ALLOCATION OF TRAFFIC TO BYPASSES

A. D. May, Jr. and H. L. Michael
Research Assistants
Joint Highway Research Project
Purdue University

SYNOPSIS

From recent experience gained in conducting before and after origin-destination studies on two Indiana bypasses, it was found that several of the current methods used for traffic assignment did not give comparable results. The traffic usages as given by various methods, including a method based on time, one based on distance, and another based on several distance factors, were compared to the known usage of the two Indiana bypasses. The results were then analyzed in an effort to verify one or more of these methods.

A new method based upon comparative travel costs which considers both time and distance factors was derived from the factual usage. This method may have a wide application to all types of facilities, and offers opportunities for easy and direct computation of highway benefits for the determination of economic justification.

IN THE DESIGN of new highway facilities, it is desirable to determine the anticipated volume and character of traffic which will use the improvement. The methods in use, however, vary considerably among the various state highway departments. Many, in fact, do not use a particular method but rely on the experience and wisdom of those associated with the planning of the facility for an estimate of the volume and character of the traffic. The problem has recently occupied the thoughts of many men, and several methods of allocating traffic on a rational basis from a consideration of various factors have been proposed and used.

A search by the authors for a method to allocate traffic to bypasses supplemented by a knowledge from before and after data of the actual usage, formed the basis for a comparison of several of the proposed methods for allocating traffic. These data were also used in the formulation of a method based upon costs of travel.

PURPOSE

The purpose of this paper is to compare three proposed methods of allocating traffic with the actual usage encountered on two Indiana bypasses. The results of the comparison have been analyzed in an attempt to verify one or more of these methods.

An additional purpose is to present a method based upon the costs of travel. Such a method might be applicable to many types of new facilities and could be used directly and easily in determining the economic justification for the new construction.

BYPASS STUDIES

In August, 1950, the State Highway Commission of Indiana and the Joint Highway Research Project of Purdue University initiated a cooperative traffic and engineering study of two bypasses. The locations of these bypasses, one at Lebanon, Indiana, and the other at Kokomo, Indiana, are shown in Figure 1. The major routes at the two locations and the street pattern of the two cities are shown in Figures 2 and 3. Before and after studies were conducted at each bypass.

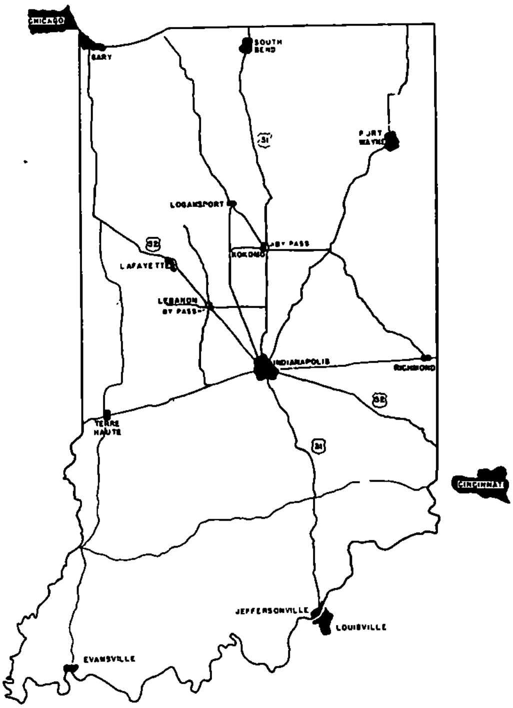

Figure 1. Principal highway routes in Indiana.

The before studies included a standard, external-cordon origin-and-destination survey conducted prior to the opening of the bypass. The cordon line in each study was placed around the urban limits of the city.

The after studies also included an origin-destination survey. In these surveys the cordon line was placed around the bypass and the traffic was intercepted as it left the bypass. The place of entry of the vehicle onto the bypass, in addition to the usual questions, was asked of each driver. These studies were conducted about six months after the opening of the bypasses.

The field data for the Kokomo before study was collected in September and October 1950. A total of 95.7 percent of the total traffic which passed through the interview stations was interviewed. The 22,107 interviews accounted for 82 percent of all the traffic which entered or left the city during an average weekday. The average 24 hr. weekday traffic in, out, and through Kokomo was 24,674 trips of which 12.4 percent was through traffic. The principal origins and destinations are shown in Figure 4.

The after study at Kokomo was conducted in May 1951. A total of 12,881 vehicles was intercepted and interviewed. Included in this total was 82 percent of the vehicles which used all or a portion of the bypass. The average 24 hr. traffic using the bypass was 7,316 trips of which 1,071 trips used the entire length (7.11 mi. of the bypass, and 6,245 trips used only a portion of the bypass. The average 24 hr. traffic volume on the central section of the bypass was 4345 vehicles.

The before study of the Lebanon bypass was conducted in October

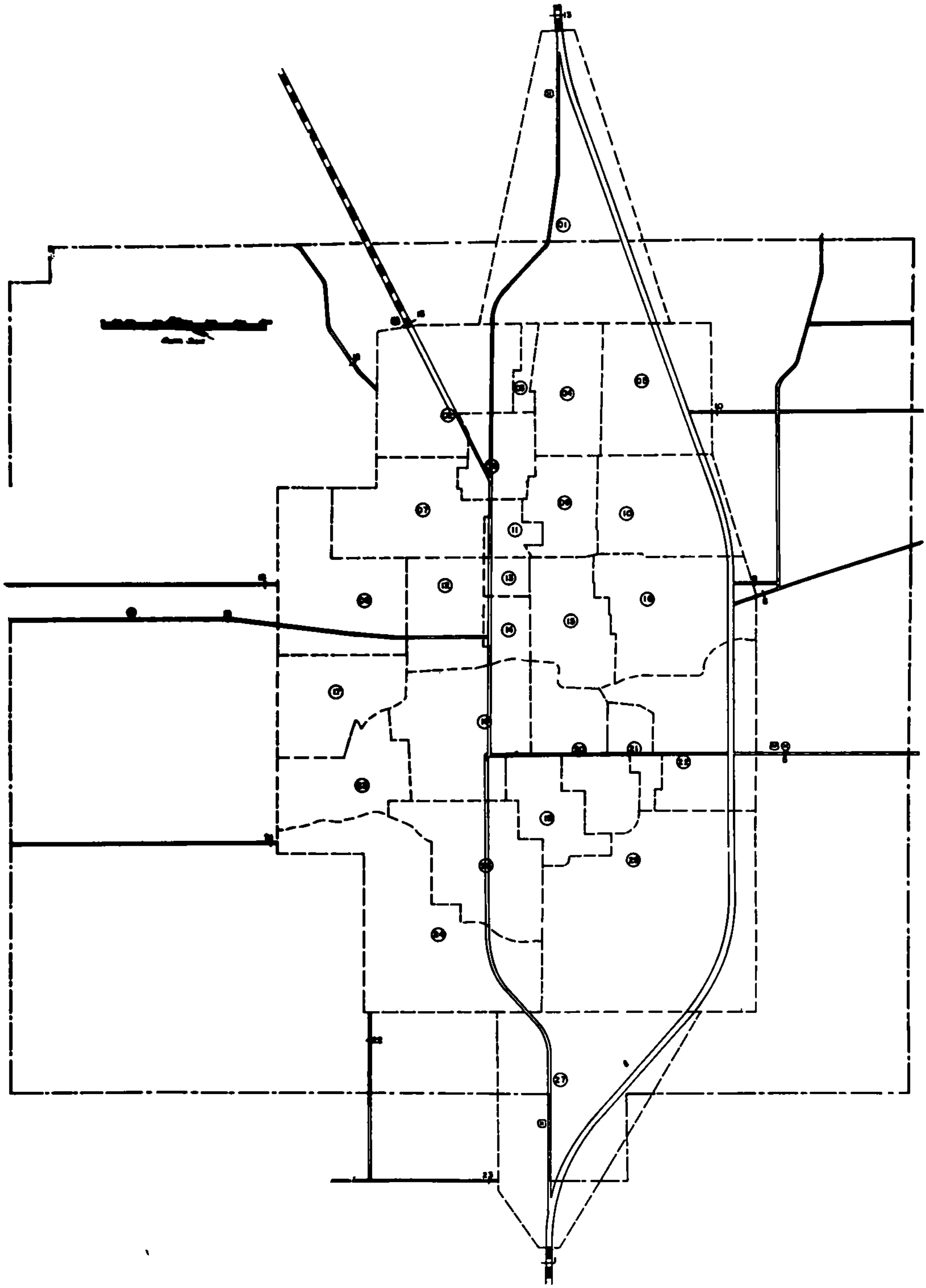

Figure 2. Major routes and urban area of Kokomo.

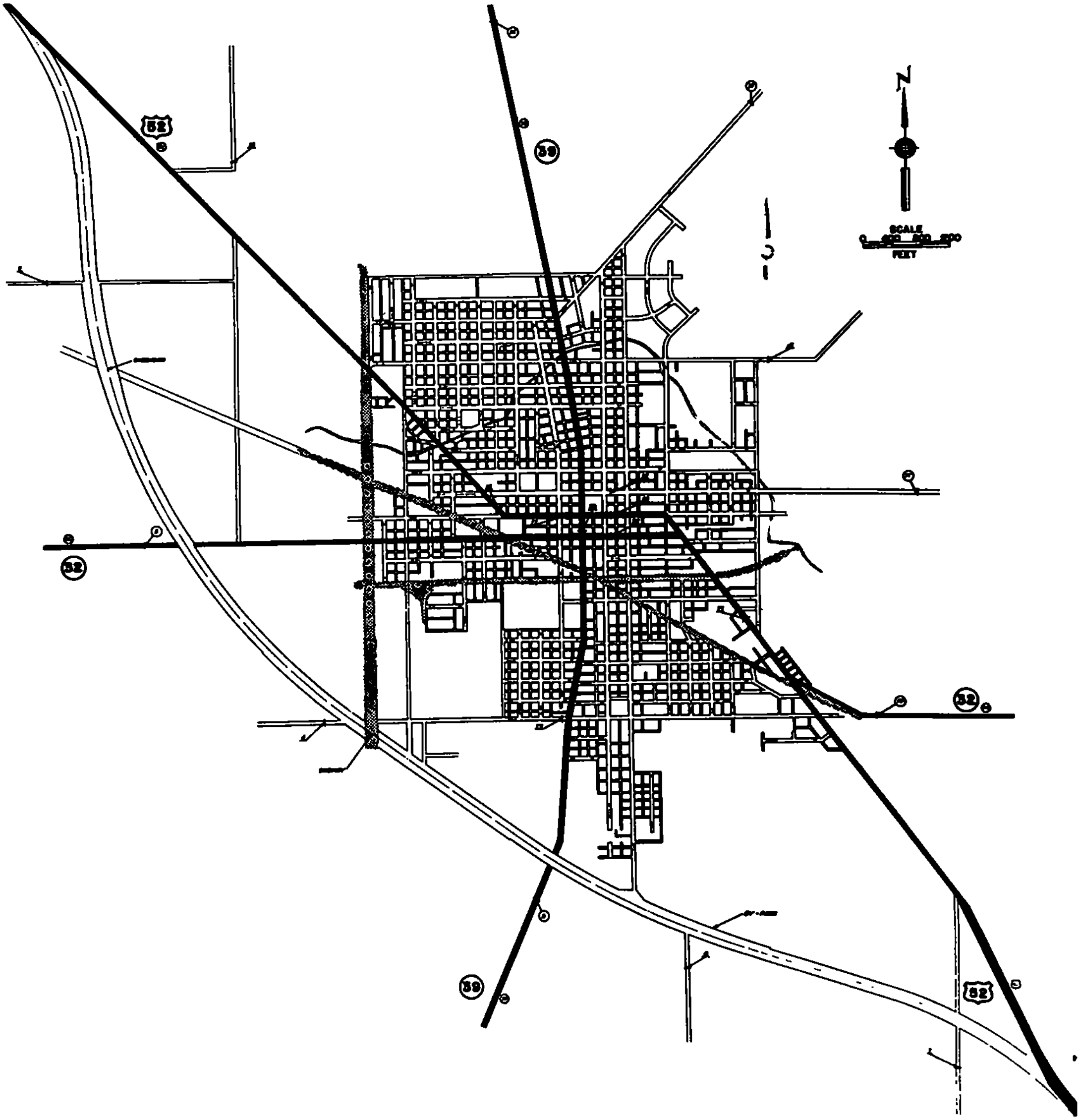

Figure 3. Major routes and urban area of Lebanon.

1950. A total of 96 percent of the total traffic which passed through the interview stations was interviewed. The 13,170 vehicles interviewed accounted for 83 percent of the average daily traffic entering or leaving Lebanon. The average 24 hr. weekday traffic in, out, and through Lebanon was 14,233 trips of which 59.3 percent was inbound or outbound from the city, and 40.7 percent was through traffic. The principal origins and destinations are shown in Figure 5.

The field data for the Lebanon-after study were collected in October 1951. A total of 9,153 vehicles was intercepted and interviewed. Included

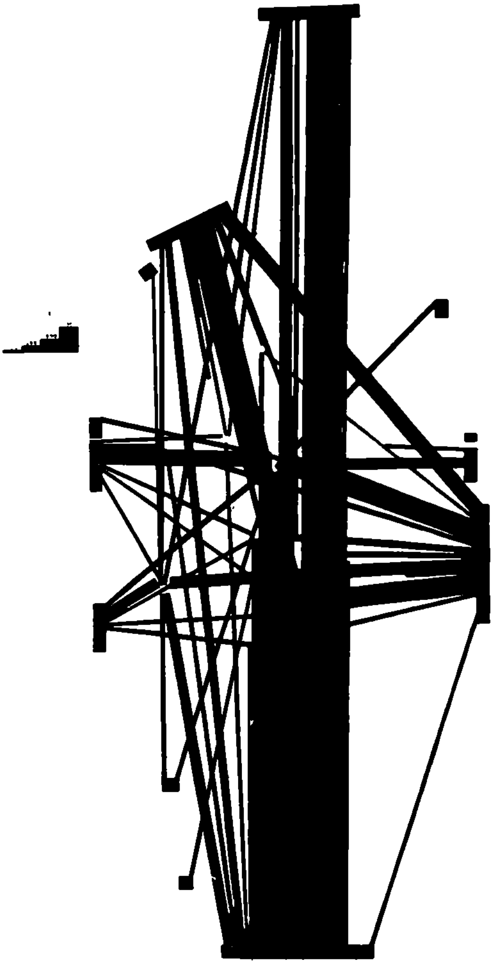

Figure 4. Origin-and-destination desire line map, automobiles and trucks, Kokomo.

in this total was about 90 percent of the vehicles which used all or a portion of the bypass. The average 24 hr. traffic volume on the central section of the bypass was 5,283 vehicles. This bypass is 5.14 mi. long.[1/]

SOME CURRENT METHODS OF TRAFFIC ALLOCATION

The first portion of this section includes a brief description of some of the presently used methods of assigning traffic to new facilities. The latter portion presents the application of the data obtained in the before and after surveys at Lebanon and Kokomo to the various methods.

INDIANA METHOD

In a paper presented to the Highway Research Board in 1947, R. M. Brown of the State Highway Commission of Indiana introduced a proposed method for determining vehicular usage for expressways (1). This method was based upon the following factors: (1) Expressway Distance (F1) - length of the expressway portion of the trip; (2) Access Distance (F2) - the length of the city streets used to enter and leave the expressway in connection with the trip; and (3) Adverse Distance (F3) - the increased distance required for the trip via the expressway as compared to a more direct route using existing city streets.

Speeds on the expressway were assumed as twice those on city streets.

The following equation expresses the predicted percent of expressway usage (F) for a given trip:

$$F = \frac{(F1 + F2) \times F3}{100}$$

1/ - NOTE: The Lebanon bypass is apparently a two-lane road and should not be compared to an expressway. - Editor.

After trial and experiment, Brown considered that F3 (adverse distance factor) rated equal in importance to the combination of F1 and F2. It was also considered that F1 (expressway distance factor) was more important than F2 (access distance factor) by a ratio of 7:3. Therefore, optimum value for F1 was 70, F2 was 30, and F3 was 100.

Three distances scaled from a map that are measured to determine the factors are: (1) Expressway Distance (a) - the length in miles of the expressway portion of the trip; (2) Access Distance (b) - the length in miles of the city street portion of the trip when using the expressway; and (3) Street Distance (c) - the total length of trip in miles by most advantageous route using only city streets.

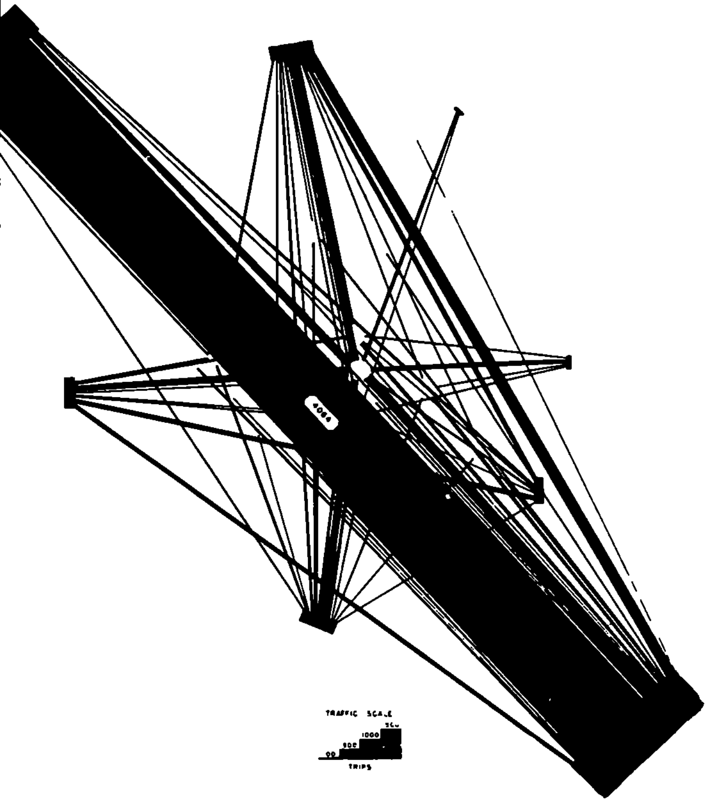

Figure 5. Origin-and-destination desire line map, automobiles and trucks, Lebanon.

The relationship between actual expressway distance and the expressway distance factor is:

$$F1 = -2.8a^2 + 30.24a - 11.65$$

(For values of "a" between 0.4 and 5.4 miles - For lesser and greater values of "a", F1 retains its respective minimum (0) and maximum (70) values.)

The relationship between actual access distance and the access distance factor is:

$$F2 = 33.3 \frac{a}{a + b} - 3.3$$

The relationship between actual adverse distance (v) and adverse distance factor is:

$$F3 = 100 - 240 \, (v/a)^2 \quad \text{where } v = a + b - c$$

The derivations of these formulas are given in the paper (1). Laborious calculations involved in the application of the formulae are eliminated by the use of a mechanical device developed by Brown.

DISTANCE RATIO METHOD

Earl Campbell of the Highway Research Board staff proposed a method of assigning traffic to proposed expressways in 1949 (2) Campbell's method is based upon three fundamental principles: (1) 100 percent vehicular usage of the new facility when the distance by existing routes is equal to or greater than the route via the new highway facility; (2) 50 percent vehicular usage when the cost of travel by existing routes is equal to the cost of travel via the new highway facility; and (3) 0 percent usage when the time of travel by existing routes is equal to or less than the time of travel via the new highway facility.

Campbell suggested that these three points, equal distance, equal cost, and equal time be adjusted to 95 percent, 60 percent, and 5 percent respectively, so as to allow for such intangibles as safety, relief from congestion, comfort, beauty, force of habit, and investigative desire.

In this method, Campbell suggested using the ratio of the expressway distance used (a) to the pure street distance (P) of city streets used. Pure street distance is computed as follows:

$P = c - b$
where
c = mileage of city streets used without using expressway.
d = mileage of city streets used by using expressway.

TIME RATIO METHOD

Of the many factors affecting selection of routes, the saving of time appears to be one of the most important to the traveling public. A method of assigning traffic to a new highway facility has been developed in which the time ratio was used for determining vehicular usage. The characteristics of this curve have been partially established by data collected in several after studies on expressways and boulevards (3, 4, 5). Time ratio is defined as the ratio of time via the expressway to the time via city streets.

OTHER METHODS

K. A. MacLachlan of the state highway department in California has presented a method of determining vehicular usage of new highway facilities (6). The application of this method is presented in an origin-and-destination survey of Sacramento, California (7). A special type of desire line chart similar to a contour map is constructed. To make such an analysis, however, it is necessary to subdivide the internal area into extremely small tracts and to use special IBM equipment.

Certain states have found that the judgment of several experienced individuals is able to duplicate with accuracy in a short period of time present mathematical means of route selection and traffic assignment (2).

APPLICATION OF BYPASS DATA TO PRESENT METHODS

The Kokomo and Lebanon bypass data were applied to the Indiana, the distance-ratio, and the time-ratio methods. A comparison of the derived percentage usage by these three methods with the actual usage is shown in Tables 1 and 2. The data are shown separately for each bypass and for automobiles and trucks. Only trips between origins and destinations having a total volume of twenty or more were used in these calculations. Through trips are shown first in the tables and then trips from or to locations within the city.

APPLICATION TO BYPASSES

In the use of the Indiana method, a few changes were made in the basic formulas as given earlier in this paper (1). Brown, in his proposal, considered that because of the difficulty of getting on or off an expressway-type facility, the factor F1 would be zero unless ½ mi. or more of the facility could be used. It was felt that this assumption would not hold true for bypasses where the difficulty of exit or entry would be small. Consequently, an F1 based on zero usage at 0 mi. of bypass traveled was computed and used in this study. The formula for this new F1 is:

$F1 = -2.8a^2 + 28a$ where the variables are as given earlier and for values of "a" between 0 and 5.0 mi.

The formulas as proposed by Brown were based on a speed ratio of 2:1 between the expressway route and the old route. In these bypass studies, the average speed ratios were about 5:3 for automobiles and 8:5 for trucks. Hence, the factor F3 in the Indiana method was revised. The formulas given by these ratios are:

$$\text{For automobiles, } F3 = 100 - 356 \left(\frac{v}{a}\right)^2$$

$$\text{For trucks, } F3 = 100 - 425 \left(\frac{v}{a}\right)^2$$

In the use of the distance-ratio method, a curve was plotted separately for automobiles and trucks. The three fundamental points (equal distance, equal cost, and equal time) were established on the basis of the average speeds which were attained on the streets and bypasses of Kokomo and Lebanon and by the use of a cost of travel per mile which considered the changing costs due to speed of travel. This curve is shown in Figure 6. The values for predicted usage were then taken from this curve.

The time-ratio percentages were taken from several curves which were published in Circular No. 139, Highway Research Correlation Service (8). These curves are shown in Figure 7. The average value as given by these curves was taken as the value given by this method. Time by the various routes was determined from a series of time-delay studies made on typical streets in all sections of Kokomo and Lebanon.

TABLE 1

COMPARISON OF ALLOCATION METHODS FOR LEBANON BY-PASS

Passenger Cars

Origin Station or Tractor	Dest. Station or Tract	Total Actual Volume	Predicted Usage: Indiana Method	Predicted Usage: Distance Ratio	Predicted Usage: Time Ratio	Actual Usage
			%	%	%	%
8	1	1206	99	95	82	95
1	8	1035	99	95	82	94
10	1	26	55	67	50	30
1	10	23	55	67	50	22
3	8	55	87	95	88	74
8	3	58	87	95	88	83
14	8	118	48	94	50	70
8	14	112	48	94	50	76
10	3	59	5	17	34	0
3	10	78	5	17	34	0
1	5	22	88	95	86	82
5	1	16	88	95	86	81
8	5	20	67	95	93	95
5	8	14	67	95	93	93
012	1	20	56	89	70	15
1	012	15	56	89	70	27
014	1	26	41	61	40	8
1	014	22	41	61	40	0
015	1	119	31	15	19	7
1	015	152	31	15	19	3
017	1	22	37	51	20	5
1	017	21	37	51	20	0
021	1	20	35	5	30	20
1	021	11	35	5	30	18
004	8	34	43	81	5	23
8	004	39	43	81	5	3

Passenger Cars

Origin Station or Tract	Dest. Station or Tract	Total Actual Volume	Predicted Usage: Indiana Method	Predicted Usage: Distance Ratio	Predicted Usage: Time Ratio	Actual Usage
			%	%	%	%
009	8	31	44	79	30	42
8	009	29	44	79	30	24
010	8	72	43	77	40	21
8	010	82	43	77	40	15
014	8	21	48	23	50	29
8	014	20	48	23	50	15
015	8	175	41	67	56	20
8	015	207	41	67	56	23
019	8	30	57	93	82	33
8	019	33	57	93	82	100
021	3	21	4	5	13	10
3	021	25	4	5	13	0
TRUCKS						
8	1	795	99	95	82	98
1	8	901	99	95	82	98
14	8	57	47	95	25	61
8	14	56	47	95	25	66
10	3	22	0	72	45	5
3	10	27	0	72	45	0
014	8	22	47	77	56	73
8	014	29	47	77	56	25
015	8	35	39	89	60	26
8	015	33	39	89	60	21
016	8	21	49	93	82	52
8	016	23	49	93	82	22

TABLE 2

COMPARISON OF ALLOCATION METHODS FOR KOKOMO BY-PASS

Origin Station or Tract	Dest. Station or Tract	Total Actual Volume	Predicted Usage: Indiana Method	Predicted Usage: Distance Ratio	Predicted Usage: Time Ratio	Actual Usage
Passenger Cars			%	%	%	%
5	1	57	87	95	90	86
1	5	99	87	95	90	80
1	13	458	99	95	80	85
13	1	446	99	95	80	87
5	13	47	98	95	90	77
13	5	68	98	95	90	67
002	1	33	72	64	55	3
006	1	66	45	13	26	6
007	1	38	45	13	33	5
008	1	25	58	26	55	16
011	1	27	48	17	42	7
012	1	48	26	5	3	8
013	1	55	54	25	49	7
014	1	351	45	13	29	5
015	1	51	72	68	66	21
018	1	120	9	5	5	9
019	1	233	21	44	17	16
020	1	59	58	52	57	22
022	1	31	84	95	83	65
023	1	126	13	5	7	6
025	1	104	0	5	2	6
026	1	29	52	53	73	31
002	5	48	68	95	81	48
006	5	61	30	95	70	15
007	5	38	30	92	68	18
009	5	27	39	95	82	33
011	5	26	32	95	78	26
012	5	43	22	64	76	21
013	5	32	33	95	79	31
014	5	366	27	74	73	17
015	5	65	36	95	72	56
016	5	38	34	72	78	47
019	5	265	25	88	67	11
025	5	60	18	47	63	13

Origin Station or Tract	Station or Tract	Total Actual Volume	Predicted Usage: Indiana Method	Predicted Usage: Distance Ratio	Predicted Usage: Time Ratio	Actual Usage
Passenger Cars			%	%	%	%
026	5	30	33	95	76	47
002	13	53	42	20	3	4
004	13	41	52	53	5	17
006	13	42	32	5	17	10
007	13	49	25	5	4	10
011	13	35	0	5	3	6
012	13	58	21	5	6	2
013	13	28	50	21	8	4
014	13	233	49	21	9	10
015	13	57	60	80	69	37
016	13	25	72	95	84	56
018	13	75	47	21	22	11
019	13	120	76	75	69	62
020	13	27	88	90	78	52
023	13	93	52	31	34	10
025	13	53	63	42	22	13
TRUCKS						
5	1	32	88	95	92	97
1	5	42	88	95	92	86
13	1	152	99	95	82	95
1	13	166	99	95	82	89
5	13	32	98	95	91	90
13	5	35	98	95	91	97
008	1	24	46	80	61	4
013	1	34	37	25	57	32
014	1	65	0	13	37	6
018	1	24	44	5	6	0
019	1	40	0	86	21	10
023	1	29	0	5	8	7
025	1	30	88	5	2	3
014	5	55	26	92	63	29
019	5	57	24	94	73	5
008	13	24	2	5	2	0
014	13	30	42	74	9	14
019	13	30	74	75	71	43

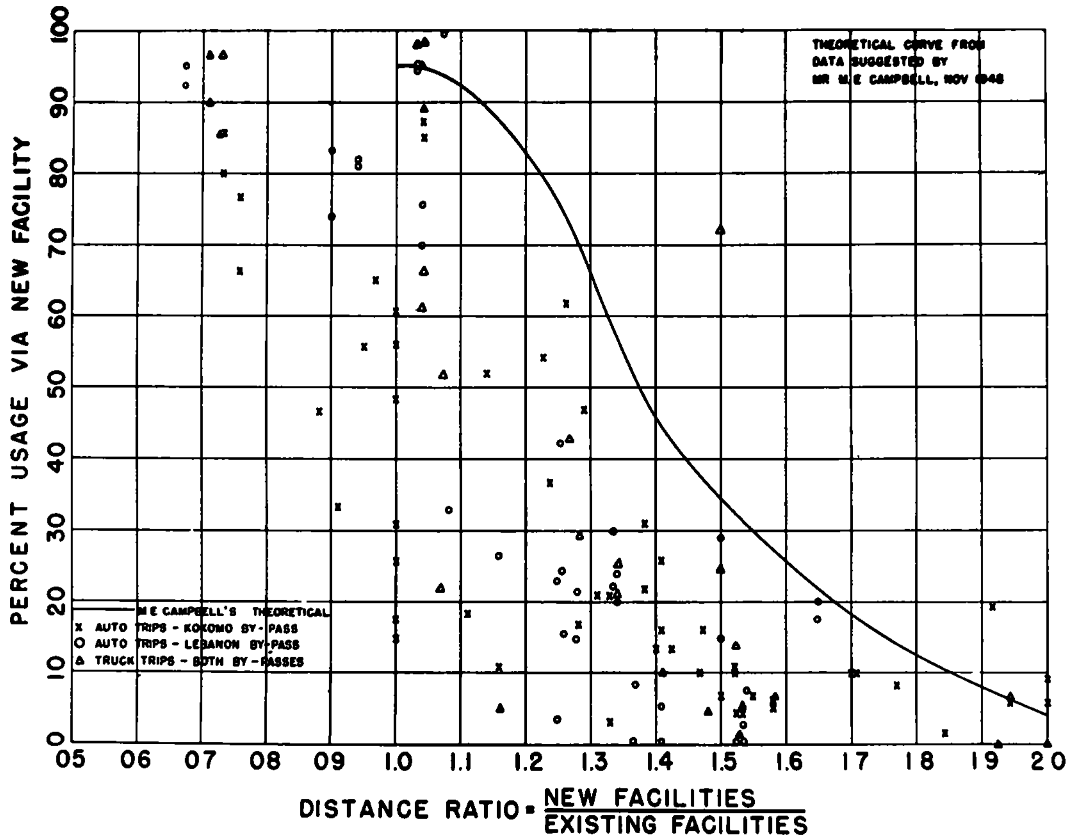

Figure 6. Percent diversion of traffic based on comparative travel distance.

COMPARISON OF RESULTS

The indices as computed for the various methods are shown in Tables 3 and 4. From these indices the points were plotted on Figures 6 and 7. A comparison of the values in Tables 1 and 2 and the plot of points in Figures 6 and 7 indicate the following conclusions:

1. The three methods give results which are not similar in value in many cases. Only at very few points do the methods closely agree.

2. The three methods give results that are too high in practically every case. This may be accounted for by the lower-type facility (a bypāss) than an expressway for which the methods were primarily designed.

3. The Indiana method gives the best results when a very short distance of the bypass (less than 1 mi.)is used.

4. The values as given by the time-ratio method appear to fall more closely to the actual usage than do those by the other two methods.

TABLE 3

INDICES FOR PERCENT USAGE
BY VARIOUS METHODS-LEBANON BYPASS

Passenger Cars

Origin Station or Tract	Destination Station or Tract	Actual Volume	Actual Usage	Distance Ratio	Time Ratio	Cost Index
		No.	%			
8	1	1206	95	1.03	.68	.80
1	8	1035	94	1.03	.68	.80
10	1	26	30	1.33	.97	1.04
1	10	23	22	1.33	.97	1.04
3	8	55	74	.90	.55	.66
8	3	58	83	.90	.55	.66
14	8	118	70	1.04	.96	.94
8	14	112	76	1.04	.96	.94
10	3	59	0	1.53	1.02	1.05
3	10	78	0	1.53	1.02	1.05
1	5	22	82	.94	.60	.72
5	1	16	81	.94	.60	.72
8	5	20	95	.67	.39	.47
5	8	14	93	.67	.39	.47
012	1	20	15	1.16	.83	.93
1	012	15	27	1.16	.83	.93
014	1	26	8	1.37	.98	1.05
1	014	22	0	1.37	.98	1.05
015	1	119	7	1.54	1.10	1.17
1	015	152	3	1.54	1.10	1.17
017	1	22	5	1.41	1.09	1.14
1	017	21	0	1.41	1.09	1.14
021	1	20	20	1.65	1.03	1.22
1	021	11	18	1.65	1.03	1.22
004	8	34	23	1.25	1.31	1.42
8	004	39	3	1.25	1.31	1.42
009	8	31	42	1.26	1.03	1.14
8	009	29	24	1.26	1.03	1.14
010	8	72	21	1.28	.99	1.02
8	010	82	15	1.28	.99	1.02
014	8	21	29	1.50	.97	1.02
8	014	20	15	1.50	.97	1.02
015	8	175	20	1.34	.94	.86
8	015	207	23	1.34	.94	.86
019	8	30	33	1.08	.67	.70
8	019	33	100	1.08	.67	.70
021	3	21	10	2.11	1.15	1.18
3	021	25	0	2.11	1.15	1.18

TABLE 3 (continued)

Origin Station or Tract	Destination Station or Tract	Actual Volume	Actual Usage	Distance Ratio	Time Ratio	Cost Index
TRUCKS						
		No.	%			
8	1	795	98	1.03	.66	.68
1	8	901	98	1.03	.66	.68
14	8	57	61	1.04	1.06	.86
8	14	56	66	1.04	1.06	.86
10	3	22	5	1.53	.98	.98
3	10	27	0	1.53	.98	.98
014	8	22	73	1.50	.93	.96
8	014	29	25	1.50	.93	.96
015	8	35	26	1.34	.92	.94
8	015	33	21	1.34	.92	.94
016	8	21	52	1.08	.68	.72
8	016	23	22	1.08	.68	.72

TABLE 4

INDICES FOR PERCENT USAGE
BY VARIOUS METHODS-KOKOMO BYPASS

Origin Station or Tract	Destination Station or Tract	Actual Volume	Actual Usage	Distance Ratio	Time Ratio	Cost Index
Passenger Cars						
		No.	%			
5	1	57	86	.73	.45	.542
1	5	99	80	.73	.45	.542
5	13	47	77	.76	.46	.555
13	5	68	67	.76	.46	.555
1	13	458	85	1.04	.70	.803
13	1	446	87	1.04	.70	.803
002	1	33	3	1.33	.94	1.020
006	1	66	6	1.58	1.05	1.130
007	1	38	5	1.58	1.03	1.130
008	1	25	16	1.48	.94	1.068
011	1	27	7	1.55	.89	1.140
012	1	48	8	1.77	1.60	1.260
013	1	55	7	1.50	.97	1.084
014	1	351	5	1.58	1.04	1.154
015	1	51	21	1.31	.87	.979
018	1	120	9	2.00	1.33	1.400
019	1	233	16	1.41	1.12	1.170
020	1	59	22	1.38	.93	1.056
022	1	31	65	.97	.64	.763
023	1	126	6	1.94	1.25	1.340
025	1	104	6	4.50	1.69	1.640
026	1	29	31	1.38	.80	1.084
002	5	48	48	1.00	.69	.795

TABLE 4 (continued)

Origin Station or Tract	Destination Station or Tract	Actual Volume	Actual Usage	Distance Ratio	Time Ratio	Cost Index
		No.	%			
006	5	61	15	1.00	.84	.872
007	5	38	18	1.11	.84	.847
009	5	27	33	.91	.67	.841
011	5	26	26	1.00	.74	.847
012	5	43	21	1.33	.76	.962
013	5	32	31	1.00	.71	.830
014	5	360	17	1.28	.79	.952
015	5	65	56	1.00	.80	.873
016	5	38	47	1.29	.74	.837
019	5	265	11	1.16	.85	.905
025	5	60	13	1.40	.88	.859
026	5	30	47	.88	.76	.832
002	13	53	4	1.53	1.46	1.410
004	13	41	17	1.00	1.29	1.270
006	13	42	10	1.70	1.12	1.230
007	13	49	10	1.71	1.38	1.350
008	13	32	19	1.92	1.26	1.590
011	13	35	6	2.00	1.45	1.460
012	13	58	2	1.84	1.26	1.300
013	13	28	4	1.52	1.23	1.270
014	13	233	10	1.52	1.20	1.240
015	13	57	37	1.24	.84	.931
016	13	25	56	.95	.64	.736
018	13	15	11	1.52	1.08	1.130
019	13	120	62	1.27	.84	.944
020	13	27	52	1.14	.72	.830
023	13	93	10	1.47	1.01	1.100
025	13	53	13	1.42	1.08	1.030
			TRUCKS			
5	1	32	97	.73	.44	.449
1	5	42	86	.73	.44	.449
5	13	32	90	.71	.45	.454
13	5	35	97	.71	.45	.454
13	1	152	95	1.04	.66	.668
1	13	166	89	1.04	.66	.668
008	1	24	4	1.48	.90	.888
013	1	34	32	1.50	.93	.950
014	1	65	6	1.58	1.00	1.018
018	1	24	0	2.00	1.30	1.290
019	1	40	10	1.41	1.08	1.090
023	1	29	7	1.94	1.25	1.240
025	1	30	3	4.50	1.57	1.580
014	5	55	29	1.28	.88	.875
019	5	57	5	1.16	.80	.800
008	13	24	0	1.92	1.72	1.720
014	13	30	14	1.52	1.20	1.200
019	13	30	43	1.27	.82	.822

5. The variation of results appears to be greatest in the distance-ratio method.

6. There appears to be very little necessity for separate curves for trucks and automobiles for the distance and the time ratio methods.

7. There appears to be only limited continuity between the actual results and those given by any of the three methods. This would indicate that all of the methods consider too few of the factors that are apparently involved.

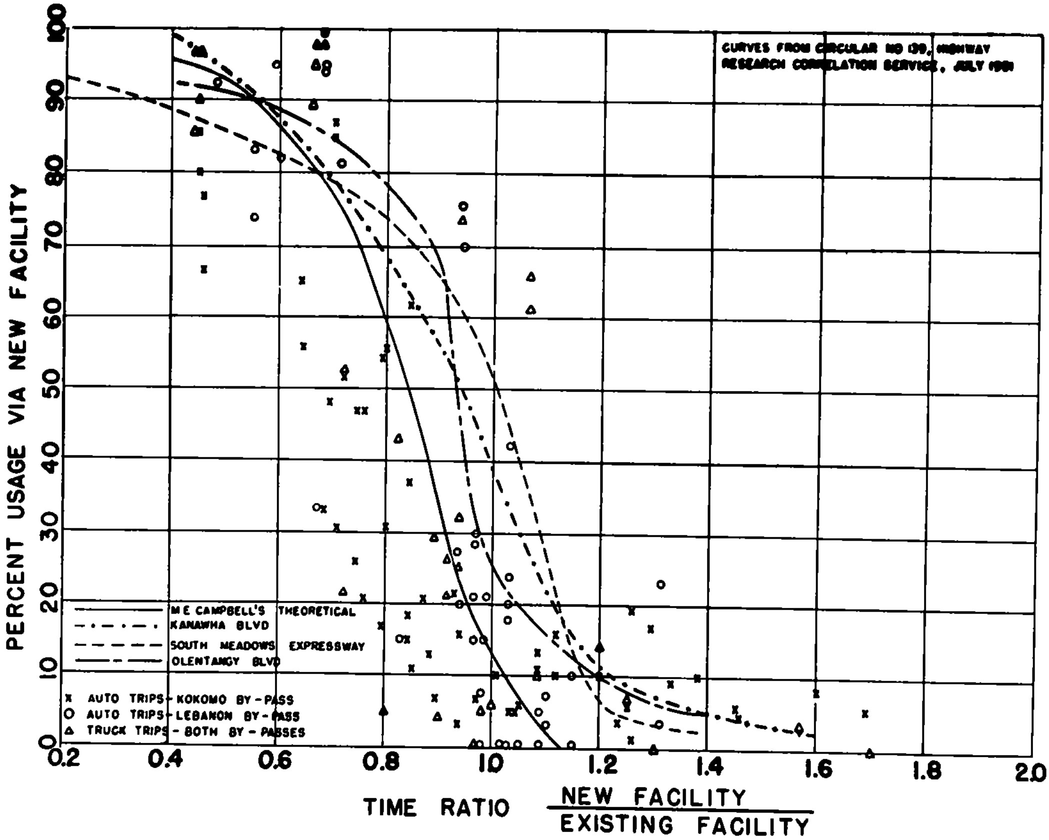

Figure 7. Percent diversion of traffic based on comparative travel time.

COST INDEX METHOD

A search for a more accurate method of allocation resulted in a consideration of the various factors as they may be reflected in the cost of travel. It is doubtful whether the individual decides to use a new facility based upon a complete cost tabulation; however, an appreciation of cost may contribute to the drivers' decision. The dollar sign is a standard system by which most benefits can be evaluated, and the public is receptive to monetary values.

It is well established that the cost of travel varies with the speed that can be attained and the number of stops and starts that are necessary. Therefore, the streets of the two cities and the highways within the internal areas were classified as open highways, arterial streets, local streets, or congested streets. This classification was based upon speed, quantity, and quality of impedances; road surface condition; and type of traffic. These factors were evaluated from speed and delay studies on the principal routes and from an inventory of the physical conditions.

Distance as a factor in the cost of travel was evaluated by measuring the distance of each type of street for each route from a scale map of the city.

Time also is a factor in the cost of travel, especially for trucks. The value of time for the truck operator as well as for the truck itself was taken from a study made by Lawrence Lawton and reported in "Traffic Quarterly" for January 1950 (9). These costs were based on the operator's wage and on the cost of operating the truck per hour considering administrative, overhead, and operating costs other than gasoline on an hourly basis. The value of time for automobile occupants was also taken from the article by Lawton. A value of $1.10 per hour was determined by the average value placed on time from a study of payments made by users of toll facilities (9). This value of $1.10 per hour per vehicle is in agreement with the frequently used value of one cent per minute per occupant, since the average vehicle on the bypasses contained 1.9 occupants.

Operational costs of automobiles and trucks were tabulated for the various classes of streets from data collected by Lawton. These costs were corrected to 1950 costs by using the wholesale price index published by the U. S. Department of Commerce (10). The total costs, operating and time, were thus determined for the passenger car and for the composite truck on a per mile basis. Time value was changed to a per mile basis by evaluating the average speeds on the four classes of streets. A composite truck is assumed to be the average weighted size of all the trucks that were found in the Kokomo and Lebanon surveys. A compilation of the costs per mile is shown in Table 5.

An example of how these values were determined follows:

For a passenger car for an ordinary street.
Average speed of travel = 30 mph.
Average gasoline consumption = 14.9 mi. per gal. (9)

From this data and from the basic price data shown in Table 5 the total costs were evaluated on a per mile basis.

Gasoline	1.76
Oil	0.21
Tires & Tubes	0.31
Maintenance	0.67
Depreciation	0.83
Total (Operational)	3.78
Time	3.66
Total	7.44

TABLE 5

VEHICULAR OPERATIONAL COSTS ON VARIOUS TYPES OF STREETS CENTS PER MILE

Item	Bypass	Class A	Class B	Class C
		Passenger Cars		
Speed (mph)	50	40	30	20
Total Operations	3.31	3.55	3.78	5.07
Time (1.83¢/min)	2.20	2.74	3.66	5.50
Totals	5.51	6.29	7.44	10.57
		Trucks*		
Speed	40	30	25	15
Gasoline	5.09	6.20	7.66	12.84
Other Operational Costs	7.13	9.50	11.40	19.00
Time	5.25	7.00	8.40	14.00
Totals	17.47	22.47	27.44	45.84

*Average weighted truck using bypasses.

Basic prices used:
Gasoline - 27 ¢ per gallon
Oil - 35¢ per quart (6 qt. per 1,000 mi.)
Tires & tubes - $24.00 for one (30,000-mi. life)
Maintenance - $100 per year (2/3 because of actual use, 10,000 mi. per year)
Depreciation - Total cost $2,200 (1/3 because of actual use, 8-yr. life, 10 percent value at end)

Operators Time:

Passenger cars	1.10 per hr.	Medium truck	1.68 per hr.
Light truck	1.20 per hr.	Heavy truck	2.37 per hr.

Most trips will involve various classes of roads and the total cost can be arrived at by simply determining the mileage of each class of road, the cost for each class of road, and adding these various costs. A comparison of the cost by using the new facility with the cost by way of only city streets gives a ratio called cost index.

The following example may clarify this method:

a. Via bypass - A passenger car makes a trip via the bypass of a total distance of 9 mi. of which 6 mi. are on the bypass, 2 mi. are on Class A (arterial streets), and 1 mi. on Class B (local streets).

b. Via existing streets - A passenger car makes the same trip by existing city streets only. The total distance is 8 mi. of which 2 mi. are on class A streets, 4 mi. are on Class B streets, and 2 mi. are on Class C (congested streets).

c. Computations (costs per mile from Table 5).

	Bypass	Class A	Class B	Class C	Total Cost
Via bypass	6 x 5.51	2 x 6.29	1 x 7.44	--------	53.08
Via existing streets	-------	2 x 6.29	4 x 7.44	2 x 10.57	63.48

$$\text{Cost Index} = \frac{53.08}{63.48} = 0.836$$

From the cost index as calculated for the various trips and shown in Tables 3 and 4, points were plotted against actual usage and a curve drawn. This curve is shown in Figure 8.

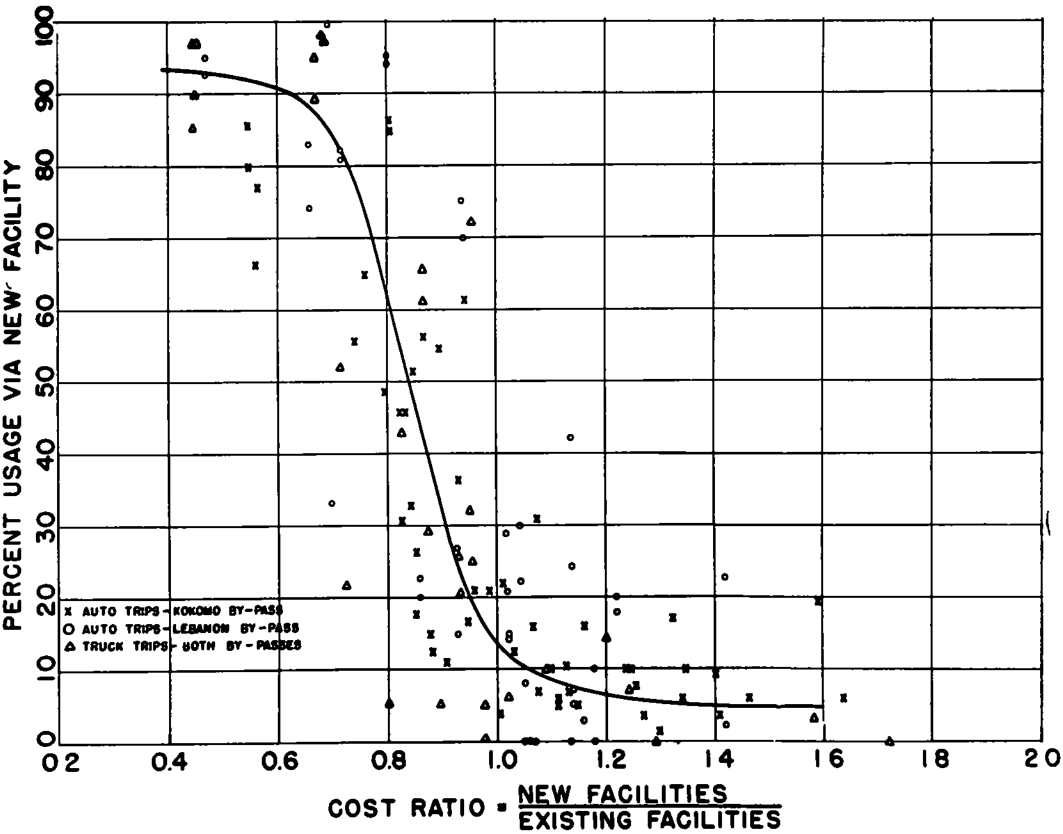

Figure 8. Percent diversion of traffic based on comparative travel cost.

OTHER USES OF COST INDEX METHOD

In the construction of a public facility such as a highway, studies are desirable that determine on a monetary basis the cost of the facility as compared to the benefits derived from its construction. Since costs of travel have been computed by existing routes and via the proposed facility, the savings to the highway user may be easily determined. In addition, a further breakdown concerning the savings to the various types of traffic, such as auto and truck, local and foreign, or recreation and business, can be determined with very little effort.

For example, in the Lebanon survey, it was estimated from this method that passenger car users saved $185 per day while the truck users saved $625 per day. These benefits were obtained directly from the cost-index calculations with very little additional computation. A similar computation for all the trips using the facility would give the total benefits of the facility. From these data the benefit-cost ratio could be determined for an economic justification of the facility.

Much speculation has been made as to the value the public places upon such factors as safety, beauty, added convenience, etc. Although exact values cannot be placed on individual factors from the cost-index method, this method may offer a means of determining the value that the public places on all these factors. In cases where certain volumes of traffic use new facilities even though the cost of travel is greater than by existing routes, a value for these intangible factors may be possible of determination.

CONCLUSIONS

The following conclusions are presented for the purpose of discussion:

1. The cost-index method appears to give a smaller dispersion of points from the central curve than do the other methods investigated.

2. The cost-index method indicates an S-type curve with a lower limit of 5 percent usage and an upper limit of 95 percent.

3. A cost index of 1.00 gives a usage of about 13 percent while 50 percent usage occurs at about 0.85 cost index.

4. From about a cost index of 0.65 to a cost index of 1.05 a change in percent usage from 90 percent to 10 percent is shown. This indicates that a careful evaluation of the comparative travel costs in this range is necessary.

5. It appears that the data from both bypass studies as well as the data for automobiles and trucks give approximately the same curve.

6. The calculations for the cost-index are relatively simple and provide data for a quick and easy determination of the benefits from the improvement for the various types of users.

7. The better accuracy of the cost-index method may be because consideration has been given to both the time and distance factors.

8. The cost-index method may offer opportunities for the evaluation of the intangible factors in highway use.

RECOMMENDATIONS FOR FURTHER STUDY

Although the cost-index method appears to give a smaller dispersion of points from the central curve than do the other methods investigated, there is still a greater variation than is desirable. Additional study is being made on factors other than time and distance that may enter into the problem. From preliminary work it appears that several other factors must be considered: (1) proximity of the origin or destination to the facility; (2) length of facility that can be used to advantage;(3) exceptional usage at any one time, such as trips to and from work in an industrial area; (4) indicational signs, such as routing of state routes over the facility; and (5) natural or man-made barriers with only a limited number of crossings. An evaluation of these factors is under study.

A mathematical study to fit a curve to the actual data is also being made. Preliminary results of this study show: (1) the Gompertz, integrated normal, or logistic curves have the properties that appear to be present and (2) the logistic curve is relatively easier to fit than the other two mentioned.

Additional study to determine the mathematical equation of the logistic curve which fits the data is being deferred until the evaluation of the factors other than time and distance has been completed.

Other investigations that the authors believe would be a contribution to the improvement of techniques for allocating highway traffic to new facilities are: (1) application of cost-index method to other facilities; (2) a study of of the value of time to the highway user by type of vehicle and type of trip; and (3) a study of vehicle operating costs by type of vehicle and type of road or street.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to those who have made this study possible, particularly K. B. Woods, associate director of the Joint Highway Research Project; A. K. Branham, research associate; R. M. Brown, in charge Metropolitan Area Traffic Survey Unit of the State Highway Commission of Indiana; M. E. Campbell, engineer of traffic and operations, Highway Research Board, for his helpful correspondence; and Paul Irick, Purdue Statistical Department, for his curve-fitting investigations.

REFERENCES

1. Brown, R. M. "Expressway Route Selection and Vehicular Usage", "Bulletin No. 16", Highway Research Board, December, 1948, pp. 12-21.

2. Campbell, M. E., "Route Selection and Traffic Assignment", Highway Research Board Correlation Service, Mimeo., 1950.

3. Jorgenson, Ray E., "Influence of Expressways in Diverting Traffic from Alternate Routes and in Generating New Traffic", "Proceedings", Highway Research Board, Vol. 27, pp. 322-330. (1947).

4. Campbell, Wilson E., "Comparative Traffic Usage of Kanawha Boulevard and Alternate City Arterials", "Thesis", Bureau of Highway Traffic, Yale University, 1951.

5. "An Analysis of Comparative Traffic Usage Via the Olentangy River Road and Alternate City Arterials", Bureau of Planning and Programming, Ohio State Highway Department, 1950.

6. MacLachlan, K. A., "Coordinate Method of Origin and Destination Analysis", "Proceedings", Highway Research Board, Vol. 29, pp. 349-367. (1949).

7. "Traffic Survey of the Sacramento Area", Division of Highways, State of California, 1947-1948.

8. Campbell, M. E., "Diversion of Traffic from City Streets to Expressways as a Basis for Traffic Assignment", "Circular No. 139", Highway Research Correlation Service, July, 1951.

9. Lawton, Lawrence, "Evaluating Highway Improvements on Mileage and Time Cost Basis", "Traffic Quarterly", January, 1950, pp. 102-125.

10. "Survey of Current Business", U. S. Department of Commerce, Vol. 31, No. 5, pp. 1 and 14-23. (1951).

11. Winfrey, Robley, "Automobile Operating Cost and Mileage Study", "Bulletin No. 106", Iowa State College.

12. Maguire, Charles A., and Associated and Deleuw, Cather and Company, "Traffic Survey and Study" - Proposed Bypass Route, Lowell, Massachusetts, October, 1948.

13. Tucker, Harry and Seager, Marc C., "Highway Economics", International Textbook Company, 1942.

14. "Highway Practice in the U.S.A.", Public Roads Administration, Washington, D. C. 1949.

15. Ritter, L. J. Jr., and Paquette, R. J., "Highway Engineering", Ronald Press, 1951.