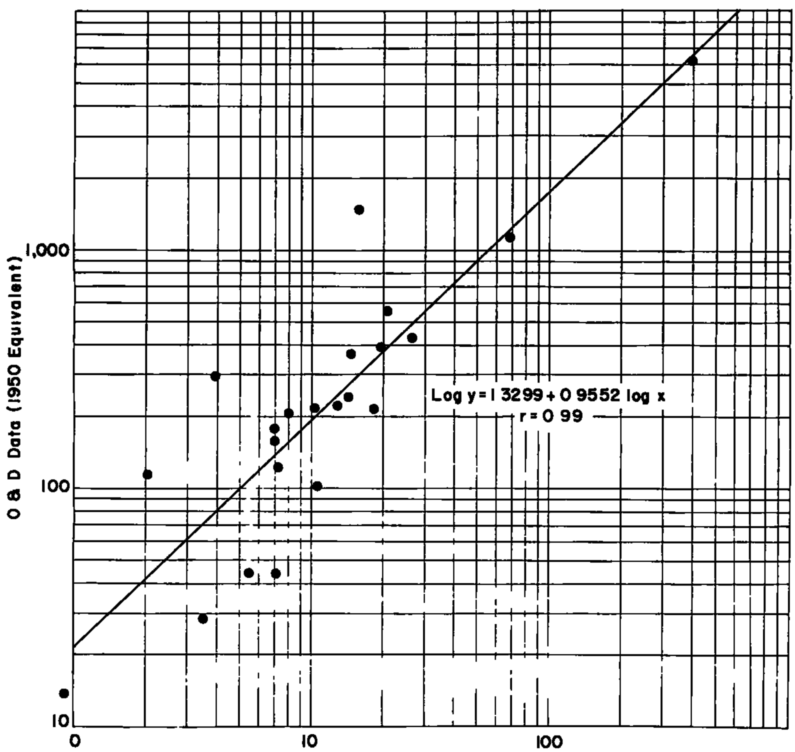
Since the square root of the sum of two numbers is less than the sum of the square roots of two numbers, the method used would tend to decrease slightly the relative weight of the combined contingent cities. This seems rational because the two contingent cities are not yet a single unit, although in time their political boundaries will undoubtedly merge. Until this happens the traffic attraction of the two towns will probably not be quite as great as though they were a single unit.

TABLE 5

CORRELATION DATA FOR ORIGIN AND DESTINATION
AND $\frac{\sqrt{(Pop1)\ (Pop2)}}{D^2}$

$\frac{\sqrt{P_1 P_2}}{D^2} = x$	x^2	log x	O&D = y	y^2	log y	log x log y	xy	$(\log x)^2$
19.7	388.09	1.29447	394	155,236	2.5955	3.3598	7762	1.6757
7.1	50.41	0.85126	160	25,600	2.2041	1.8763	1136	0.7246
16.1	259.21	1.20683	1048	1,098,304	3.0406	3.6695	16,873	1.4564
5.5	30.25	0.74036	45	2025	1.6532	1.2240	248	0.5481
0.9	0.81	-1.95424	14	196	1.1461	-0.0524	13	-0.0021
2.04	4.16	0.30963	113	12,769	2.0531	0.6357	231	0.0959
392.8	154,291.84	2.59417	6216	38,638,656	3.7935	9.8410	2,441,645	6.7297
26.7	712.89	1.42651	422	178,084	2.6253	3.7450	11,267	2.0349
10.6	112.36	1.02531	218	47,524	2.3385	2.3977	2311	1.0513
7.03	49.42	0.84696	179	32,041	2.2528	1.9080	1258	0.7173
21.	441.00	1.32222	566	320,356	2.7528	3.6398	11,886	1.7483
68.7	4,719.69	1.83696	1156	1,336,336	3.0630	5.6266	79,417	3.3744
14.4	207.36	1.15836	243	59,049	2.3856	2.7634	3499	1.3418
7.1	50.41	0.85126	44	1936	1.6434	1.3990	312	0.7246
18.5	342.25	1.26717	216	46,656	2.3344	2.9581	3996	1.6057
13.	169.00	1.11394	227	51,529	2.3560	2.6244	2951	1.2409
7.3	53.29	0.86332	122	14,884	2.0864	1.8012	891	0.7453
3.5	12.25	0.54407	29	841	1.4624	0.7956	102	0.2960
10.7	114.49	1.02938	101	10,201	2.0043	2.0632	1081	1.0596
14.7	216.09	1.16732	364	132,496	2.5611	2.9896	5351	1.3626
3.99	15.92	0.60097	296	87,616	2.4713	1.4852	1181	0.3612
7.98	63.68	0.90200	207	42,849	2.3160	2.0890	1652	0.8136
679.34	162,304.87	22.90671	12,380	42,295,184	51.1394	58.8397	2,595,063	29.7058

n = 22



$\Sigma \frac{\sqrt{POP_1\ POP_2}}{D^2}$ Plotted Against Origin and Destination Data

Figure 8.

TABLE 6

CORRELATION COMPUTATIONS FOR ORIGIN AND DESTINATION DATA AND $\frac{\sqrt{(\text{Pop 1})(\text{Pop 2})}}{D^2}$

CORRELATION COEFFICIENT

$$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2) - (\Sigma x)^2}\ \sqrt{n(\Sigma y^2) - (\Sigma y)^2}}$$

$$r = \frac{22(2,595,063) - (679.34)(12,380)}{\sqrt{22(162,304,87) - (679.34)^2}\ \sqrt{22(42,295,184) - (12,380)^2}}$$

$$r = \frac{48,681,157}{49,150,677} = 0.99$$

REGRESSION LINE EQUATION

I. $\Sigma \log y = n \log a + b\Sigma \log x$

II. $\Sigma (\log x \log y) = (\log a)(\Sigma \log x) + b\Sigma (\log x)^2$

$$\log a = \frac{\Sigma \log y}{n} - \frac{b\Sigma \log x}{n}$$

$$\log a = \frac{51.1394}{22} - \frac{22.90671}{22}\, b$$

$$\log a = 2.3245 - 1.0412b$$

II. $58.8397 = (2.3245 - 1.0412b)(22.90671) + 29.7048b$

$$b = 0.9552$$

$$\log a = 2.3245 - (1.0412)(0.9552)$$

$$\log a = 1.3299$$

$$\log y = 1.3299 + 0.9552 \log x$$

6. If two feasible routes exist between two cities, their weighted, cumulative, intercity-travel-desire factor will be split on a mileage basis. If the difference in the mileage of the two routes is more than 15 to 20 percent, only the shortest route will be considered.

7. If more than two feasible routes exist between the two cities only the two shorter routes will be considered. Since logically the factor would be based on the shortest route between two cities, their entire weighted, cumulative, intercity-travel-desire factor would be computed upon this basis as if it were the only route. When there are two routes, this factor is to be divided between the two routes in the ratio of $\frac{1}{F} = \frac{1}{F_1} + \frac{1}{F_2}$

where

F = weighted cumulative intercity-travel-desire factor between two cities computed for the shortest route = $\frac{\Sigma \sqrt{P_1 P_2}}{D}$ $F_1 = \frac{FD_2}{D_1 + D_2}$ and $F_2 = \frac{FD_1}{D_1 + D_2}$ where D_2 =

TABLE 7

TRAVEL DESIRE FACTORS FROM WENATCHEE TO ALL OTHER CITIES OVER 1000 IN WASHINGTON AND BOUNDARY CITIES

Wenatchee √Pop = 132 8	√Pop	$dist_1$	$Route_1$	F_1	$dist_2$	$Route_2$	F_2	$d_1 + d_2$	√Pop√Pop	$\frac{d_L}{d_S}$
Granger	34 6	205	M,D,L,	45				-	4,594 88	-
Issaquah	30 9	132	M,D,K,	31				-	4,103 52	-
Kalama	33 2	292	M,D,K,O,B,	8	332	M,D,J,B,	7	624	4,408 96	1 1370
Kelso-Longview	166 4	286	M,D,K,C,B,	42	340	M,D,J,B,	35	626	22,097 92	1 1888
Kent	56 6	165	M,C,	24	151	M,D,K,C,	26	316	7,516 48	1 0927
Leavenworth	38.7	25	M,	206				-	5,139 36	-
Lynden	46 9	211	M,C,	15	206	M,B,	15	417	6,228.32	1 0243
McCleary	34 6	224	M,B, [23]	21				-	4,594 88	-
Marysville	65 1	135	M,B,	64				-	8,645 28	-
Medical Lake	67 1	157	M,	57				-	8,910 88	-
Monroe	40 0	113	M	47				-	5,312 00	-
Montesano	48.0	246	M B [23]	26				-	6,374 40	-
Morton	33.2	224	M,D,L, [44]	10	218	M,D,K,C, [69],	10	442	4,408.96	1 0275
Moses Lake	52 0	72	[139], K,	96				-	6,905 60	-
New Port	37 4	212	M,B, [101]	23				-	4,966 72	-
Oak Harbor	34 6	171	M, [107]	27				-	4,594.88	-
Odessa	33 2	100	[139],N	44				-	4,408.96	-
Omak-Okanogan	76 2	95	D	107				-	10,119.36	-
Oroville	38 7	137	D	37				-	5,139 36	-
Orting	36 1	173	M,D,K,C, [69]	28				-	4,794 08	-
Palouse	31.6	242	M,H, [186]	9	227	M,H, [187]	10	469	4,196 48	1 0660
Pomeroy	42 4	282	M,H,L,G,	10	261	[139] N, KE/KG, J,L,G	11	543	5,630 72	1 0804
Port Angeles	105 8	326	M,C,B,A,	23	278	M,C, Ferry, S,A	27	604	14,050 24	1 1726
Port Townsend	83 1	303	M,C,B,A, [9]	20	261	M,C, Ferry,S,A	23	564	11,035 68	1 1609
Poulsbo	31.6	226	M,C,B,S,	11	172	M,C, Ferry	14	398	4,196 48	1 3140
Prosser	51 0	167	M,D,L, abo [154]	41				-	6,772 80	-
Pullman	109 5	241	M,H,	60				-	14,541.60	-
Ray-So Bend	77 5	268	M,C,B, [123], [A]	38				-	10,292 00	-
Ritzville	45 8	116	[139],N,K,	52				-	6,082 24	-
Sedro Wooley	57 4	171	M,C,	22	172	M,B,	22	343	7,622 72	1 0058
Sequim	31 6	310	M,C,B,A,	7	296	M,C, Ferry [9], A	7	606	4,196 48	1 0473
Shelton	70 7	226	M,C,B,A,	42				-	9,388 96	-
Snohomish	55 7	123	M,	60				-	7,396 96	-
Soap Lake	45 8	57	[139],N	107				-	6,082 24	-
Sunnyside	64 8	153	M,D,L,	56				-	8,605 44	-
Tekoa	34 6	217	M,H, [187] [190]	11	209	M,K, [190],	11	426	4,594 88	1 0383
Tenino	31 2	219	M,B,	19				-	4,143.36	-
Tonasket	31 6	115	D	36				-	4,196 48	-
Toppenish	72 8	137	D	71				-	9,667 84	-
Met Van B C	629 1	244	M,B,	175	255	M,C,	167	499	83,544 48	1 0451
Port Van	880 4	302	M,D,J,	199	322	M,D,K,C,B,	187	624	116,917 12	1 0662
Pasco	212 6	150	[139], N,K,E,J,G	94	149	[139], N,K,E,J,	101	299	28,233 28	1 0067
Bremerton	188 9	158	M,C, Ferry	91	212	M,C,B,S,	68	370	25,085 92	1 3417
Olympia	143 1	205	M,C,B, [23]	93				-	19,003 68	-
Ab-Hoquiam	178 7	255	M,C,B,	93				-	23,731 36	-
Annacortes	83 1	179	M,B, [108]	62				-	11,035 08	-
Arlington	40 0	149	M,B,C,	18	144	M,C,	19	293	5,312 00	1 0347
Bellingham	184 7	191	M,B,	65	196	M,C,	63	387	24,528 16	1 0262
Blaine	41 2	212	M,B,	13	226	M,C, [122]	12	438	5,471 36	1 0660
Buckley	52 0	173	M,D,K,T, [148] [62]	20	185	M,C,T, [62]	19	358	6,905 60	1 0694

TABLE 7 (continued)

Wenatchee $\sqrt{Pop}$ - 132 8	$\sqrt{Pop}$	$dist_1$	$Route_1$	F_1	$dist_2$	$Route_2$	F_2	$d_1 + d_2$	$\sqrt{Pop}\sqrt{Pop}$	$\frac{d_L}{d_S}$
Burlington-Mt Vernon	87 1	168	M,B,	34	168	M,B,	34	336	11,566 88	1 0000
Camas	88 3	287	M,D,J,	22	337	M,D,K,C,B,J	19	624	11,726.24	1 1742
Cashmere	42 4	12	M,	469				-	5,630.72	-
Castle Rock	34 6	270	M,C,B,	17				-	4,594.88	-
Cent-Cheh	119 6	237	M,C,B,	64				-	15,282 88	-
Chelan	47 9	40	D,	159				-	6,361 12	-
Cheney	52 9	181	M,K,	20	167	[139],N,K,	22	348	7,025 12	1 0838
Chewelah	41 2	225	M,H,	13	240	[139],N,K,H	12	465	5,471 36	1 0667
Clarkston	143 2	261	M,H,	38	292	[139] KG/KE J,L,G,	34	553	19,016 96	1 1188
Cle Elum	46 9	65	M,D,K,	96				-	6,228 32	-
Colfax	55 7	225	M,H,	33				-	7,396 96	-
Colville	54 8	222	M,N,	17	248	M,H,	15	470	7,277 44	1 1171
Coulee City	31 6	68	M	62				-	4,196 48	-
Davenport	37 4	128	M	39				-	4,966 72	-
Dayton	54 8	297	M,H,L,	14	224	[139],N, KE/KG, J,L,	19	521	7,277 44	1 3259
Deer Park	31 6	188	M,H,	22				-	4,196 48	-
Eatonville	31 6	187	M,D,K,C,[69]	11	212	M,C,[69]	10	399	4,196 48	1 1337
Ellensburg	91 6	86	[139], N	73	81	M,D,K,	78	167	12,164 48	1 0617
Elma	38 7	229	M,B,[23]	22				-	5,139 36	-
Enumclaw	52 9	170	M,D,K,T	41				-	7,025 12	-
Ephrata	67 8	52	[139], N	173				-	9,003 84	-
Everett	205 4	130	M,	210				-	27,277 12	-
Ferndale	31 2	200	M,B,	10	205	M,C,B,	10	405	4,143 36	1 0250
Forks	33 2	360	M C B [23], A	12				-	4,408 96	-
Goldendale	43 6	187	M,D	31				-	5,790 08	
Grand Coulee	85 7	91	M, [138],	125				-	11,380 96	-
Grandview	50 0	159	M,D,L	42				-	6,640 00	-
Waitsburg	31 6	205	[139] N,K,G,E,J,L	20				-	4,196 48	-
Walla Walla	165 2	185	[139] N,K,G,E,J,L	119				-	21,938 56	-
Wapato	56 3	130	D	58				-	7,476 64	-
Waterville	31 6	17	M	247				-	4,196 48	-
Rainier	35 8	286	M,D,K,C,B	10	340	M,D,J,B	8	626	4,754 24	1 1888
White Salmon	45 7	235	D,J,	26					6,068 96	-
Wilbur	31 6	101	M,	42				-	4,196 48	-
Woodland	36 1	303	M,D,K,C,B	8	321	M,D,J,B	8	624	4,794 08	1 0594
Astoria	111 0	378	M,D,K,C,B,A, Ferry	20	349	M,D,K,C,B, Ore	22	727	14,740 80	1 0031
Pendleton, Ore	108 2	257	D, [160]	56				-	14,368 96	-
The Dalles, Ore	87 4	219	D,J, Ferry	27	218	D, Oregon	27	437	11,606 72	1 0046
Hood River Ore	60 8	235	D,J, Ferry	18	243	D, Oregon	17	478	8,074 24	1 0340
Milton, Ore	48 6	197	[139] N,K,E,J,L, [170]	33				-	6,454 08	-
Moscow I	102 8	249	M,H,L,	55				-	13,651 84	-
Coeur D'Alene, I	110 3	200	M,K,	73				-	14,647 84	-
Priest River, I	39 8	220	M	24				-	5,285 44	-
Sand Point, I	65 3	243	M	36				-	8,671 84	-
Lake Stevens	50 8	128	M,C	53				-	6,746 24	-
Seattle	817 9	143	M, [99]	759				-	108,617 12	-
Tacoma	491 7	148	D, [148], T, [62], [70],	234	168	M, [99], C,	207	316	65,297 76	1 135
Spokane	432 9	167	M	341				-	57,489 12	-
Yakima	247 5	105	D,M,D,	161	112	[139] N K D	151	217	32,868 00	1 067
Pasco Richland	212 6	145	[139] N K J	195				-	28,233 28	-

the longer route and D_1 = the shorter route. Substituting $\sqrt{\frac{P_1 P_2}{D_1}}$ for F,

$$F_2 = \sqrt{\frac{P_1 P_2}{D_1 + D_2}} \quad \text{and } F = \frac{F_2 D_2}{D_1}$$

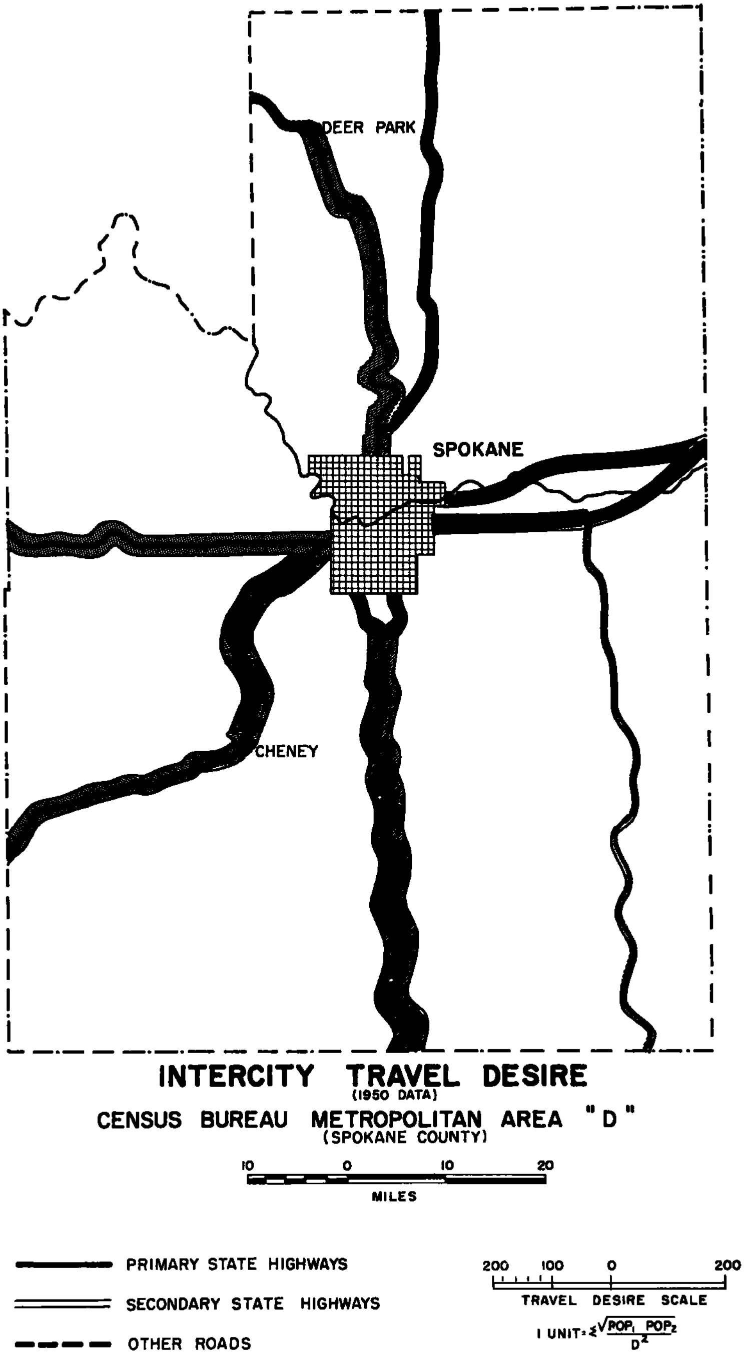


Figure 9.

F_1 then will be the proportion of the weighted cumulative intercity-travel-desire-factor that will apply to the shorter route, and F_2 will be the proportion that will apply to the longer route.

Table 8

$\Sigma \frac{\sqrt{(Pop\ 1)(Pop 2)}}{D}$ for Highways Radiating from Wenatchee

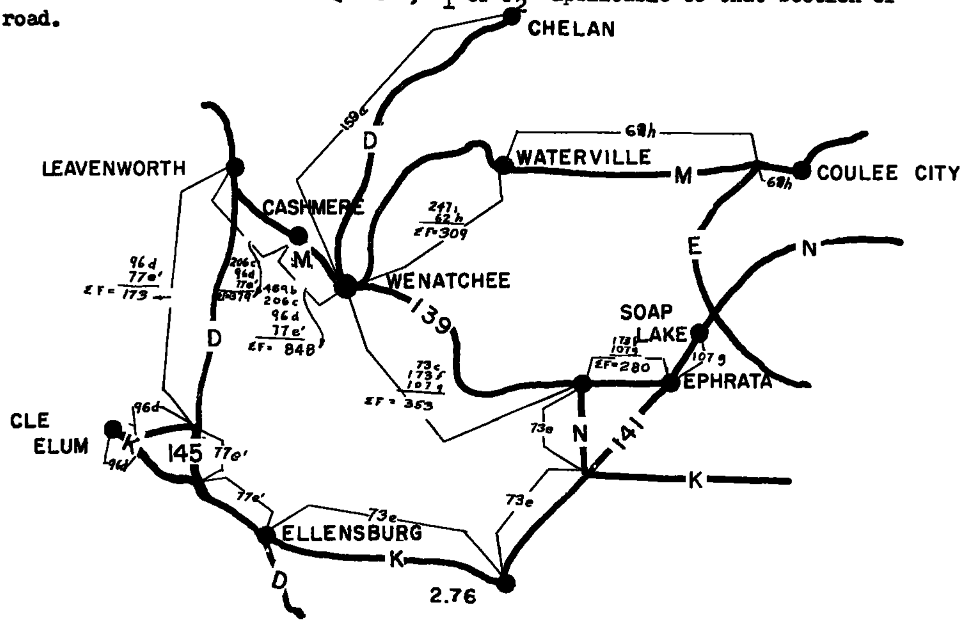
Wenatchee $\sqrt{Pop.}$ = 132.8	$\sqrt{Pop_2}$	$Dist_1$	$Route_1$	F_1	$Dist_2$	$Route_2$	F_2
a) Chelan	47.9	40	D↗	159a			
b) Cashmere	42.4	12	M←	469b			
c) Leavenworth	38.7	25	M←	206c			
d) CleElum	46.9	65	←M D↓ K←	96d			
e) Ellensburg	91.6	86	↖139 N↓ K←	73e	81	← M ↓ D ↘ 145k →	77e'
f) Ephrata	67.8	52	↖139 N←	173f			
g) Soap Lake	45.8	57	↖139 N←	107g			
h) Coulee City	31.6	68	M→	62h			

for one route: $F = \frac{\sqrt{Pop_1 \times Pop_2}}{dist}$

for two routes: $F_2 = \frac{\sqrt{Pop_1 \times Pop_2}}{(Dist_1 + Dist_2)}$ for longer route

$F_1 = \frac{F_2\ (Dist)\ Longer}{Dist.\ Shorter}$ for shorter route

Total F between junctions = Σ all F, F_1 or F_2 applicable to that section of road.



The weighted desire for travel factor for all sections of highway connecting all the cities in Washington over 1,000 population was computed. This was done for all the cities in the manner shown for Wenatchee in Table 7. Once the factors for travel desire for one town were completed, that town did not appear on any subsequent lists. Consequently, as the computations continued, the list of towns to be considered for factor computation shortened.

After all these factors were computed, entry sheets headed by road-identification numbers were prepared for each section of road connecting towns or junctions. Any weighted travel-desire factor that would apply to any given section of road was listed on the correct sheet for that road. After all entries had been made, the factors for each section of road were added giving a weighted, cumulative, travel-desire index for each section of road under consideration for classification. A sample of this operation is shown in Table 8 for some of the roads that radiate from Wenatchee. This sample will not give the total index for any of the sections of road shown because only the factors between Wenatchee and the cities shown are included.

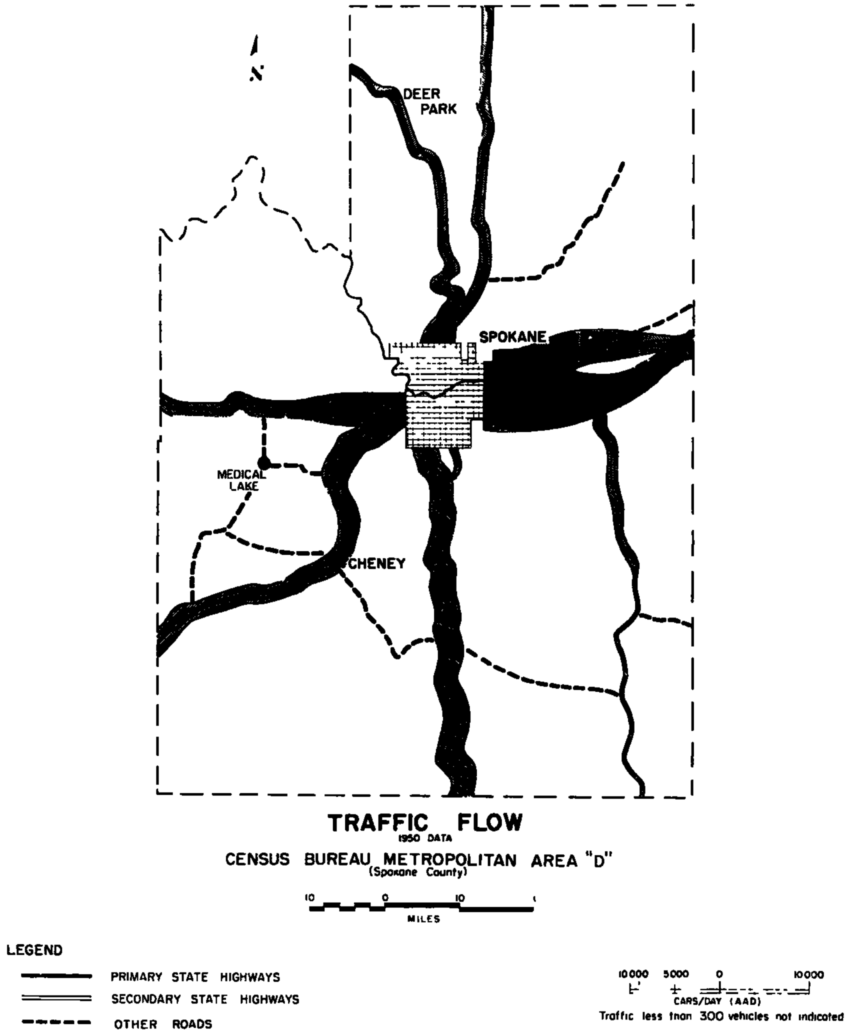


Figure 10.

These indexes were then plotted on a map similar to a traffic-flow band showing graphically the intercity-travel desire. This map, a traffic-flow map and a population-density map for the state of Washington for 1950 are shown in Figures 11, 12, and 13.

The intercity-travel-desire factor is not intended to supplant traffic counts, nor is it intended as a complete measure of highway usage. If applied with judgment, it has a definite usefulness. It can be used to predict the desire for travel on a proposed road that does not now exist if it will connect, directly or indirectly, two population centers. This desire-for-travel factor can be correlated with data worked up on existing roads for the state and a probable minimum flow of traffic forecast for any road. Projected

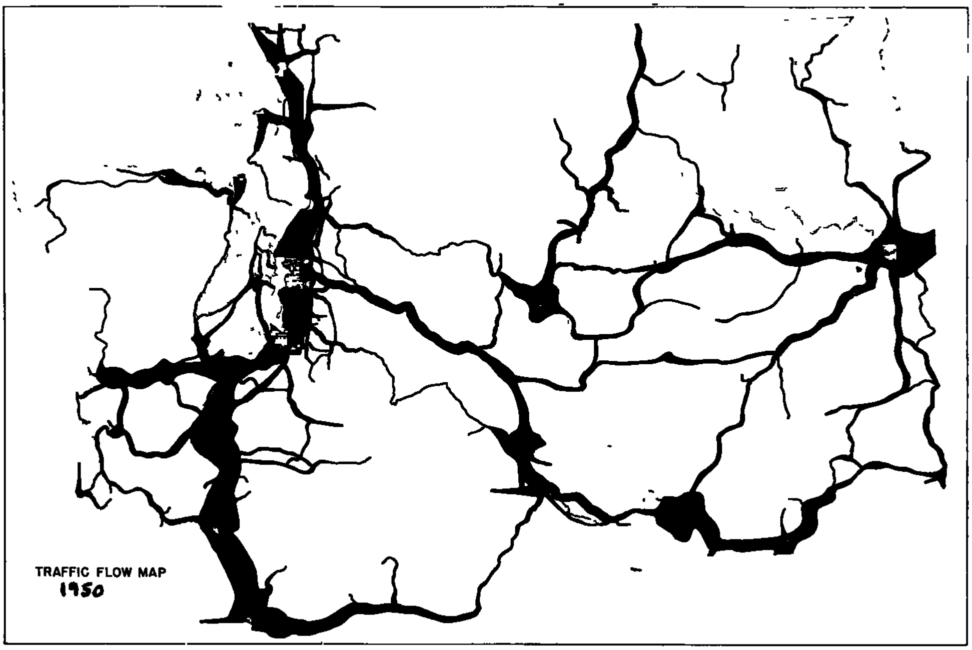


Figure 11.

populations can be used for the towns of the state and a future minimum traffic flow predicted for any road on this basis. It is planned to use this weighted, cumulative, intercity-travel-desire factor at the present time to measure the relative use of the highways by the citizens of the various urban groups in the state of Washington.

The factor could also be used to determine the number of highways or number of lanes that are needed between two cities. Since the factor measures the total desire for travel between the two cities, the size of factor which would be adequately served by a present four-lane highway could be divided into the cumulative factor for the two

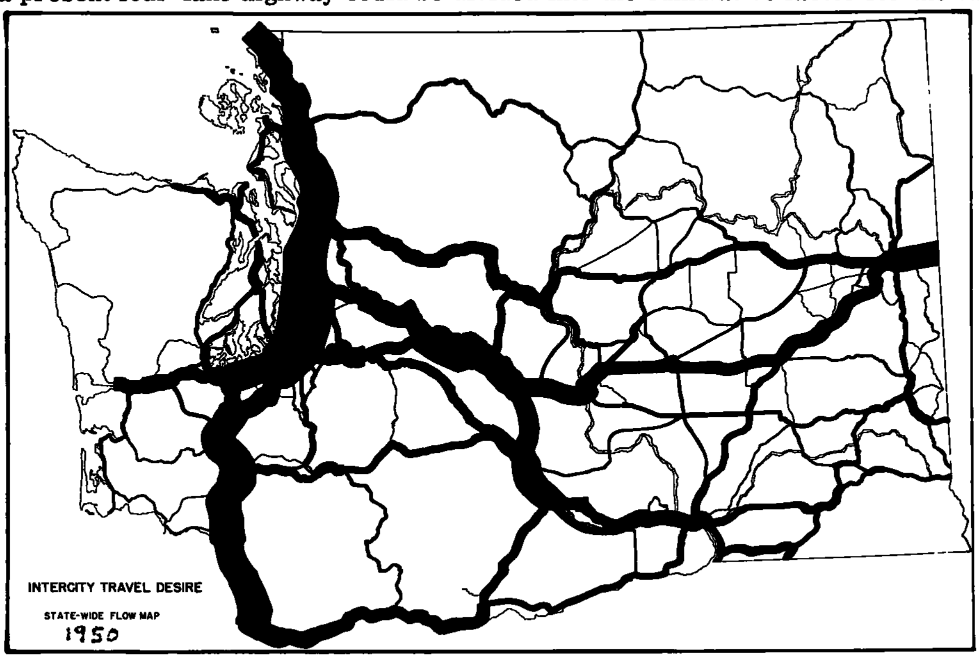


Figure 12.

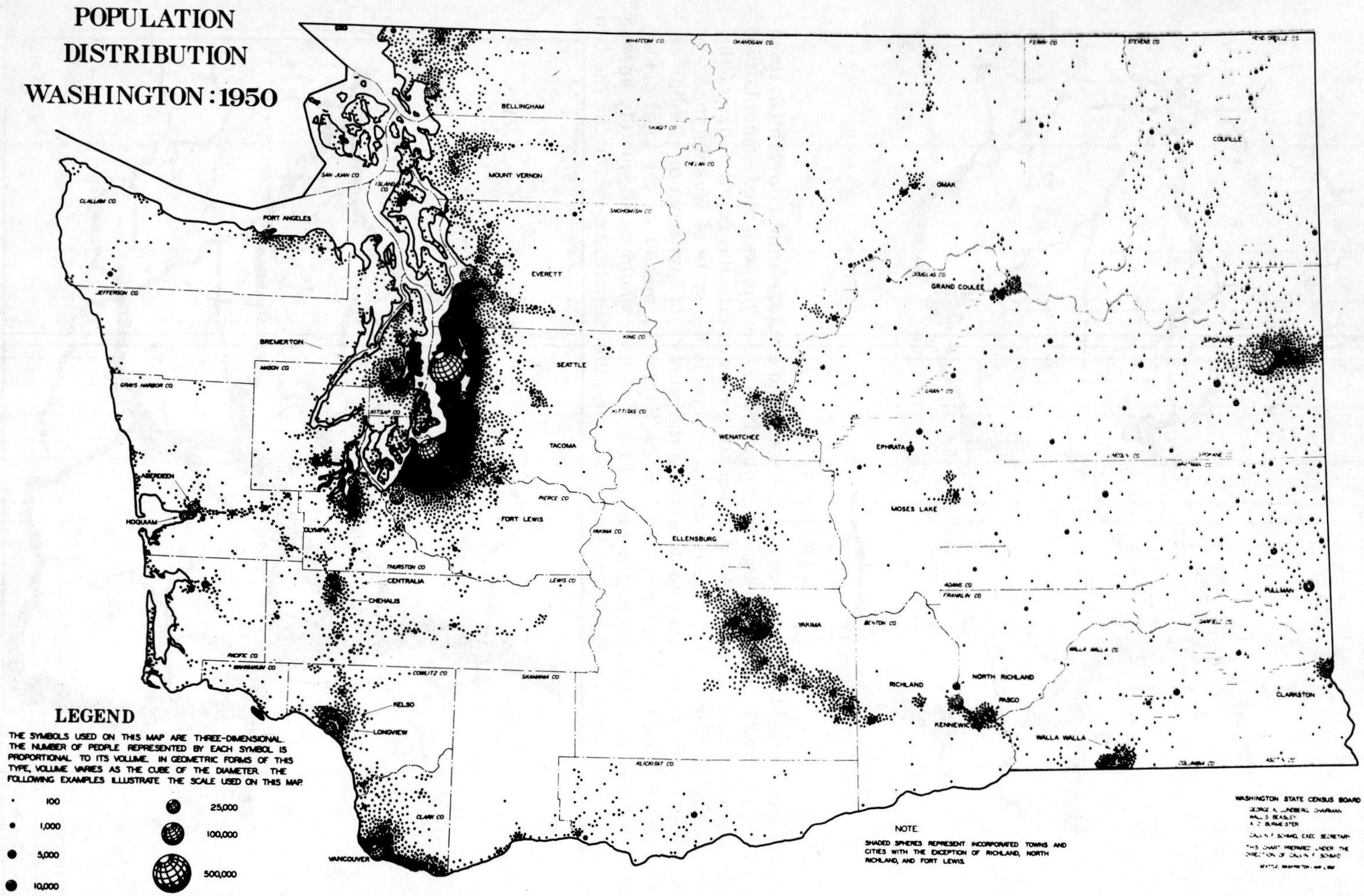

POPULATION
DISTRIBUTION
WASHINGTON: 1950
BELLINGHAM
MOUNT VERNON
PORT ANGELES
EVERETT
BREMERTON
SEATTLE
TACOMA
ABERDEEN
HOQUIAM
OLYMPIA
FORT LEWIS
CENTRALIA
CHEHALIS
KELSO
LONGVIEW
VANCOUVER
WENATCHEE
ELLENSBURG
YAKIMA
OMAK
GRAND COULEE
EPHRATA
MOSES LAKE
RICHLAND
NORTH RICHLAND
PASCO
KENNEWICK
WALLA WALLA
COLVILLE
SPOKANE
PULLMAN
CLARKSTON
LEGEND
THE SYMBOLS USED ON THIS MAP ARE THREE-DIMENSIONAL. THE NUMBER OF PEOPLE REPRESENTED BY EACH SYMBOL IS PROPORTIONAL TO ITS VOLUME. IN GEOMETRIC FORMS OF THIS TYPE, VOLUME VARIES AS THE CUBE OF THE DIAMETER. THE FOLLOWING EXAMPLES ILLUSTRATE THE SCALE USED ON THIS MAP.
100
1,000
5,000
10,000
25,000
100,000
500,000
NOTE:
SHADED SPHERES REPRESENT INCORPORATED TOWNS AND CITIES WITH THE EXCEPTION OF RICHLAND, NORTH RICHLAND, AND FORT LEWIS.
WASHINGTON STATE CENSUS BOARD

Figure 13.

towns under consideration and the total number of roads or lanes the intercity travel for that road would support could be determined.

For example, there is a four-lane highway between Seattle and Tacoma at the present time which is overloaded during peak hours and not fully loaded yet between peak hours. Is another highway between Tacoma and Seattle needed? If the highway were built would there be enough traffic attraction to keep them both in sufficient use to warrant their existence? The intercity-travel-desire factor could answer this question. If the routes were both the same length the cumulative travel desire factor between Seattle and Tacoma would be evenly divided between the two roads and if the factor were large enough, half of it would still warrant the existence of a highway. If the factor were not large enough, the existence of two roads between Seattle and Tacoma could result in neither road being used sufficiently to warrant its maintenance at a standard required for intermetropolitan travel.

The intercity-travel-desire factor has been tested enough to show that it has merit and can be a useful tool. A more-thorough understanding of the merits and limitations of the intercity-travel-desire factor and the techniques of its application will undoubtedly be crystallized with further usage.

In order to use this factor to obtain reasonable results, certain facts and limitations must be recognized:

1. A population center, if it is metropolitan in nature, cannot be limited to the population within the political boundaries if the populace transcends these boundaries and still give a factor representative of the actual travel desire generated or attracted by the center.

2. Two cities within approximately 5 miles of each other would more logically be considered as one population unit rather than two separate units in computing the statewide travel desire inherent in their existence.

3. If the population centers under consideration were 250 miles more apart, it is quite possible that the total intercity-travel desire would not be satisfied by automobile travel alone. Some of the population would travel by train, bus, or plane. The farther apart the cities were the more true this would be. If this travel-desire factor were used for measuring cross-country travel, some corrective factor might be needed to account for the travel desire fulfilled by bus, train, and plane.

4. The intercity-travel-desire factor yields the total desire for movement between population centers and does not directly give the percentage desiring to use each of two different highways between the same two cities. In this study the division of the factor between two possible routes was made on the basis of distances. Perhaps a better technique for this division could be developed.

5. It is possible that an industrial city of 50,000 might generate more highway traffic than a farming city of 50,000 or vice versa. In a general overall picture, considering a cumulative travel-desire factor between two towns, this variance according to the Illinois city population-trade center rating comparison would not have a consequential influence on the results.

No one method of attack is a panacea for all ills, but this cumulative intercity-travel-desire index holds promise of being a representative indicator of the total amount of intercity-travel-desire generated by separated population centers.

ACKNOWLEDGMENTS

This work was carried out as part of the work done at the University of Washington on the Washington State Highway Classification study.

Acknowledgment is made of the encouragement and suggestions given the author by R. G. Hennes, of the Civil Engineering Department, and the hours of organizing and computing done by two of the department's graduate students, Harry R. Lee, Jr., and Alan N. Corthell.

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Discussion

J. D. CARROLL, Jr. —It was a pleasure to read the most interesting paper by Willa Mylroie on the evaluation of intercity travel desire. The following comments may well be subject to modification because the copy received by the writer was incomplete.

The author seeks a measure of forecasting intercity vehicle volumes. She looks for this predictive tool principally to classify roads according to the governmental unit responsible for their maintenance. She suggests that such predictive factors can also be used to forecast travel on new roads.

The usefulness of these formulas for the purpose of road classification depends upon the criteria of classes. Since these are not known, no comment can be made other than that it does not seem proper to state that a "200 mile trip is of greater value to the economy of the state than a 100 mile trip."

The author has used an ingenious device to approximate intercity travel. However some proof of intercity travel producing the total minimum count on state roads or a fixed proportion of such minimum should be presented. It would be surprising if any single cross-section of traffic on a route would be completely free of local volumes not intercity in character.

The outside observer is impressed with the improvement in correlation as a result of changes in the relationship of population and distance. But this will be meaningful only if the author discloses why these particular formulations were chosen. For example it would seem that $\frac{\sqrt{\text{Pop 1} \cdot \text{Pop 2}}}{\text{D}}$ should not give different correlation from $\frac{\text{Pop 1} \cdot \text{Pop 2}}{\text{D}^2}$ since the second formula merely multiplies the logarithms of the numerator and denominator by two. Since different universes of road sections are used, one cannot conclude whether the correlations are, in fact, the same. It appears that the author has simply tried three different formulas. The product of the two populations is divided by distance to the first, second, and fourth power. If this is so, it would seem much better to use the data to narrow the search for the exponent of distance. This should give the best predictive measure.

One thing has been omitted to make this formula useful for future predictions. It appears that the author has assumed an unlimited supply of trips for each population. The entire system of trips in the state, however, should be a constant for a given population. Thus, for example, if a new four-lane superhighway is built from Seattle to Vancouver, the increased travel from Seattle to Vancouver and to Portland must be compensated for by less travel from Seattle to Spokane, to Yakima, and to other places in the state. Therefore, some constant is necessary to a proper formula for prediction of traffic.

The paper represents a significant contribution to the growing literature concerning the predictability of auto travel both between and within cities and the author is commended for the large amount of work done in preparing the paper.

WILLA MYLROIE, Closure—The object of the highway classification study in Washington was to find a method or methods for defining a system of highways that would include those roads which primarily benefit the state as a whole and that would have the same total mileage as the present state system. In Washington any rural road mileage not included in the state system would automatically be classified as county mileage and any urban street mileage not included on the state system would automatically be classified as city mileage.

The residents of a state share a common interest in the prosperity of their state. They all benefit as a group whenever any one community in the state increases its productivity. However, this is only possible if low cost transportation is available between the communities. Adjacent communities could manage to provide intercommunity transportation. Communities farther apart need state administered roads for assurance of continuous high standard intercommunity transportation. As better highways lower the cost of transportation to agriculture, industry, and commerce everyone ultimately benefits. Consequently longer trips tend to be of more value to the State whereas shorter trips tend to be of more value to the neighborhood or community.

The total minimum traffic count between cities was used as the best available measure of through traffic for the entire state at the time the study was made. The minimum count undoubtedly would include a percentage of local traffic. A correlation check was made with the available origin and destination data. Data covering this correlation is shown in Tables 5 and 6 of the subject paper. This correlation was even better than that obtained with the minimum traffic count data; however, the 22 origin-and-destination items available for the routes under consideration were not deemed sufficient to warrant the drawing of definitive conclusions. Origin-and-destination data, if available, would undoubtedly be a better measure of through traffic than the minimum traffic counts between cities.

Four different formulas, all a general form of $\frac{PP}{D^n}$, were tried in order to find a tolerable mathematical fit of an interactance measure with the actual minimum traffic counts. When such a fit was found prediction of interaction could be made for road sections other than those used in the sample. The same road sections were used for testing all four of the formulas tried. A table of statistical indices for two different combinations of the two better-fit formulas are shown in Table 3. The formulation $\sqrt{\frac{\text{Pop 1 . Pop 2}}{D}}$ will give a different correlation than $\frac{\text{Pop 1 . Pop 2}}{D^2}$. Translating $F = \sqrt{\frac{\text{Pop 1 . Pop 2}}{D}}$ into log terms gives: $\log F = \frac{1}{2} (\log P_1 + \log P_2) - \log D$. Multiplying through by 2 gives $2 \log F = \log P_1 + \log P_2 - 2 \log D$. Converting from log terms gives the formula $F^2 = \frac{P_1 . P_2}{D^2}$. $F \neq F^2$.

Only the first and second powers of D were used in the formulas tried. The term D^4 appears only when the term D^2 is put under a square root sign. D to the first power was used for all the sample road sections once in combination with the product of the respective populations, and once in combination with the geometric mean of the respective populations. The same is true of D^2. Perhaps D to the 2.2 or some other power would give a better predictive measure for through traffic then D to the second power. However, a correlation coefficient of 0.9 and a standard error of estimate of 0.17 obtained by using the second power of D in combination with the geometric mean of the respective populations, and the minimum traffic count between cities, were felt to be sufficiently accurate for the particular use to be made of the formula computations. Considerably more research could be done exploring the applications and limitations of the hypothesis and also on refining the hypothesis.

Basically this formula computes the probability that people will travel given distances and then multiplies this probability by populations to qualify the probability. As a road is shortened or the travel time is shortened between two cities the probability of trips being taken will increase even though the population has not increased. Though populations have not increased at two specific points the number of trips between these two points may have increased without affecting the number of trips between other points.

New four-lane highways have proved to be traffic generators and have not reduced traffic on roads in other directions, even though populations have not changed. In fact, routes in other directions may also carry increased traffic as feeder roads for the new facility.