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Interchange of Congress Street Expressway and Northwest Expressway, Chicago, Ill., showing Congress Street Expressway going under the Post Office Building. Halsted Street is in foreground.

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IN THIS ISSUE

TITLE SHEET, VOL. 32

The title sheet for vol. 32, Apr. 1962–Feb. 1964, of Public Roads magazine is now available. This sheet contains a chronological list of article titles and an alphabetical list of authors' names. Copies of this title sheet can be obtained by a request to the editor of the magazine, Bureau of Public Roads, Washington, D.C., 20402.

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Effect of Linseed Oil Coatings on Resistance of Concrete to Scaling

BY THE MATERIALS RESEARCH DIVISION
BUREAU OF PUBLIC ROADS

Reported by[1] WILLIAM E. GRIEB, Highway Research Engineer, and ROGER APPLETON, Supervisory Engineering Technician

This article reports the results of a study of the use of linseed oil sruface coatings to prevent scaling caused by the use of de-icing chemicals. These tests were made because of the wide variation in the State specifications governing the use of this material. It is a continuation of tests by the Bureau of materials and procedures for protecting concrete pavements against scaling caused by the use of deicing chemicals. These tests are being continued. In this investigation four different linseed oil surface coatings were used on air-entrained and non-air-entrained concrete with high and low slumps.

The data presented show that for non-air-entrained concrete, all of the linseed oil coatings were of some benefit in protecting the concrete surfaces from scaling. However for the air-entrained concrete, only two of the surface coatings tested were beneficial.

Introduction

MANY State highway departments have been using surface coatings to protect concrete pavements from scaling and disintegration caused by the use of de-icing chemicals. These coatings are often applied to concrete placed late in the fall to give it added protection and to compensate for the short aging period before the concrete is subjected to freezing. One of the materials often used for surface protective coatings is linseed oil. The specifications governing the use of this material vary. Some States specify its use as an emulsion and others require that it be diluted with mineral spirits when applied. One or two applications of the linseed oil may be required.

Tests were made in the laboratory of the Bureau of Public Roads to determine whether the use of the surface treatments of linseed oil are beneficial in preventing scaling of the concrete. In these tests, four different concrete mixes were used. They were non-air-entrained low slump concrete and non-air-entrained high slump concrete; air-entrained low slump concrete, and air-entrained high slump concrete. Five different surface treatments were used on concrete slabs. The control slabs were given no surface treatment, and the test slabs were treated respectively with two coats of boiled linseed oil, two coats of raw linseed oil, one coat of boiled linseed oil, or two coats of linseed oil emulsion.

Conclusions

The results of the tests made in the laboratory of the Bureau of Public Roads warrant the following conclusions:

- For non-air-entrained concrete, each of the linseed oil surface treatments tested was of some benefit in preventing or delaying surface scaling on the test slabs.
- For air-entrained concrete, only two of the four linseed oil surface treatments were beneficial. These beneficial treatments were two applications of either boiled or raw linseed oil. One application of the boiled linseed oil or the two applications of the linseed oil emulsion were of no benefit in preventing or delaying scaling on the test slabs.
- When two applications of the linseed oil were used, the concrete had slightly better overall resistance to scaling when boiled linseed oil was used.
- As would be expected, these tests with linseed oil also showed that slump affected the resistance of concrete to scaling. Both the air-entrained and non-air-entrained concrete having a low slump had equal or better resistance to scaling than similarly treated concrete having a high slump.
- The air-entrained concrete had equal or better resistance to scaling than the similarly treated non-air-entrained concrete.

The pattern of scaling developed on the different groups of slabs during the freezing and de-icing tests is shown in figure 5. These conclusions are most readily apparent when related to this figure.

Mix Data

Four different mixes were used for the concrete test slabs. The mixes were: Non-air-entrained concrete having a 2½-inch slump, non-air-entrained concrete having a 6-inch slump, air-entrained concrete having a 2½-inch slump, and air-entrained concrete having a 6-inch slump. The mix data for the four mixes are given in table 1. All mixes contained approximately 6 bags of cement per cubic yard of concrete. The air content for the air-entrained concrete was 5 percent. For both the air-entrained and non-air-entrained mixes, the 6-inch slump concrete contained 0.7 gallon of water per bag of cement more than the corresponding 2½-inch slump concrete.

Materials

The same materials were used for all mixes. They were a type I portland cement having an equivalent alkali content of 0.6 percent, a siliceous sand having a fineness modulus of 2.75, and a crushed limestone uniformly graded from 1 inch to No. 4. When needed, a commercially available aqueous solution of neutralized Vinsol resin was used to entrain air. The linseed oils used met Federal Specifications.

Curing

The test specimens were concrete slabs 16 by 24 inches by 4 inches in depth and having a raised edge or dam around the perimeter of the top surface. The specimens were similar to those described in a previous article in PUBLIC ROADS on resistance of concrete surfaces to scaling.[2] The slabs were cast in watertight molds that had metal bases. The top surfaces of the slabs were screeded with a wooden straightedge then, about 3 hours after the molding, the slab surfaces were given a light broomed finish. This finish was similar to that given a concrete pavement. All specimens were molded, finished, and cured, in the same manner. All slabs were cured in the molds with wet burlap for 2 days, ponded for 12 days, and then dried in laboratory air at 70° to 80° F. and 30 percent relative humidity for 7 days prior to the application of the surface treatments. After the surface treatments had been applied, the slabs were kept in laboratory air for 7 to 14 days and then placed in the outdoor exposure area. When two applications of a surface treatment were used, they were applied 24 hours apart. All specimens were from 28 to 35 days old

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[1] Presented at the 43d annual meeting of the Highway Research Board, Washington, D.C., January 1964.

[2] *Resistance of Concrete Surfaces to Scaling by De-Icing Agents*, by William E. Grieb, George Werner, and Donald O. Woolf, PUBLIC ROADS, vol. 32, No. 3, August 1962, pp. 64–73.

Table 1.—Mix data [1]

Proportions by dry weight	Cement content	Water content	Slump	Air content	Weight of plastic concrete
Pounds	*Bags/cu. yd.*	*Gal./bag*	*Inches*	*Percent*	*Lb./cu. ft.*
94-205-305	6.2	5.5	2.6	2.0	149.1
94-205-305	6.1	6.2	6.0	1.4	148.7
94-190-305	6.2	5.2	2.7	5.0	145.9
94-190-305	6.1	5.9	6.2	5.1	144.2

[1] Materials used were: (1) type I portland cement; (2) crushed limestone, 1-inch maximum size; and (3) siliceous sand, fines modulus of 2.75.

Table 2.—Rating of slabs

Surface coatings	Rating [1] after freezing and thawing for cycles—						
	10	20	30	45	60	80	105
Non-air-entrained concrete—2.6-in. slump, 2.0 percent air:							
None	4	9	10	—	—	—	—
2 coats boiled linseed oil	0	0	0	0	0	0	1
2 coats raw linseed oil	0	0	0	0	1	1	1
1 coat boiled linseed oil	0	0	0	1	2	2	4
2 coats linseed oil emulsion	0	0	0	2	4	5	6
Non-air-entrained concrete—6.0-in. slump, 1.4 percent air:							
None	8	10	—	—	—	—	—
2 coats boiled linseed oil	0	0	1	1	1	1	2
2 coats raw linseed oil	0	0	1	1	3	4	4
1 coat boiled linseed oil	1	4	9	10	—	—	—
2 coats linseed oil emulsion	0	2	5	7	9	9	9
Air-entrained concrete—2.7-in. slump, 5.0 percent air:							
None	0	0	0	0	1	1	3
2 coats boiled linseed oil	0	0	0	0	0	0	1
2 coats raw linseed oil	0	0	0	0	0	0	1
1 coat boiled linseed oil	0	0	0	1	2	3	4
2 coats linseed oil emulsion	0	0	0	0	1	2	3
Air-entrained concrete—6.2-in. slump, 5.1 percent air:							
None	0	0	0	0	3	4	6
2 coats boiled linseed oil	0	0	0	0	0	0	2
2 coats raw linseed oil	0	0	0	1	3	3	4
1 coat boiled linseed oil	0	2	4	5	6	6	5
2 coats linseed oil emulsion	0	1	1	1	4	4	5

[1] Each rating is an average for two test specimens: Rating of 0 indicates no scaling; rating of 5 indicates a significant amount of scaling; rating of 10 indicates deep scaling over entire surface of specimens.

when they were stored in the exposure area and the first natural freeze occurred 3 days later.

Surface Treatments

Ten identical slabs were made from each of the four mixes. Two slabs made for each mix were given one of the following surface treatments: (1) Control slabs, no surface treatment; (2) two applications of boiled linseed oil; (3) two applications of raw linseed oil; (4) one application of boiled linseed oil; and (5) two applications of linseed oil emulsion. The first coating for both the boiled and raw linseed oil treatment was applied as a mixture of equal parts by volume of linseed oil and mineral spirits at a rate of 1 gallon per 40 square yards of surface. The second coat was applied as undiluted linseed oil at a rate of 1 gallon per 67 square yards.

The linseed oil emulsion used was the same as that described in the special provisions of one of the State specifications for surface sealing of bridge decks. It consisted of 1 part boiled linseed oil, 1 part kerosene, 3 parts water plus a small amount of trisodium phosphate, and a small amount of a nondetergent soap powder as an emulsifying agent. The emulsion was applied at a rate of 1 gallon per 10 square yards of surface for each application. Similar emulsions have been used by other State highway departments.

Observations were made to determine the time necessary for the different coatings to be absorbed by the concrete. The boiled and raw linseed oils diluted with mineral spirits were absorbed in about 30 minutes, whereas the linseed oil emulsion was absorbed in about 1 hour and 40 minutes. The rate of absorption varied according to the mix used in the slabs on which the coating was applied. Slabs made with the air-entrained concrete having a high slump absorbed the coating more rapidly than slabs made with the other mixes. Those made with the non-air-entrained concrete having high slump absorbed the coating the next fastest, followed by those made with the air-entrained low-slump concrete. Slabs made with the non-air-entrained low-slump concrete took the longest time to absorb the coatings. A longer period of time was required for absorption of the second coating by all of the slabs. This information may be of value as a guide for the use of these coating materials in the field.

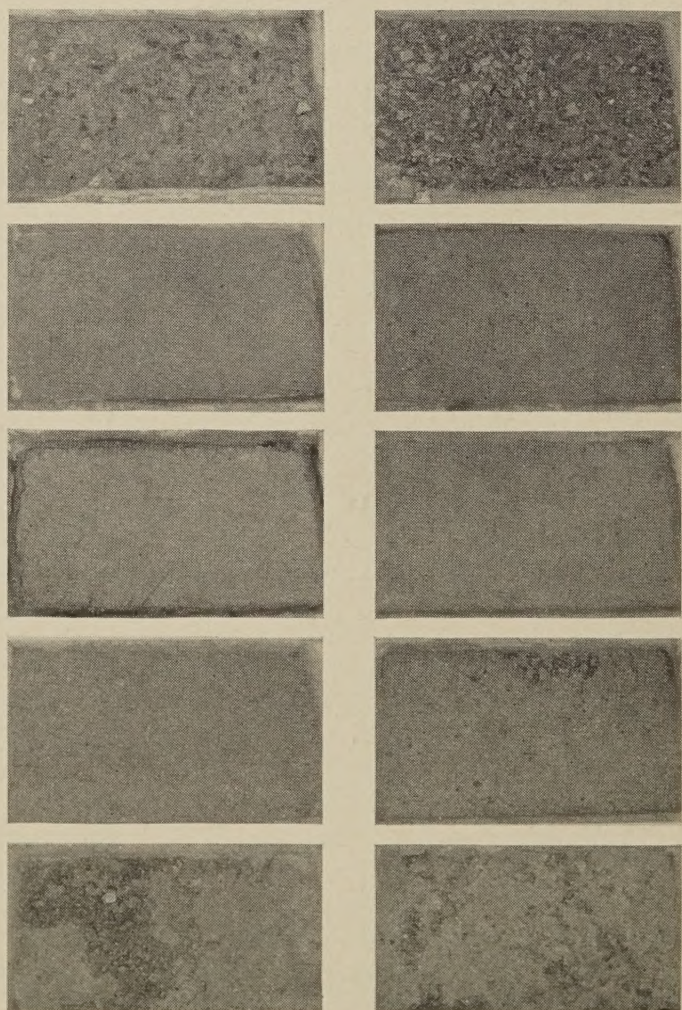
Testing Procedure

Each evening when freezing was expected, the top surface of each slab was covered with one-fourth to one-half inch of water. The next morning after the water had frozen, flake calcium chloride was spread uniformly over the ice-encrusted surface at a rate of about 2.4 pounds per square yard of surface. Although this rate of application was greater than would be used in the field, this is the rate of application that has been used on other research projects. After the ice had melted, the surface was washed and fresh water was left on the surface. The specimens were examined periodically and were rated by visual observations according to the amount and depth of the scaling. A general description of the numerical ratings is as follows:

0–no scale.

1–scattered spots of very light scale.

2–scattered spots of light scale with mortar surface above coarse aggregate removed.



NO SURFACE TREATMENT RATINGS 10 & 10

2 COATS BOILED LINSEED OIL RATINGS 1 & 1

2 COATS RAW LINSEED OIL RATINGS 1 & 1

1 COAT BOILED LINSEED OIL RATINGS 3 & 4

2 COATS LINSEED OIL EMULSION RATINGS 7 & 6

Figure 1.—Effect of linseed oil surface treatments on scaling—105 cycles, 2.6-in. slump, 2.0 percent air.

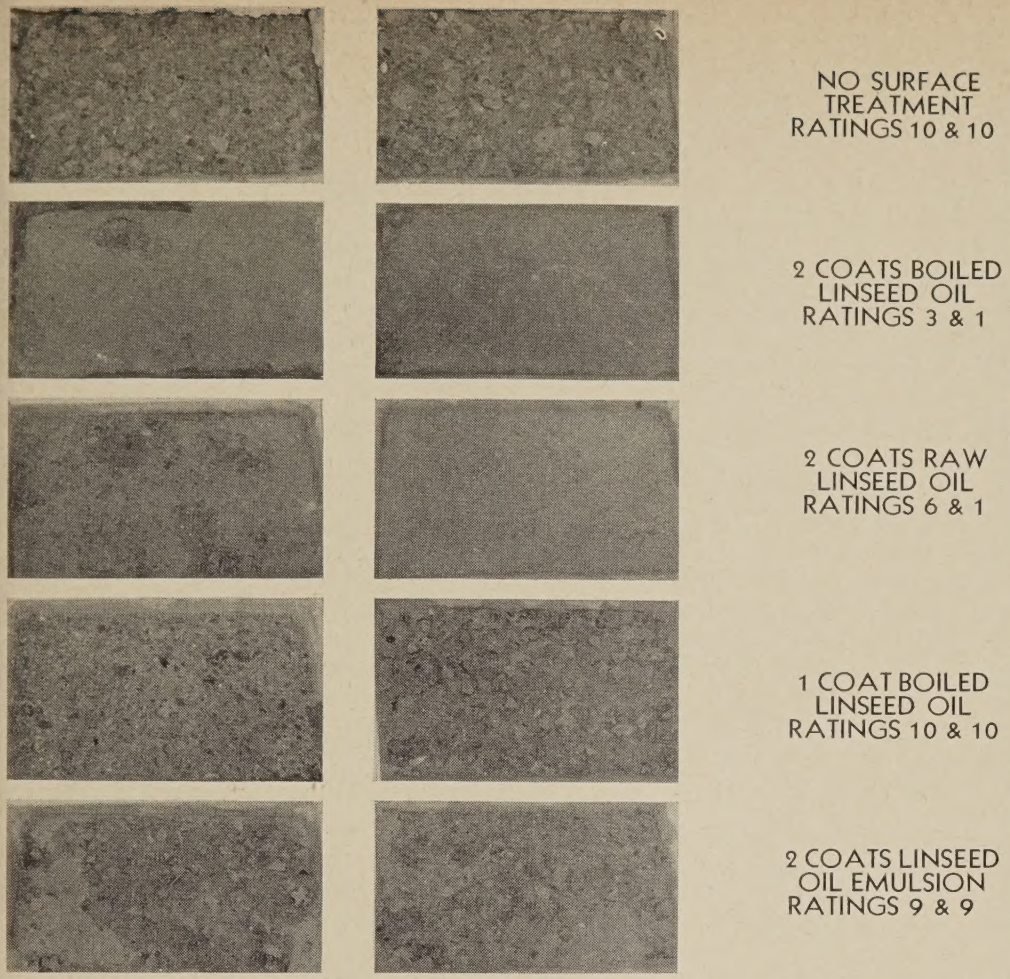


Figure 2.—Effect of linseed oil surface treatments on scaling—105 cycles, 6.0-in. slump, 1.4 percent air.

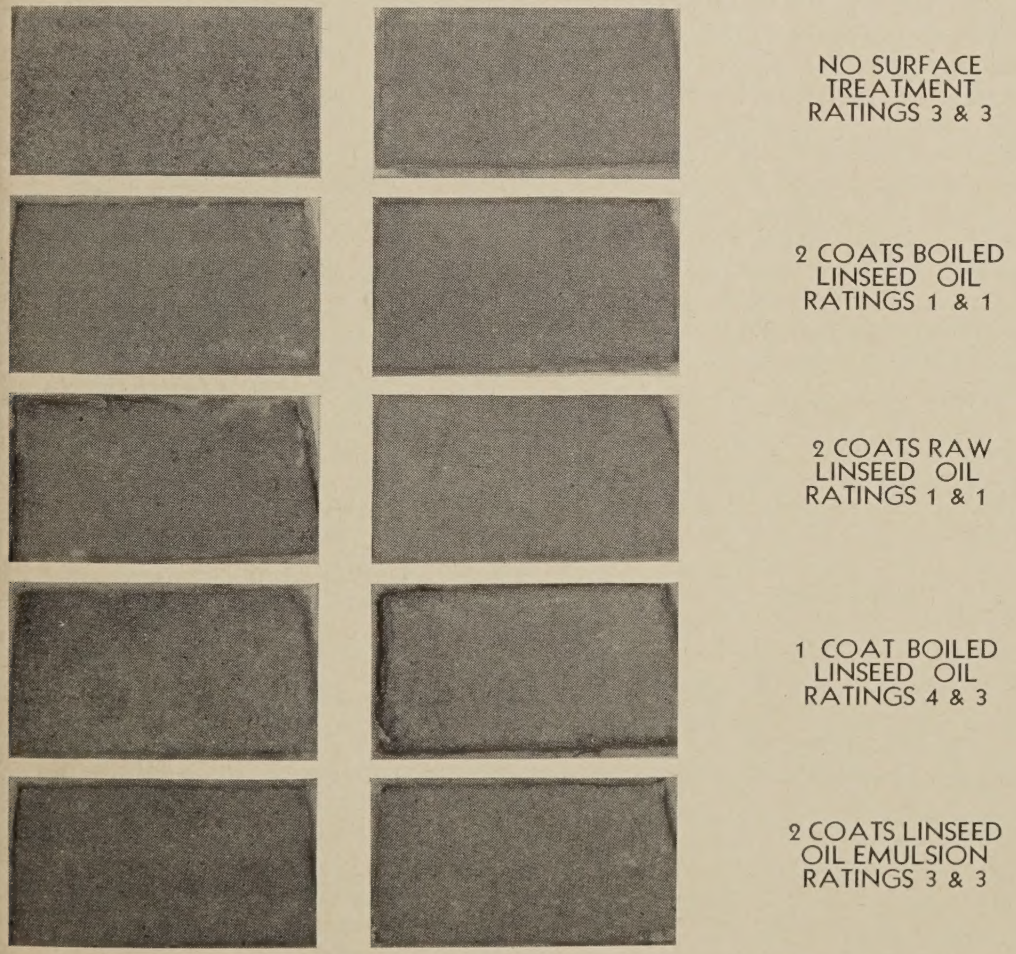


Figure 3.—Effect of linseed oil surface treatments on scaling—105 cycles, 2.7-in. slump, 5.0 percent air.

3–light scale over about one-half of the surface.

4–light scale over most of the surface.

5–light scale over most of the surface, with a few moderately deep spots, where the mortar surface was below the upper surface of the coarse aggregate.

6–scattered spots of moderately deep scale.

7–moderately deep scale over one-half of the surface.

8–moderately deep scaling over entire surface.

9–scattered spots of deep scale with the mortar surface well below the upper surface of the coarse aggregate; otherwise moderately deep scaling.

10—deep scale over entire surface.

A rating of 5 or more would indicate significant or major scaling. The ratings given the slabs were based on the judgment of different observers at the various times that the observations were made, which accounts for occasional slight reversals. The rating scale used was the same as that given in the previous article (see footnote 2).

These specimens were in the outdoor exposure area for two winters and had a total of 105 cycles of freezing and thawing (45 cycles the first winter and 60 cycles the second). Previous tests have shown that exposure for two winters is sufficient to indicate the resistance of concrete test specimens to scaling caused by the use of calcium chloride.

Test Results

Non-air-entrained-concrete, low slump

The average ratings of the slabs after 10, 20, 30, 45, 60, 80, and 105 cycles of freezing and thawing are given in table 2. These data show that for the non-air-entrained concrete having a low (2.6-inch) slump, when the slabs had no surface coatings, their ratings were 10 after 30 cycles of freezing and thawing. The tests on these slabs were then discontinued. None of these slabs coated with the linseed oil showed any sign of scaling at 30 cycles of freezing and thawing. At 45 cycles, scaling had started on the slabs that had received one coat of boiled linseed oil and on those treated with the two coats of the emulsion. At 105 cycles, the slabs treated with two coats of the emulsion showed severe scaling over part of the surface and were given an average rating of 6. The slabs treated with one coat of boiled linseed oil showed light scaling over the entire surface and were given a rating of 4. The slabs that had received two coatings of boiled or raw linseed oil showed very little scaling and were given a rating of 1.

Non-air-entrained concrete, high slump

For the non-air-entrained concrete having a high slump (6 inches), the slabs that had received no surface treatment were completely scaled after only 20 cycles of freezing and thawing and were given a rating of 10. For this same number of cycles, the slabs treated with one coat of boiled linseed oil and those treated with two coats of the emulsion had ratings of 4 and 2, respectively. Those re-

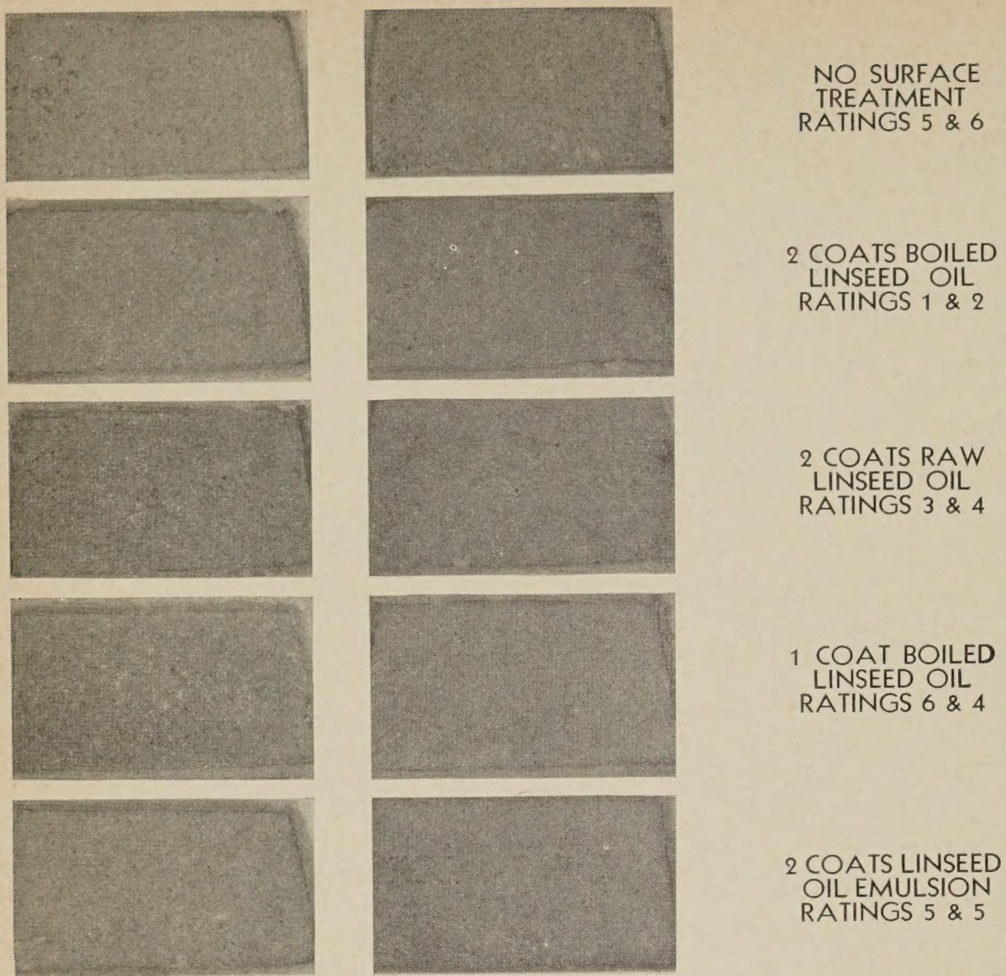


Figure 4.—Effect of linseed oil surface treatments on scaling—105 cycles, 6.2-in. slump, 5.1 percent air.

ceiving two coatings of raw and boiled linseed oil showed no signs of scaling at that time. After 45 cycles, deep scaling over the entire surface (rating of 10) was found on the slabs treated with one coat of boiled linseed oil. Those covered with two coats of the emulsion had a rating of 9 after 60 cycles. After 105 cycles, the slabs treated with two coats of the boiled linseed oil had an average rating of 2, and those treated with two coats of raw linseed oil had an average rating of 4. There was a marked difference in the amount of scaling between the two slabs given the two coats of the raw linseed oil. One slab had virtually no scaling and was given a rating of 1. The other slab was severely scaled over a portion of its surface and was rated at 6. No reason can be given for the difference in performance of these presumably identical slabs.

Air-entrained concrete, low slump

All of the slabs prepared with air-entrained concrete having a low slump showed good resistance to scaling. After 105 cycles of freezing and thawing, the slabs covered with two applications of the boiled or raw linseed oils showed very little scaling and were rated as 1. The average rating for all the other slabs was 3 or 4, these ratings applied to both the treated and the untreated reference (control) slabs.

Air-entrained concrete, high slump

The slabs prepared with air-entrained concrete having a high slump showed good to fair resistance to scaling. The slabs that had two coatings of the boiled linseed oil had the best resistance, having a rating of 2 after 105 cycles of freezing and thawing. Slabs treated with two coatings of the raw oil had a rating of 4 after 105 cycles. There was little difference in the surface condition of the other slabs, they all had average ratings of 5 or 6.

Condition of all specimens

Photographs of all the slabs after 105 cycles of freezing and thawing, or when they were given a rating of 10, are shown in figures 1 to 4, inclusive. These figures also show the final rating of each slab. There was, in general, good uniformity between the two slabs from the same mix given the same surface treatment. Only for one pair of slabs made with non-air-entrained concrete having a high slump, as previously mentioned, was the difference in ratings between the two similar slabs greater than two. For more than half of the similar pairs of slabs, the ratings given were the same.

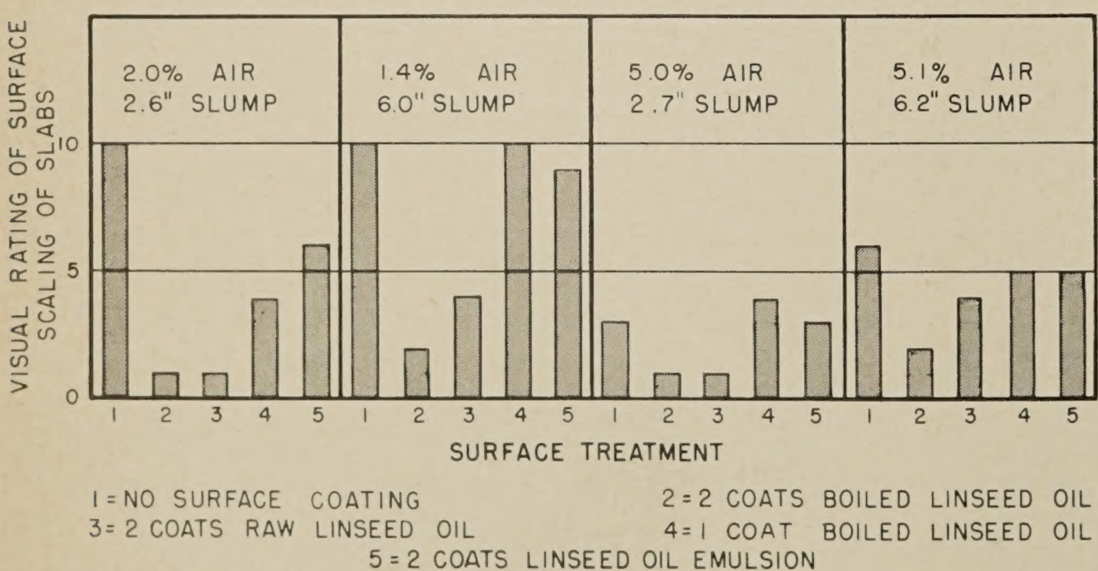


Figure 5.—Effect of linseed oil surface coatings on scaling after 105 cycles of freezing and thawing with calcium chloride.

Summary

A summary of the ratings of the slabs after 105 cycles of freezing and thawing is shown in figure 5. This figure shows that, for both the low and the high slump non-air-entrained concretes, all of the linseed oil surface treatments were beneficial in preventing or delaying scaling caused by the use of de-icing chemicals. Applications of two coats of either the boiled or the raw linseed oil were the most beneficial surface treatments. With one exception, the slabs given the two coats of the boiled or raw linseed oil were the only ones of the non-air-entrained concretes that did not show significant scaling after 105 cycles of freezing and thawing.

For the air-entrained concrete having either low or high slump, the two-coat application of either the boiled or the raw linseed oil was the only surface treatment effective in preventing or delaying scaling. The other surface treatments were of little or no benefit. No significant scaling occurred on any slabs prepared with the low-slump, air-entrained concrete, including those that received no surface treatment. All of the slabs except those given the two coats of the boiled or raw linseed oil showed significant scaling when they had been prepared with the high-slump air-entrained concrete.

The slabs treated with two coats of the boiled linseed oil were equally or more resistant to scaling than those treated with two coats of the raw linseed oil.

Greater resistance to scaling was furnished by the low-slump concrete than by the corresponding high-slump concrete, and greater resistance was furnished by the air-entrained concrete than by the corresponding non-air-entrained concrete.

Evaluation of a New Modal Split Procedure

BY THE OFFICE OF PLANNING
BUREAU OF PUBLIC ROADS

Reported by [1] ARTHUR B. SOSSLAU,[2] KEVIN E. HEANUE, and ARTHUR J. BALEK, Highway Engineers, Urban Planning Division

A Bureau of Public Roads evaluation of a new modal split technique of interest to urban transportation planners responsible for estimating future public transit requirements is presented in this article. The new modal split technique was developed by the Traffic Research Corporation for the use of the National Capital Transportation Agency in estimating 1980 transit requirements for the Washington, D.C., area. Because sound estimates of transit patronage are required for the development of comprehensive urban transportation plans, Pubic Roads conducted a two-phase test of this procedure.

In the first phase, the effectiveness of the new modal split procedure to reproduce a known situation was tested. In the second phase, the sensitivity of the procedure was assessed; that is, its ability to reflect changes in input variables.

The evaluation tended to confirm the usefulness of this new modal split procedure but also revealed limitations that should be considered before further application. Comments of three transportation planning officials on the evaluation and the findings therefrom have also been included with this article.

Introduction

AN EVALUATION of a new technique developed for estimating the relative use of the private and public modes of transportation is presented in this article. The development of comprehensive urban transportation plans requires sound estimates of transit patronage. The Traffic Research Corporation (TRC) under contract to the National Capital Transportation Agency (NCTA) developed a new modal split procedure for estimating the relative usage of the private and public modes of transportation. This procedure was utilized by the NCTA in developing a 1980 transportation plan for the Washington, D.C. area, prior to this Public Roads evaluation. This evaluation of the modal split procedure was made to gain insight into its accuracy and to provide potential users with a quantitative analysis of a research application.

The evaluation project conducted by the Bureau of Public Roads consisted of two distinct phases: (1) A test of the modal split technique as a means of reproducing a known situation; specifically the transit usage reported in the 1955 Washington, D.C., origin and destination survey; and (2) a test of the sensitivity of this new modal split procedure to changes in the input parameters.

Background

The relationship of the usage of private automobiles and of public transportation is growing in importance, particularly in large cities. Although useful planning techniques were available for use in developing comprehensive urban transportation plans, the ultimate in such planning techniques has not been attained. Of the techniques that have been developed one relates the proportion of use of public transportation to car ownership and population density; and another relates the proportion of use of public transportation to some function of the traveltime required for transit and automobile travel.

Many factors influence the choice of a mode of transportation, according to different studies reported. One study conducted in Cook County, Ill., in 1957, revealed that 32.4 percent of travelers consider time the most important factor in choosing a mode of travel. Other prime factors reported were comfort, 17.4 percent; cost, 5.3 percent; and walking distance, 8.0 percent. A car was reported to be a requisite for transportation by 12.5 percent of those surveyed, and 12.8 percent reported they had no choice other than public transportation. Miscellaneous factors were reported by 11.6 percent (*1*).[3]

Modal Split Technique

Two basic approaches to the modal split technique are possible. In one, the split between private and public transportation trips for each zone is estimated and the transit and automobile trips are distributed separately between zones. In the other approach—the one used by the new modal split procedure—the split is considered after the distribution of total person movements between zones has been made.

The new modal split technique is basically a diversion curve procedure in which relative transit usage is related to five selected variables. These variables are: (1) The ratio of door-to-door traveltime by public transit to the door-to-door traveltime by private automobile. (2) The ratio of excess traveltime by public transit to excess traveltime by private automobile. This ratio is used as a measure of relative travel service and is referred to as the "service ratio." (3) The ratio of out-of-pocket travel cost by public transit to the out-of-pocket travel cost by private automobile. (4) The economic status of the person making the trip. (5) Trip purpose.

The items considered in the development of the five variables are shown in the following expressions.

$$\text{Traveltime ratio} = \frac{a+b+c+d+e}{f+g+h} \qquad (1)$$

Where,

a = time on transit vehicle
b = transferring time between transit vehicles
c = time spent in waiting for transit vehicle
d = walking time to transit vehicle
e = walking time from transit vehicle
f = automobile driving time
g = parking delay time at destination
h = walking time from parking place to final destination
$i = \text{gasoline cost}\left[\frac{\text{gallons}}{\text{mile}} \times \text{distance} \times \frac{\text{cost}}{\text{gallon}}\right]$
j = oil change and lubrication cost (cost of oil change per mile times distance)
k = parking cost at destination
L = number of persons per vehicle

$$\text{Service ratio} = \frac{b+c+d+e}{g+h} \qquad (2)$$

$$\text{Cost ratio} = \frac{\text{transit fare}}{\left(\frac{i+j+\frac{k}{2}}{L}\right)} \qquad (3)$$

Economic status = median income per worker. (4)

Trip purpose = either, home-based work trips or all nonwork trips except those made to school. (5)

To develop the modal split relationships for each trip purpose, determinations were made of the percentage of travelers that

[1] Presented at the 43d annual meeting of the Highway Research Board, Washington, D.C., January 1964, as a report titled, *Test of the Modal Split Procedure Developed by the National Capital Transportation Agency.*

[2] Mr. Sosslau is now employed by the Tri-State Transportation Committee.

[3] References indicated by italic numbers in parentheses are listed on page 17.

used public transit and private automobiles from each origin to each destination. This usage was then related to the four basic determinant factors—traveltime ratio, travel cost ratio, service ratio, and economic status. The trip information, from which these relationships were developed, was obtained from travel surveys made in the Washington area and from supporting evidence gathered in other cities (*2*). All observations from each study were stratified by trip purpose. Next, divisions were made of: The cost ratio into four ranges, the excess time ratio into four ranges, and the income level into five ranges. By multiplying the number of ranges (4×4×5), 80 individual combinations of these three determinant factor ranges were obtained, thereby providing 80 time-ratio diversion curves for each trip purpose. For each of the 80 combinations the observations concerning modal split were plotted against the traveltime ratio. Figure 1 shows four of these curves.

Information for curve development was obtained from the 1955 Washington, D.C., origin and destination survey and from the 1961 Federal employee survey. For the work-trip relationships, those trips arriving at zero sector destinations (see figure 2) between 6:54 a.m. and 9:06 a.m. were analyzed. For nonwork, nonschool trips the data studied were for the period 9:12 a.m. to 3:45 p.m. Selected trips to nonzero sector destinations were also used to supplement the zero sector oriented data. Data for 1955 and 1961 were combined, after adjustments had been made to put the two sets of information on an equal basis, and average grouped points calculated to obtain one set of relationships. As sufficient information upon which to base the relationships was not available from Washington, D.C., travel survey data from Toronto, Canada, and Philadelphia, Pennsylvania, were used to supplement it (*2*). Basically, these data were necessary to extrapolate the curves developed from Washington data for the 1980 estimate because: (1) Little information was available for Washington that showed traveltime ratios of less than one, and (2) little information was available that showed cost ratios of less than 0.5. A computer program was developed to apply the modal split procedure. Briefly, this program has been written for a 7090 computer in the FORTRAN language. A complete description of the modal split relationship development can be obtained from references *2* and *6*.

Summary of Findings

The Public Roads test of the new modal split technique developed by TRC for use of the NCTA to estimate 1980 transit usage in Washington, D.C., shows that it may be a useful tool for forecasting transportation system usage. Although the tests confirmed its usefulness, they also revealed limitations that should be considered before further application of this particular modal split technique. A more accurate and useful tool may be developed upon further investigation and analysis of this method.

The results of the BPR test against 1955 O–D data indicate that the technique can reasonably reproduce the conditions from which the modal split relationships were developed. The estimate of transit work trips to the zero sector from the entire area obtained by use of the procedure was as good as could be expected. This estimate of transit trips was within one root-mean-square error of the 1955 O–D survey estimate. Total nonzero sector destined transit work trips were less accurately estimated by the modal split procedure, probably because the curves were developed almost entirely from zero sector oriented trips. Additional research many well indicate that separate sets of curves are required for CBD and non-CBD oriented trips.

The restraint added to the transfer matrix in the test, which eliminated certain non-CBD to non-CBD trips, may be unnecessary if a separate set of non-CBD curves is developed, or if a new set of relationships that indicate zero transit ridership at a traveltime ratio of 5.00, instead of 10.00, is used. The corridor analysis indicated a geographical bias in the modal split estimates for work trips.

The estimate of nonwork transit trips to zero sector destinations from the entire area was also within acceptable limits of accuracy, although it was not as accurate as for work trips. Perhaps this difference in accuracy was caused by the nonwork curves being developed from offpeak time period data and applied to the peak period. Further re earch is needed to evaluate the application to another time of a set of relationships developed for one time period.

On a corridor basis, estimates for all trips having origins outside the zero sector and destinations in the zero sector were slightly less accurate than the O–D estimate. The analysis of district-to-district trips for both work and nonwork showed the variation between the estimate of transit trips and O–D trips to be less than the expected variation in the O–D trips.

All the variables considered in the test of the modal split technique appear to relate to modal choice. However, this alone does not necessarily indicate a generally applicable procedure. Estimates of necessary input variables must be sufficiently accurate so as to not seriously impair the accuracy of the estimated transit usage. The sensitivity tests showed that substantial weight is given to certain of the input variables that are difficult to estimate. The observed change in the modal split when automobile excess time was varied indicates the high weight placed on this parameter. The 2 minutes added to automobile parking delay and walking times in the CBD had a greater effect on the modal split of trips destined to the CBD than doubling fares, doubling parking costs, factoring transit or highway times by 0.75, or factoring transit times by 1.5. These excess time values are among the most difficult to estimate. The 2-minute increase in excess time (test *C*) is not considered unrealistic in that the mean 1955 CBD excess automobile time used in the development of the curves was 3.6 minutes and the mean excess automobile time estimated for 1980 was 6.7 minutes.

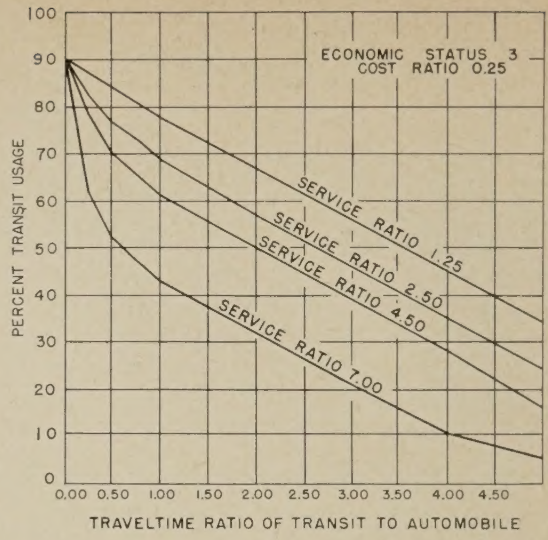


Figure 1.—Example of modal split relationship.

The sensitivity analysis indicated that parameters reflecting 1980 automobile terminal conditions; that is, parking delay, walking time, and parking costs, had a far greater weight in the modal split determination than any of the parameters that reflected the proposed transit system. The range of meaningful cost ratio values was too narrow to permit evaluation of alternate fare structures.

Additional work indicated as being desirable includes: (1) Extension of the cost ratio ranges and level of service ratio ranges to reflect wider variations in system conditions. (2) Better estimating procedures to improve the accuracy of those model inputs that show the greatest sensitivity to modal split. (3) The testing of time differences rather than or in conjunction with time ratios, which may produce greater sensitivity of the procedure to highway and transit system changes.

Test of Modal Split Technique Against 1955 O–D Survey

The modal split technique was used by NCTA for estimating 1980 transit usage on a proposed system. Public Roads developed parameters reflecting highway system and transit system 1955 operating characteristics and applied the modal split procedure to 1955 conditions. The estimated transit usage was then compared to the transit usage reported in the 1955 Washington, D.C., O–D survey. The 160 modal split diversion curves (80 for each purpose) used in the Public Roads test were the same curves used by NCTA in developing the 1980 transit usage estimates.

Two principles were established for the test procedure: (1) The data from the 1955 Washington, D.C., origin and destination survey were to be adhered to as closely as possible in preparing the input parameters. (2) The same procedures used by NCTA in preparing input parameters for the application of the modal split procedure to estimate the 1980 transit usage were to be used.

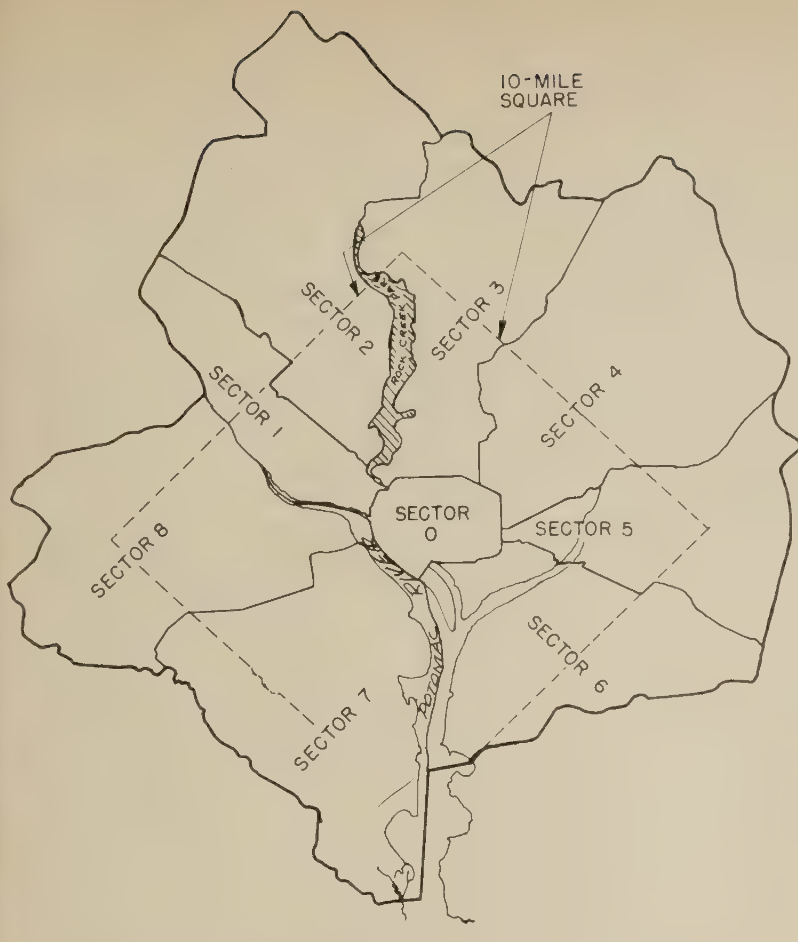


Figure 2.—1955 Washington, D.C. survey sectors.

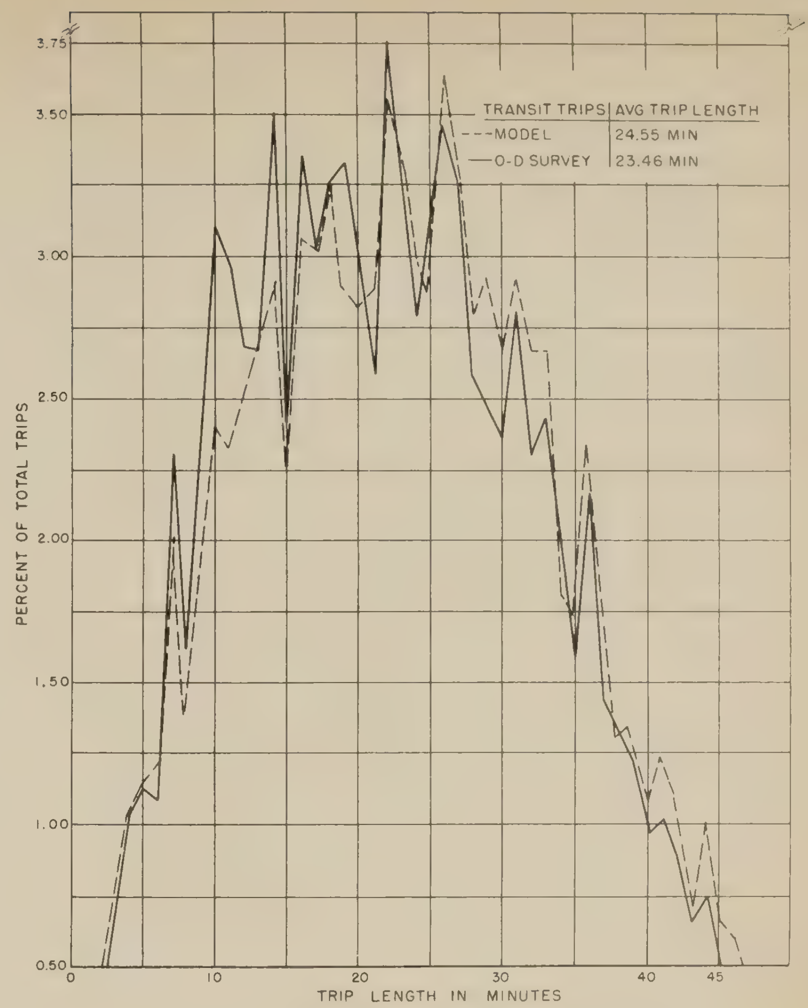


Figure 3.—Trip length frequency distribution comparison.

The modal split technique was tested to determine its ability to predict: (1) Areawide modal split; (2) areawide to Central Business District (CBD) destination (zero sector) modal split; (3) areawide to non-CBD destination modal split; (4) modal split from each of eight survey sectors (corridors) to the CBD; (5) modal split between each of the survey sectors; and (6) modal split between each district in the survey area.

Preparation of Input Data

Generally, data were developed on a zone basis for each of the 400 survey zones considered. Adjustments were made in the zonal data so that the summary of this zonal data by district would closely match the district data used for curve development. This was in accordance with a goal of the test; that is, to evaluate the modal split technique rather than the manner in which the input parameters were prepared.

System Parameters

O–D interchanges

TRC in its development of the modal split relationships reproduced the 1955 O–D trip data in a linked form (*3*). The only deviations from the normal linking process made by TRC are described in the next paragraph.

Linked trips that originated at home but having intermediate change mode or serve passenger purposes and finally destined for home were omitted from the linked trip file. The procedure usually followed is to produce two trips; for example, one from home to personal business and another from personal business to home. All unlinkable, serve passenger, or change travel mode trips were omitted in this test. Normally, each trip is evaluated and a decision reached as to the purpose to be considered. For example, a change mode trip having a destination at an airport—not a linkable trip as the person presumably leaves the area—is usually classified as a business trip.

Only trips made during the peak traffic period of 6:54 a.m. to 9:06 a.m. were considered for this test. However, the modal split nonwork curves were developed from offpeak traffic data for the period of 9:12 a.m. to 3:54 p.m. Work trip curves were developed from data on peak traffic period trips—6:54 to 9:06 a.m. As the modal split model had been used to estimate 1980 transit usage in the a.m. peak traffic period, for this test both sets of curves—work and nonwork—were applied to the peak traffic period.

Two sets of origin and destination survey trip interchanges were developed for the test: trips to and from work, and all nonwork trips except those to and from school. For each set two trip files were required: (1) total person trips—automobile driver; transit passenger; and truck, taxi, and automobile passenger—for input to the modal split program; and (2) trips by transit for comparison with the output of the modal split program.

Highway times and distances

A necessary input to the modal split procedure is the traveltime between zones via the highway network. These times were obtained from the 1955 O–D survey for use in the development of the modal split relationships. For testing the 1980 application of the modal split procedure, times were obtained from "trees" or minimum time paths (*4*). Again, the procedure used by NCTA for their 1980 estimate of transit usage was followed as the guide for this test. A highway network was coded in order to obtain these minimum time paths.

A 1955 highway network was available for use in this testing. However, the times coded on each section of highway derived from 1955 speed runs were more representative of average daily traveltimes than the peak traffic times required. It was necessary to adjust the average daily traveltimes obtained from trees built with this system to match those peak traffic times used for developing the modal split relationships (district to district reportings from O-D survey). The adjusted highway times used in combination with highway distances to obtain a gasoline cost per mile were determined from minimum time routes obtained in this process.

Transit time

Available traffic assignment programs that build minimum time paths between zones were utilized for the determination of zone-to-zone time via the transit system. The general rules required for coding a highway network were followed for this purpose (*5*).

The route schedules for the 7- to 9-a.m. time period for each of the four transit companies operating in the Washington, D.C., area in 1955 were used for the preparation of a transit network. Link lengths were determined by measurement from scaled maps showing actual route locations and times. All connections from zone centroids to the transit stops were coded as having zero distance and time because these excess traveltimes were coded as zone parameters.

The transit times reported in the 1955 O–D showed such great variation that it was impossible to develop general rules for adjusting the tree times obtained from the transit network prepared from schedules. As there was no apparent bias in the use of tree times, O–D times sometimes being less than and sometimes greater than tree times, the schedule times were utilized in this test.

Transit fare matrix

The modal split procedure requires input information that will provide the zone-to-zone cost via transit. It was obvious that if all 400 zones were considered, a matrix having 160,000 entries would be required. Because many zone-to-zone movements have similar costs, larger areas—termed superzones—can usually be used for this representation. For this test, the 68 districts of the 1955 O–D survey were used.

Transit transfer matrix

The excess traveltime for a transit trip includes the time spent transferring between vehicles. Again, as for the fare matrix, a determination of these times for each zone-to-zone movement would have been a most time-consuming task. Many district-to-district transfer times were already available from the work accomplished in the development of the modal split relationships. The coded transit system provided the necessary detail for the computation of the remaining transfer times. Transfer times were determined by tracing the most logical route(s) between pairs of districts and accumulating one-half the headway for each transit route to which a transfer was made. This procedure deviates from that used when the NCTA estimates were made of 1980 transit usage. For 1980, corridors of influence were drawn about the major radial transit lines, and the times to transfer between these corridors were determined and later expanded to zone-to-zone movements by the modal split program.

The results obtained from the work done by TRC in developing the modal split relationships were used as a general control on the procedure. That is, many of the transfer times available were recalculated for checking purposes and to provide a consistent means for developing the remaining transfer times.

During NCTA's calibration of the procedure to estimate 1980 transit usage, it appeared that illogical zonal trip interchanges by transit between areas outside the 10-mile square (see figure 2) had been estimated by the modal split procedure. To eliminate these illogical interchanges, excessively large transfer times had been entered into the transfer matrix for these movements. These excessive times tended to produce a travel-time ratio greater than ten, thereby producing a zero percent transit usage. To conform with this NCTA procedure, certain interchanges between areas outside the 10-mile square were also eliminated in the BPR test of the procedure against the 1955 O–D survey.

Zonal Parameters

Economic status

TRC, in the development of the modal split relationships, calculated the median 1955 income per worker. As travelers' incomes were not reported in the 1955 O–D survey, average district incomes were calculated from 1950 and 1960 census reports and converted to median income per worker. This calculation was made by multiplying the census income per dwelling unit by the ratio of dwelling units per worker from the expanded household data obtained in the 1955 home interview survey (*6*). The results obtained for district incomes are tabulated in volume II of the TRC reports. These reported incomes were used directly for the Public Roads test after they were coded into the five economic status groups.

Parking costs

Average parking costs are required for inclusion in the cost ratio in the modal split procedure. As every trip is considered to have a return portion, only one-half of the parking cost was assessed at the destination end when the cost ratio was calculated. The parking costs for 1980 were developed basically for work trips. To obtain an estimate of parking costs for nonwork trips, costs calculated for work trips were divided by two. Parking costs were assessed only for zero sector destinations and were developed for each zone. The 1955 average automobile parking costs were obtained for each of the nine zero sector districts by determining the weighted average cost of commercial and government parking facilities in each district.

Car occupancy

Car occupancy rates are required by the modal split procedure for two reasons: In calculating automobile costs for each zone-to-zone movement, the sum of the automobile operating costs and one-half of the total daily parking rate was divided by the number of persons per vehicle to obtain an average automobile travel cost per person. Although the modal split program allows the use of car occupancy at the origin and/or destination, destination car occupancy rates were used in the Public Roads test because they were the rates used in the NCTA estimate for 1980. Car occupancy rates also were used to convert the person trip output from the modal split technique to automobile driver trips. As car occupancy rates for 1980 were developed on a district basis, district rates also were used for the test. These rates were developed by TRC by a special run of the 1955 O–D data through available summary programs.

Walking time

Walking times from parking places to destinations were developed on a district basis for the 1980 estimate and for the development of the modal split technique. One minute walking time was used for every district outside the zero sector. For zero sector districts, the district walking times from parking places to destinations, which had been used by TRC for curve development, were used for this test. All walking time was calculated from blocks reported as walked in the travel surveys.

Parking delay time

For curve development, and in the tests with the 1955 O–D data, parking delay times were based on delays of 1 minute at government parking lots and garages and of 2 minutes at public and private lots and garages—weighted averages were used for each zero sector district (*6*). A 1-minute time was used for each district outside the zero sector.

Transit waiting times

For both the curve development with 1955 data and the 1980 application of the procedure, transit waiting times were determined from a map showing all transit routes, vehicle headways, and transfer points. In general, one-half the average headway of the transit facility serving a zone was used where only one facility served the area. The modal split program allows only one figure as the average transit waiting time for the passengers of each zone. For this reason, the zonal transit waiting times were calculated by utilizing the peak hour transit network, which had been coded for this test. These zonal estimates were averaged by district for comparison with the district waiting times used by TRC for curve development; when different, adjustments were made to the zonal estimates.

Transit walking time

Average walking times to and from transit stops in each zone were determined in a systematic manner based on empirical formulas in the initial development of the modal split technique (*6*). For the 1980 estimates of transit usage, the walking times were obtained from an analysis of the relationship between the location of each zone centroid and the transit routes available in the zone. This latter relationship was used for developing walking times by zone for this test. Again, the average transit walking time obtained for a district for use in this test was compared with the district times used in the development of the modal split tech-

Table 1.—Results of modal split procedure applied to entire study area

Trip	1955 O–D data	BPR test estimates	Percentage point difference	Percent trip difference
Work:				
All modes	389, 301. 0	389, 301. 0	----------	----------
Transit passenger	131, 066. 2	123, 305. 2	----------	−5. 9
Percent transit usage	33. 7	31. 8	−1. 9	----------
Nonwork:				
All modes	30, 294. 0	30, 294. 0	----------	----------
Transit passenger	5, 614. 4	7, 040. 8	----------	+25. 4
Percent transit usage	18. 5	23. 0	+4. 5	----------
TOTAL:				
All modes	419, 595. 0	419, 595. 0	----------	----------
Transit passengers	136, 680. 6	130, 346. 0	----------	−4. 6
Percent transit usage	32. 6	31. 1	−1. 5	----------

Table 2.—Modal split to zero sector (excludes intrazero sector trips)

Trip	1955 O–D data	BPR test estimates	Percentage point difference	Percent trip difference
Work:				
All modes	171, 329. 9	171, 329. 9	----------	----------
Transit passenger	76, 723. 9	75, 678. 0	----------	−1. 36
Percent transit usage	44. 8	44. 2	−0. 6	----------
Nonwork:				
All modes	5, 141. 0	5, 141. 0	----------	----------
Transit passenger	2, 203. 5	2, 410. 0	----------	+9. 37
Percent transit usage	42. 9	46. 9	+4. 0	----------
TOTAL:				
All modes	176, 470. 9	176, 470. 9	----------	----------
Transit passengers	78, 927. 4	78, 088. 0	----------	−1. 06
Percent transit usage	44. 7	44. 2	−0. 5	----------

Table 3.—Modal split to nonzero sector destination

Trip	1955 O–D data	BPR test estimates	Percentage point difference	Percent trip difference
Work:				
All modes	203, 942. 8	203, 942. 8	----------	----------
Transit passenger	45, 529. 4	38, 459. 2	----------	−15. 53
Percent transit usage	22. 3	18. 9	−3. 4	----------
Nonwork:				
All modes	22, 776. 6	22, 776. 6	----------	----------
Transit passenger	2, 607. 1	3, 423. 9	----------	+31. 33
Percent transit usage	11. 4	15. 0	+3. 6	----------
TOTAL:				
All modes	226, 719. 4	226, 719. 4	----------	----------
Transit passengers	48, 136. 5	41, 883. 1	----------	−12. 99
Percent transit usage	21. 2	18. 5	−2. 7	----------

nique. Adjustments were made when necessary. These transit walking times were applied at both the origin and destination of a trip.

Single Parameters

The modal split procedure requires that certain constants be specified. The constants used for the test are, as follows: Cost per gallon of gasoline, 29.5 cents: cost of oil change and lubrication, $2.85; miles between oil change and lubrication, 1,000. These are the same constants used for curve development. The coefficients used in the equations (*6*) for the calculation of car operating costs are the same as those used for development of the modal split technique. The modal split relationships used by Public Roads were the same relationships used for NCTA's 1980 estimates. Other than as heretofore explained, all parameters used in the Public Roads test were the same as those used for the 1980 transit usage estimates (*6*).

Results

The data described in the foregoing paragraphs were used as input to the modal split computer program to obtain an estimate of zone-to-zone transit usage. This estimate was obtained by applying the modal split technique to the total person trip file. These estimates of zone-to-zone transit usage could then be compared with the transit usage observed from the 1955 O–D survey. These comparisons are shown in tables 1 through 8.

Modal split to entire area—table 1

The number of transit work trips for the entire area obtained by application of the modal split procedure to the 1955 O–D survey data was 5.9 percent less than the actual number reported in the survey. The modal splits differed by 1.9 percentage points: Transit work trips reported in the 1955 O–D survey were 33.7 percent of total usage and those estimated by application of the procedure were 31.8 percent. A greater difference between the actual 1955 data and the test data was obtained for nonwork trips, but this difference was an overestimate of 25.4 percent by application of the modal split technique. Total trips via transit were underestimated by 4.6 percent—a 1.5 percentage point difference.

Estimates of citywide transit trips based on relationships developed from actual data would be expected to correspond closely to the base data. In this test the procedure reproduced the base data reasonably well for work trips. However, the modal split technique produced a nonwork trip figure showing a larger difference from the actual data than should be acceptable on a citywide basis. This was true although the volume of nonwork trips was relatively small in comparison to the number of work trips. The difference in test results and actual data for nonwork trips might have been caused by the following listed conditions. (1) The nonwork trip curves were developed from data for offpeak traffic hours but applied to the peak hour traffic. (2) Input parameters were highly oriented to work trips. The only input variable changed for the nonwork trips was the parking cost, and this was estimated to be equal to one-half of the parking costs for work trips. Other variables such as car occupancy, walking times, parking delay time, etc., generally were developed for peak hour work trips but were applied unchanged to nonwork trips.

Modal split to zero sector—table 2

The test with the modal split to the zero sector reproduced the 1955 O–D transit usage remarkably well for work trips. The nonwork trip test estimate differs from the O–D transit usage by +9.37 percent. From the data in tables 1 and 2, the following conclusions might be drawn:

As the modal split relationships for the test were developed almost entirely from zero sector oriented trips, it would be expected that such trips would have been reproduced more accurately than nonzero sector destination trips. Only about 100 nonzero sector interchanges were considered when the modal split relationships were developed.

The modal split technique was more accurate for estimating work trips than nonwork trips because the work-trip input data were developed from and applied to peak-hour traffic conditions; whereas, the nonwork trip data were applied to the peak-hour traffic but had been developed from nonpeak-hour traffic conditions.

Application of nonwork relationships to the peak traffic hours implied that relationships established for any period of the day could be used satisfactorily with the modal split technique. The results obtained in the test against the 1955 O–D data did not substantiate this implication. Therefore, further stratification of data for the input curves by destination—downtown separate from nondowntown—and time of day may be warranted.

(*Continued on page 12*)

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STATE LEGAL MAXIMUM DIMENSIONS AND WEIGHTS C

Prepared by th

Dece

Line	State	Width inches[1]	Height ft.-in.	Length-feet[2]: Single unit: Truck	Single unit: Bus	Single unit: Semi-trailer or trailer	Truck tractor semi-trailer	Other combination	Number of towed units[3]: Semi-trailer	Full trailer	Semi-trailer and full trailer	Axle load-pounds: Single: Statutory limit	Single: Including statutory enforcement tolerance	Tandem: Statutory limit	Tandem: Including statutory enforcement tolerance	Operating tire inflation pressure pounds per sq. in.	Pounds per engine net horsepower delivered to clutch or equivalent
1	Alabama	96	13-6	40	40	NS	55	NP	1	NP	NP	18,000	19,800	36,000	39,600	NS	NS
2	Alaska	96	12-6	35	[6]40	[7]40	60	60	1	1	2	18,000		32,000		NS	NS
3	Arizona	96	13-6	40	40	NS	65	65	1	1	2	18,000		32,000		NS	NS
4	Arkansas	96	13-6	40	40	NS	55	55	1	1	NP	[8]18,000		32,000		NS	NS
5	California	96	13-6	35	[9]35	[7]40	60	65	NR	NR	NR	18,000		32,000		NS	NS
6	Colorado	[10]96	[11]13-6	35	40	NR	60	[12]60	1	2	2	18,000		36,000		NS	NS
7	Connecticut	102	12-6	50	50	NR	50	NP	1	NP	NP	22,400	22,848	36,000	36,720	NS	NS
8	Delaware	96	13-6	40	42	40	55	60	1	1	NP	20,000		36,000		NS	NS
9	Florida	96	13-6	[13]35	40	[14]NS	55	55	1	1	NP	20,000	22,000	40,000	44,000	NS	NS
10	Georgia	96	13-6	[15]+39	[15]+45	NR	50	50	1	1	NP	18,000	20,340	36,000	40,680	NS	NS
11	Hawaii	108	13-0	40	40	NR	55	65	1	1	2	24,000		32,000		NS	NS
12	Idaho	[10]96	14-0	[18]35	[18]35	NR	[19]60	65	1	1	2	[20]18,000		[20]32,000		NS	NS
13	Illinois	96	13-6	42	42	42	[21]55	[22]60	1	1	2	[23]18,000		32,000		NS	NS
14	Indiana	[10]96	13-6	36	40	NR	55	[21]55	1	1	2	[25]18,000	[25]19,000	[25]32,000	[25]33,000	NS	NS
15	Iowa	96	13-6	35	[6]40	[7]NS	[26]55	[26]55	1	1	2	18,000	18,540	32,000	32,960	NS	NS
16	Kansas	96	13-6	35	[6]40	NS	50	50	1	1	NP	18,000		32,000		NS	NS
17	Kentucky	96	[11]13-6	[27]35	[27]35	NR	[28]50	[28]50	1	1	NP	18,000	[29]18,900	[29]32,000	33,600	NS	NS
18	Louisiana	96	13-6	35	[6]40	NR	55	60	1	1	NP	18,000		32,000		NS	NS
19	Maine	102	[31]13-6	55	55	NR	55	55	1	1	NP	[31]22,000		[31]32,000		NS	NS
20	Maryland	[32]96	[33]12-6	55	55	NR	55	[34]55	NR	NR	NR	22,400		[35]40,000		NS	NS
21	Massachusetts	96	NS	35	[6]40	NR	50	NP	1	NP	NP	22,400		36,000		NS	NS
22	Michigan	96	13-6	35	40	40	55	55	1	1	2	[37]18,000		[38]32,000		NS	NS
23	Minnesota	96	13-6	40	40	40	50	50	1	1	NP	18,000		32,000		NS	NS
24	Mississippi	96	13-6	35	40	NR	55	55	1	1	NP	18,000		28,650	[22]32,000	NS	NS
25	Missouri	96	12-6	35	40	NR	50	50	1	1	2	18,000		32,000		NS	NS
26	Montana	[10]96	13-6	35	40	NR	60	60	1	1	2	18,000		32,000		NS	NS
27	Nebraska	96	13-6	40	40	[39]NR	60	60	1	1	2	18,000	18,900	32,000	33,600	NS	NS
28	Nevada	96	NR	NR	NR	NR	NR	NR	NR	NR	NR	18,000	18,900	32,000	33,600	NS	NS
29	New Hampshire	96	13-6	35	[22]40	NR	55	55	NR	NR	NR	22,400		36,000		NS	NS
30	New Jersey	[41]96	[41]13-6	35	[42]35	[7]40	53	50	1	1	NP	22,400	23,520	32,000	33,600	NS	NS
31	New Mexico	[43]96	13-6	40	40	NR	65	65	1	1	2	21,600		34,320		NS	NS
32	New York	96	[33]13-0	35	[44]35	[7]NR	50	50	1	1	NP	22,400		36,000		NS	NS
33	North Carolina	96	13-6	35	[6]40	NR	55	55	1	1	NP	18,000	19,000	36,000	38,000	NS	NS
34	North Dakota	[41]96	[41]13-6	[13]35	[6]40	NR	60	60	1	1	2	18,000		32,000		NS	NS
35	Ohio	96	13-6	35	[6]40	[7]40	55	60	1	NR	NR	19,000		31,500		NS	NS
36	Oklahoma	96	13-6	35	45	NR	[45]50	[45]50	1	1	NP	18,000		32,000		NS	NS
37	Oregon	96	[11]13-6	35	[22]40	[22]40	[21]55	[22]65	1	1	[22]2	[46]18,000		[46]32,000		NS	NS
38	Pennsylvania	96	[33]12-6	35	40	40	[48]50	[34]50	1	1	NP	22,400	23,072	36,000	37,080	NS	NS
39	Rhode Island	102	12-6	40	40	40	50	50	1	1	NP	22,400		NS		NS	NS
40	South Carolina	96	13-6	40	[6]40	NR	55	[54]60	1	1	NP	20,000		[55]32,000		NS	NS
41	South Dakota	96	13-6	35	40	NR	[22]65	[22]65	1	1	2	18,000		32,000		NS	NS
42	Tennessee	96	13-6	35	40	[7]NS	50	50	1	[56]1	NP	18,000		32,000		NS	NS
43	Texas	96	13-6	35	40	NS	50	50	1	1	NP	18,000		32,000		NS	NS
44	Utah	96	14-0	45	45	45	60	60	NR	NR	NR	18,000		33,000		NS	NS
45	Vermont	96	13-6	50	50	NS	55	55	1	1	NP	22,400	23,520	[57]36,000		NS	NS
46	Virginia	96	13-6	35	40	NR	50	50	1	1	NP	18,000		[58]32,000		NS	NS
47	Washington	96	13-6	35	[6]40	40	[19]60	65	1	1	2	18,000		32,000		NS	NS
48	West Virginia	96	[33]12-6	35	[6]40	35	50	50	1	1	NP	18,000	18,900	32,000	33,600	NS	NS
49	Wisconsin	96	13-6	35	40	35	55	55	1	1	NP	18,000	[60]19,500	30,400	32,000	NS	NS
50	Wyoming	96	13-6	40	40	NR	65	65	1	1	2	18,000		32,000	[62]36,000	NS	NS
51	District of Columbia	96	12-6	40	40	NS	50	50	1	1	NP	22,000		38,000		NS	NS
52	Puerto Rico	96	12-6	35	40	NS	50	50	1	1	NP	NS		NS		NS	NS
	AASHO Policy	102	13-6	40	40	40	55	65	1	1	2	20,000		32,000		95	400
	Number of States: Higher	1	4	7	10	35	14	1	5	7	6	16		26		52	52
	Number of States: Same	3	37	12	37	7	20	9	47	42	18	2		25		0	0
	Number of States: Lower	48	11	33	5	10	18	42	0	3	28	34		1		0	0

NP–Not permitted. NR–Not restricted. NS–Not specified.

[1] Various exceptions for farm and construction equipment; public utility vehicles; house trailers; urban, suburban, and school buses; haulage of agricultural and forest products; at wheels of vehicles for safety accessories, on designated highways, and as administratively authorized.

[2] Various exceptions for utility vehicles and loads, house trailers and mobile homes.

[3] When not specified, limited to number possible in practical combinations within permitted length limits; various exceptions for farm tractors, mobile homes, etc.

[4] Legally specified or established by administrative regulation.

[5] Computed under the following conditions to permit comparison on a uniform basis between States with different types of regulation:

A. Front axle load of 8,000 pounds.

B. Maximum practical wheelbase within applicable length limits:

(1) Minimum front overhang of 3 feet; minimum spacing from first to second axle of truck tractor 8 feet.

(2) In the case of a 4-axle truck-tractor semitrailer, rear overhang computed as necessary to distribute the maximum possible uniform load on the maximum permitted length of semitrailer to the single drive-axle of the tractor and to the tandem axles of the semitrailer, within the permitted load limits of each.

(3) In the case of a combination having 5 or more axles, minimum possible combined front and rear overhang assumed to be 5 feet, with maximum practical load on maximum permitted length of semitrailer, subject to control of loading on axle groups and on total wheelbase as applicable.

C. Including statutory enforcement tolerance as applicable.

[6] Less than three axles 35 feet.

[7] Trailer 35 feet.

[8] Steering axle 12,000 pounds.

[9] On specific routes in urban or suburban service under special permit from P.U.C. 40 feet, also 3-axle buses with turning radius less than 45 feet without restriction.

[10] Buses 102 inches on highways of surfaced width at least 20 feet or otherwise as administratively authorized.

[11] On class AA, or designated highways, 12 ft. 6 in. on other highways; log and lumber trucks limited to 12 ft. 6 in. on all highways in Oregon.

[12] Except 3-unit combinations may use up to 65 ft. combinations on certain highways designated by the Department of Highways.

[13] Three-axle vehicles 40 feet.

[14] Two-axle trailer 35 feet, three-axle trailer 40 feet.

[15] Truck 39.55 feet; bus 45.20 feet.

[16] 63,280 pounds maximum, except on roads under Rural

[17] 700 (L + 40) when L is 18' or less; 800 (L + 40) when span of 20' or over.

[18] On designated highways 40 feet.

[19] Auto transports on designated highways 65 feet.

[20] Special limits for vehicles hauling timber and timber livestock; single axle 18,900 pounds, tandem axle 37,800 po pounds maximum at 21-foot axle spacing, vehicle with 5 or m

[21] 60 ft. in special cases: Illinois, auto transports on trailers on designated major routes.

[22] On designated highways only.

[23] On designated highways, 16,000 pounds on other hi

[24] Axle spacing 44 feet or more; otherwise 72,000 pou

[25] On designated highways; single axle 22,400 pounds, of weight under one or more limitations of axle load and gro axle.

[26] Auto and boat transports and three-unit combination wise 50 feet.

[27] On designated highways, trucks 26.5 feet and buses

[28] Class AA highways; 45 feet on other highways.

[29] Class AA highways only.

[30] Maximum gross weight on Class A highways 42,000

[31] Including load 14 feet, various exceptions for vehic

[32] Vehicles loaded with tobacco hogsheads–103 inche

[33] Auto transports 13 feet 6 inches; Maryland also all flat glass.

[34] Exception for poles, pilings, structural units, rowi

[35] Less than 48-inch spacing, 36,000 pounds.

[36] Subject to axle and tabular limits.

[37] Single axle spaced less than 9 feet from nearest ax

...TOR VEHICLES COMPARED WITH AASHO STANDARDS

... of Public Roads

... 1963

...s weight limit			Specified maximum gross weight-pounds[4]						Practical maximum gross weight-pounds[5]						
	Applicable to:		Truck		Truck-tractor semitrailer				Truck		Truck-tractor semitrailer				
... of ...tion	Any group of axles	Total wheel-base only	2-axle	3-axle	3-axle	4-axle	5-axle	Other combi-nation	2-axle	3-axle	3-axle	4-axle	5-axle	Other combi-nation	Line
		X					73,280		27,800	47,600	47,600	67,400	73,280	NP	1
...ap.	Under 18'	Over 18'	36,000	50,000	50,000	72,000	76,800	76,800	26,000	40,000	44,000	58,000	72,000	76,800	2
	Under 18'	Over 18'							26,000	40,000	44,000	58,000	72,000	76,800	3
...um									26,000	40,000	44,000	58,000	72,000	73,280	4
	Under 18'	Over 18'							26,000	40,000	44,000	58,000	72,000	76,800	5
...c. lim.		X							26,000	44,000	44,000	62,000	76,000	76,000	6
...re cap.			32,000	53,800	53,800	67,400	73,000	NP	30,848	44,720	53,800	67,400	73,000	NP	7
... lim.	X		30,000	46,000	48,000				28,000	44,000	48,000	64,000	73,280	73,280	8
		X							30,000	52,000	52,000	73,271	73,271	73,271	9
...6								63,280	28,340	48,680	48,680	63,280	63,280	63,280	10
	X								32,000	40,000	56,000	64,000	72,000	80,000	11
	X								26,000	40,000	44,000	58,000	73,280	76,800	12
...ire cap.			' 36,000	50,000	50,000	64,000	[24]73,280	[24]73,280	26,000	40,000	44,000	58,000	72,000	73,280	13
...ire cap.			36,000	50,000	54,000			72,000	27,000	41,000	45,000	59,000	[25]73,000	[25]73,000	14
	X								26,540	40,960	45,080	59,500	73,280	73,280	15
	X								26,000	40,000	44,000	58,000	72,000	73,280	16
...ire cap [30]			27,000	42,000	42,000	59,640	73,280	NP	27,000	42,000	42,000	59,640	73,280	73,280	17
...e cap.									26,000	40,000	44,000	58,000	72,000	76,000	18
...ap.	X		32,000	[31]51,800	51,800	62,050	73,280	73,280	30,000	40,000	51,800	62,000	72,000	73,280	19
		X			[36]65,000	[36]73,280	[36]73,280	[36]73,280	30,400	48,000	52,800	70,400	73,280	73,280	20
... lim.			[36]46,000	[36]60,000	[36]60,000	[36]73,000	[36]73,000	NP	30,400	44,000	52,800	66,400	73,000	NP	21
...e cap.									26,000	[22]40,000	44,000	[22]58,000	[22]66,000	[22]102,000	22
	X						73,280	73,280	26,000	40,000	44,000	58,000	72,000	73,280	23
...ap.	X								26,000	[22]40,000	44,000	58,000	[22]64,650	[22]73,280	24
	X								26,000	40,000	44,000	58,000	[22]72,000	[22]73,280	25
	Under 18'	Over 18'							26,000	40,000	44,000	58,000	72,000	76,000	26
	X		36,000	54,000	54,000	71,146	71,146	71,146	26,780	41,200	45,320	59,740	73,280	73,280	27
	Under 18'	Over 18'							26,900	41,600	45,800	60,500	75,200	76,800	28
... lim.		X	33,400	[40]55,000	[40]55,000	66,400	73,280	73,280	30,400	44,000	52,800	66,400	73,280	73,280	29
...re cap.									31,520	41,600	55,040	65,120	73,280	73,280	30
	Under 18'	Over 18'							29,600	42,320	51,200	63,920	76,640	86,400	31
		X					71,000	71,000	30,400	44,000	52,800	66,400	71,000	71,000	32
			31,500	49,875	49,875	67,200	73,280	73,280	27,000	46,000	46,000	65,000	73,280	73,280	33
	Under 18'	Over 18'							26,000	40,000	44,000	58,000	72,000	73,280	34
		X							27,000	39,500	46,000	58,500	71,000	78,000	35
	X								26,000	40,000	44,000	58,000	72,000	73,280	36
	Under 18'	Over 18'					[47]76,000	[47]76,000	26,000	40,000	44,000	58,000	72,000	[47]76,000	37
...9			33,000	47,000	50,000	60,000	71,145	71,145	31,072	45,080	51,500	61,800	73,280	73,280	38
			[50]36,000	[51]44,000	[52]53,800	[53]67,400	73,280	88,000	30,400	44,000	53,800	67,400	73,280	88,000	39
			32,000	46,000	50,000	65,000	73,280	73,280	28,000	40,000	48,000	60,000	72,000	73,280	40
	X								26,000	40,000	44,000	56,000	72,000	73,280	41
		X		44,000	48,000	62,000	73,280		26,000	40,000	44,000	58,000	72,000	43,500	42
	X								26,000	40,000	44,000	58,000	72,000	72,000	43
	X		36,000	51,000	54,000	69,000	79,900	79,900	26,000	41,000	44,000	59,000	74,000	79,900	44
...cap.	X						73,280	73,280	31,520	44,000	55,000	66,400	73,280	73,280	45
	X						70,000	70,000	26,000	40,000	44,000	60,000	70,000	70,000	46
	Under 18'	Over 18'	28,000	36,000	46,000	60,000	68,000	72,000	26,000	36,000	44,000	60,000	68,000	72,000	47
	X					[59]70,000	[59]70,000	[59]70,000	26,900	41,600	45,800	60,500	73,280	73,280	48
	X								27,500	40,000	47,000	59,500	73,000	73,000	49
	X								26,000	44,000	44,000	62,000	73,950	73,950	50
...cap.	X					70,000	70,000	70,000	30,000	46,000	52,000	68,000	70,000	70,000	51
...tire cap.															52
	X								28,000	40,000	48,000	60,000	72,000	86,500	
5 32 15	20	17							15 2 34	25 24 2	15 2 34	22 3 26	24 19 8	2 0 49	

...hority 56,000 pounds maximum.
... than 18'; 900(L + 40) on highways having no structures with

...s, concentrates, aggregates, and agricultural products including
...weight table: vehicle with 3 or 4 axles permitted 66,000
...rmitted 79,000 pounds maximum at 43-foot axle spacing.
...trucks pulling house trailers only; Oregon, truck tractor semi-

...36,000 pounds; tolerance of 1,000 pounds on total of all excesses
...epending upon the placing of 9000# on the front or steering

...50 feet on highways with surface width 22 feet or more; other-

...other highways.

...Class B highways 30,000 pounds.
...forest products and construction materials.

... inches for vehicles loaded with hay or straw, or carrying

..., permitted 70 feet.

... 13,000 pounds.

38 On designated highways only and limited to one tandem axle in combination; otherwise 26,000 pounds.
39 Trailer 40 feet.
40 On Interstate System 47,500 pounds.
41 Vehicles in excess may be operated under special permit obtained in advance; in New Jersey from the Department of Motor Vehicles; in North Dakota, from State Highway Truck Regulatory Department.
42 Or as prescribed by P.U.C.
43 On designated highways 102 inches. Body restricted to 96", additional 6" for tires only.
44 Trackless trolleys and buses 7 passengers or more, P.S.C. certificate 40 feet.
45 Auto transports, oil field equipment, by special permit only, 60 feet.
46 Logging vehicles permitted 7-foot wheelbase tolerance, 19,000-single axle, 34,000-pounds tandem axle.
47 Governs gross weight permitted on highways designated by resolution of State highway commission.
48 Where truck-tractor was properly registered in Pennsylvania as of December 31, 1961, 55 feet.
49 Single unit truck with 4 axle permitted 60,000 pounds.
50 Axles spaced less than 6 feet 32,000 pounds; less than 12 feet 36,000 pounds; 12 feet or more gross weight governed by axle limit.
51 Single vehicle with 3 or more axles spaced less than 16 feet 40,000 pounds, less than 20 feet 44,000 pounds; 20 feet or more governed by axle limit.
52 Tractor semitrailer with 3 or more axles spaced less than 22 feet 46,000 pounds, not less than 27 feet 53,800 pounds.
53 Legal limit 67,400 pounds, axle spacing 27 feet or more.
54 House trailers only, otherwise 55 feet.
55 On Interstate System, 36,000 pounds on other roads.
56 Limited to 3,500 pounds.
57 Three-axle tandem 42,700 pounds.
58 Vehicles registered before July 1, 1956, permitted limits in effect January 1, 1956, for life of vehicle.
59 Only on certain highways, or portions thereof, designated by State Roads Commissioner, and consistent with Congressional action.
60 Axle load 21,000 pounds on 2-axle trucks hauling peeled or unpeeled forest products cut crosswise or transporting milk from farm to market but not over Interstate System.
61 On Class A highways. All axles of a vehicle or combination—73,000 pounds maximum. Wheel, axle, axle group and gross vehicle weights on Class B highways are 60% of weights including tolerance authorized for Class A highways.
62 Based on ruling of Attorney General.

Evaluation of a New Modal Split Procedure

(*Continued from page 9*)

Table 4.—Modal split from each corridor to CBD

Sector (origin)	All modes	1955 O-D data: Transit trips	1955 O-D data: Percent transit usage	BPR test estimates: Transit trips	BPR test estimates: Percent transit usage	Percentage point difference	Percent trip difference
A—WORK TRIPS							
			Percent		*Percent*	*Percent*	*Percent*
0	14, 028. 3	8, 807. 9	62. 8	9, 168. 0	65. 4	+2. 6	+4. 1
1	9, 529. 9	5, 114. 1	53. 7	4, 407. 3	46. 2	−7. 5	−13. 8
2	25, 231. 3	9, 209. 5	36. 5	8, 428. 8	33. 4	−3. 1	−8. 5
3	45, 720. 9	23, 748. 7	51. 9	25. 337. 6	55. 4	+3. 5	+6. 7
4	24, 291. 8	9, 948. 0	41. 0	10, 948. 0	45. 1	+4. 1	+10. 1
5	12, 348. 1	6, 199. 9	50. 2	6, 484. 1	52. 5	+2. 3	+4. 6
6	21, 119. 2	10, 272. 4	48. 6	10, 569. 9	50. 0	+1. 4	+2. 9
7	15, 750. 7	6, 315. 9	40. 1	4, 922. 6	31. 3	−8. 8	−22. 1
8	17, 338. 0	5, 915. 4	34. 1	4, 579. 7	26. 4	−7. 7	−22. 6
B—NONWORK TRIPS							
0	2, 376. 4	803. 8	33. 8	1, 206. 9	50. 8	+17. 0	+50. 2
1	240. 7	67. 2	27. 9	91. 1	37. 8	+9. 9	+35. 6
2	601. 2	108. 8	18. 1	142. 6	23. 7	+5. 6	+31. 1
3	1, 663. 8	821. 1	49. 4	969. 8	58. 3	+8. 9	+18. 1
4	626. 8	326. 2	52. 0	354. 8	56. 6	+4. 6	+8. 9
5	569. 5	369. 5	64. 9	306. 6	53. 8	−11. 1	−17. 0
6	712. 4	339. 8	47. 6	355. 6	49. 9	+2. 3	+4. 7
7	368. 8	105. 5	28. 6	140. 8	38. 2	+9. 6	+33. 0
8	357. 8	65. 4	18. 3	48. 7	13. 6	−4. 7	−26. 0
C—WORK AND NONWORK TRIPS							
0	16, 404. 7	9, 611. 7	58. 6	10, 374. 9	63. 2	+4. 6	+7. 9
1	9, 770. 6	5, 181. 3	53. 0	4, 498. 4	46. 0	−7. 0	−13. 2
2	25, 832. 5	9, 318. 3	36. 1	8, 571. 4	33. 2	−2. 9	−8. 0
3	47, 384. 7	24, 569. 8	51. 9	26, 307. 4	55. 5	+3. 6	+7. 1
4	24, 918. 6	10, 274. 2	41. 2	11, 302. 8	45. 4	+4. 2	+10. 0
5	12, 917. 6	6, 569. 4	50. 9	6, 790. 7	52. 6	+1. 8	+3. 4
6	21, 831. 6	10, 612. 2	48. 6	10, 925. 5	50. 0	+1. 4	+3. 0
7	16, 119. 5	6, 421. 4	39. 8	5, 063. 4	31. 4	−8. 4	−21. 1
8	17, 695. 8	5, 980. 8	33. 8	4, 628. 4	26. 2	−7. 6	−22. 6

Modal split to nonzero sector destinations—table 3

Results of the analysis of test results obtained with the modal split technique for nonzero sector destinations strengthens the conclusions reached from data shown in tables 1 and 2. That is, estimates for zero sector trips were more reliable than estimates for nonzero sector trips.

Modal split from each corridor to the CBD—table 4

The amount of transit travel along individual corridors or sectors to the downtown area shows a greater dispersion than does the areawide test estimate. The sectors considered are shown in figure 2. An analysis of the test results indicated a geographical bias in the estimates of modal split for work trips. Sectors 1, 2, 7, and 8 are all west of a line set by Rock Creek Park and the Potomac River. For these sectors the estimates of transit trips were about 16 percent less than shown by the O-D data. For all sectors east of this line a 6-percent overestimate of transit trips was obtained with the modal split technique.

The nonwork trip dispersion was far greater than dispersion for work trips in this test, but the test result for the nonwork trips does not indicate the same geographical bias as the work trip estimate. The total estimate (work and nonwork) shows the same geographical bias as the estimate for the work trips because the number of nonwork trips was relatively small. Knowledge of the weakness of the modal split in providing reliable estimates for transit travel along corridors to the CBD is particularly important because it is these corridor movements that are used for system planning when transit usage must be estimated for some future period.

Modal split between survey area sectors—tables 5 and 6

The data on the modal split between survey area sectors were used in the development of the previously discussed tables. The test results for dispersion in trip estimation between sectors did not follow any clearly observable pattern. The tables are presented for reference purposes.

Analysis of district-to-district transit trips—tables 7 and 8

The zone-to-zone transit trip files for both the test estimated and O–D trips were summarized into district-to-district movements for the 68 districts within the 1955 O–D survey area. These movements were classified into volume groups, in accordance with the O–D survey movements, and compared. The statistical procedure used was the root-mean-square error analysis (7):

$$\text{RMS error} = \sqrt{\frac{\sum_{i=1}^{n} (\text{O-D} - \text{model})^2}{n}}$$

Where,

O–D = movement between pair of districts from O–D survey for a specified volume group.

model = movement between the same pair of districts from modal split procedure.

n = number of O–D pairs in volume group.

The percent root-mean-square error, equal to the root-mean-square error divided by the mean O–D volume for the volume group, was used as the measure of comparison to relate the accuracy of the test results obtained from the model to the O–D survey data and also to state the accuracy of the O–D survey volumes. The Washington, D.C., 1955 survey was made with an average dwelling unit sample of 6.2 percent. From the results of previous research (7), the percent RMS errors to be expected from such a sample were known. For both work and nonwork trips, the percent RMS error between the estimate of transit trips produced by the modal split technique and the 1955 O–D survey estimate of these trips is less than the error expected in the expanded 6.2 percent sample of survey volumes.

If the comparison had shown a greater error between O–D and modal split procedure transit trips than was shown between the O–D trips and actual trips, it could be stated that the estimate of actual transit trips made with the model was worse than the estimate made by the O–D survey. However, the results obtained only indicate that the variation between the O–D and model estimates was less than the variation in the survey. On this basis, the modal split procedure would appear to give reasonable results.

Trip length frequency

Figure 3 presents a comparison of trip length frequency distributions from the O–D survey and modal split estimates for work trips. The modal split procedure produced an average trip length estimate just slightly longer than that produced by the O–D survey, 24.6 and 23.5 minutes, respectively. The trip length distributions were in reasonably close agreement. A cumulative frequency by 10-minute increments is shown in table 9.

Sensitivity Tests

Sensitivity tests also were developed by Public Roads to assess the reliability of the procedure when input variables were changed. The effectiveness of the modal split procedure to realistically project changes that might occur in the input variables over a period of time were not assessed as part of the Public Roads evaluation previously described herein. As the 1955 O–D survey data were a primary source for development of the procedure, a test performed on the same data would asically indicate whether the procedure ould recreate the information from which t had been developed. The sensitivity tests ere made because the change in the modal plit that would be predicted if, for example, he headways on the transit system were alved, had not been measured, in the test gainst the 1955 O–D.

The tests made with the 1955 O–D data nd the sensitivity tests were made concurrently, this necessitated use of the 1980 NCTA stimates as a basis for the sensitivity tests. Data developed by the NCTA for 1980 were sed for all sensitivity tests, except for the hanges made in items selected for testing urposes. Only work trips were evaluated. This evaluation was made by using person trip stimates from 1980 land-use plan B (corridor lan). Inputs changed were: Transit fare, nedian income, automobile parking delay and valking time, transit waiting and transfer imes, parking costs, transit vehicle times, ighway vehicle times, parking costs in combination with automobile excess times, and ighway times in combination with parking osts and automobile trip walking times. In hese sensitivity analyses, feedback between he automobile and transit systems and the stimates of the usage of the systems was not onsidered. A complete account of these ests and the results is presented in the following paragraphs.

Procedure

The modal split computer program is designed to permit changes in input data with a minimum of effort. Certain parameters may be varied by changing a single constant on an input punch card, others require substitution of one input tape. As summarized, 13 runs of the model were made. Initially only one parameter was changed per run. In two of the last runs, several parameters were changed so that joint effects could be analyzed. Although the changes were not necessarily intended to reflect realistic changes in system operation, they were made so that justifiable conclusions could be drawn as to the effect of the change in a particular parameter on the estimated modal split.

Base—NCTA run 23

NCTA run 23 was used throughout the sensitivity analysis as a base for comparison purposes. It was the final run for the 1980 NCTA plan B (corridor plan) morning peak traffic hour (7:30-8:30) work trips. The output data were NCTA's final estimate for this land-use plan and its recommended transportation system.

Sensitivity test *A*

For sensitivity test *A*, a 15-cent fare increase was applied to each zonal interchange. This change was accomplished by changing the transit fare matrix and rerunning the model; NCTA run 23 data were used for all other inputs.

Sensitivity test *B*

In sensitivity test *B*, the 1980 zonal incomes were factored by 1.5. This change effectively raised the median economic status areawide to 50 percent above the 1960 level. Because the 1980 income distribution is related to the 1980 land-use plan, the change (1960–1980) was not necessarily 50 percent for each zone.

Table 5.—Modal split between each of survey area sectors—work trips

Sector		All modes	1955 O–D data		BPR test estimates		Percentage point difference	Percent trip difference
Origin	Destination		Transit trips	Percent transit usage	Transit trips	Percent transit usage		
				Percent		*Percent*	*Percent*	*Percent*
0	0	14,028.3	8,807.9	62.8	9,168.0	65.4	+ 2.6	+ 4.1
0	1	1,304.7	803.4	61.6	483.1	37.0	−24.6	−39.8
0	2	2,704.8	1,611.8	59.6	965.1	35.7	−23.9	−40.1
0	3	3,408.6	1,956.1	57.4	1,491.0	43.7	−13.7	−23.8
0	4	2,151.4	1,163.8	54.1	818.8	38.1	−16.0	−29.6
0	5	1,158.9	501.2	43.2	434.5	37.5	− 5.7	−13.4
0	6	2,136.0	1,089.2	51.0	644.4	30.2	−20.8	−40.8
0	7	3,738.3	2,026.4	54.2	1,435.2	38.4	−15.8	−29.2
0	8	1,043.0	441.1	42.3	430.1	41.2	− 1.1	− 2.5
1	0	9,529.9	5,114.1	53.7	4,407.3	46.2	− 7.5	−13.8
1	1	1,455.6	149.9	10.3	284.2	19.5	+ 9.2	+89.4
1	2	1,492.4	156.0	10.5	126.8	8.5	− 2.0	−18.6
1	3	881.7	209.7	23.8	215.5	24.4	+ 0.6	+ 2.9
1	4	692.8	125.2	18.1	180.5	26.1	+ 8.0	+43.9
1	5	281.2	71.2	25.3	82.9	29.5	+ 4.2	+16.8
1	6	379.1	36.9	9.7	70.8	18.7	+ 9.0	+92.1
1	7	1,275.4	190.8	15.0	194.7	15.3	+ 0.3	+ 2.1
1	8	181.8	0.0	0.0	3.3	1.8	+ 1.8	-------
2	0	25,231.3	9,209.5	36.5	8,428.8	33.4	− 3.1	− 8.5
2	1	1,512.5	221.1	14.6	86.4	5.7	− 8.9	−61.0
2	2	8,518.3	340.8	40.0	56.7	0.7	−39.3	−83.3
2	3	4,185.9	119.0	2.8	137.4	3.3	+ 0.5	+15.1
2	4	1,650.0	10.3	0.6	112.9	6.8	+ 6.2	+1000.0
2	5	445.2	74.0	16.6	35.5	8.0	− 8.6	−51.4
2	6	1,117.9	148.4	13.3	124.1	11.1	− 2.2	−16.2
2	7	2,795.7	378.9	13.6	442.5	15.8	+ 2.2	+16.9
2	8	193.8	0.0	0 0	6.5	3.4	+ 3.4	-------
3	0	45,720.9	23,748.7	51.9	25,337.6	55.4	+ 3.5	+ 6.7
3	1	2,420.4	875.2	36.2	676.8	28.0	− 8.2	−22.6
3	2	58,961.1	1,670.8	2.8	1,125.5	1.9	− 0.9	−32.6
3	3	13,076.2	3,223.1	24.6	2,883.4	22.1	− 2.5	−10.5
3	4	4,628.5	786.3	17.0	803.0	17.3	+ 0.3	+ 2.2
3	5	1,513.1	338.9	22.4	515.7	34.1	+11.7	+52.2
3	6	4,224.9	1,063.0	25.2	1,373.7	32.5	+ 7.3	+29.2
3	7	6,726.1	2,180.9	32.4	2,926.3	43.5	+11.1	+34.2
3	8	951.8	241.3	25.4	263.8	27.7	+ 2.3	+ 9.1
4	0	24,291.8	9,948.0	41.0	10,948.0	45.1	+ 4.1	+10.1
4	1	1,118.1	217.2	19.4	251.0	22.4	+ 3.0	+15.6
4	2	2,412.1	524.4	21.7	524.8	21.8	+ 0.1	+ 0.0
4	3	4,715.7	847.7	18.0	930.4	19.7	+ 1.7	+ 9.8
4	4	10,517.3	1,391.4	13.2	725.2	6.9	− 6.3	−47.9
4	5	2,017.9	274.2	13.6	372.1	18.4	+ 4.8	+35.7
4	6	4,204.0	799.0	19.0	659.3	15.7	− 3.3	−17.5
4	7	3,324.5	582.6	17.5	957.4	28.8	+11.3	+64.3
4	8	392.2	68.8	17.5	107.9	27.5	+10.0	+56.7
5	0	12,348.1	6,199.9	50.2	6,484.1	52.5	+ 2.3	+ 4.6
5	1	789.2	417.0	52.8	273.5	34.7	−18.1	−34.5
5	2	1,255.6	624.0	49.7	391.9	31.2	−18.5	−37.2
5	3	2,468.3	950.6	38.5	1,001.5	40.6	+ 2.1	+ 5.4
5	4	3,378.9	881.0	26.1	742.4	22.0	− 4.1	−15.8
5	5	1,981.7	233.4	11.8	335.6	16.9	+ 5.1	+43.7
5	6	3,960.1	1,153.9	29.1	783.7	19.8	− 9.3	−32.1
5	7	2,528.8	606.6	24.0	931.2	36.8	+12.8	+53.6
5	8	342.5	114.0	33.3	71.7	20.9	−12.4	−36.8
6	0	21,119.2	10,272.4	48.6	10,569.9	50.0	+ 1.4	+ 2.9
6	1	908.2	286.1	31.5	332.0	36.6	+ 5.1	+16.1
6	2	1,689.9	689.2	40.8	616.4	36.5	− 4.3	−10.6
6	3	2,073.1	1,018.7	49.1	904.1	43.6	− 5.5	−11.3
6	4	2,530.9	693.0	27.4	595.2	23.5	− 3.9	−14.1
6	5	1,804.5	469.1	26.0	413.1	22.9	− 3.1	−11.9
6	6	10,869.1	1,545.7	14.2	2,131.9	19.6	+ 5.4	+37.9
6	7	3,623.6	582.9	16.1	1,054.3	29.1	+13.0	+80.8
6	8	353.5	112.0	31.7	65.2	18.4	−13.3	−42.0
7	0	15,750.7	6,315.9	40.1	4,922.6	31.3	− 8.8	−22.1
7	1	553.0	68.4	12.4	53.7	9.7	− 2.7	− 2.7
7	2	876.5	164.5	18.8	71.0	8.1	−10.7	−57.1
7	3	707.6	99.6	14.1	134.2	19.0	+ 4.9	+35.1
7	4	436.5	51.4	11.8	47.7	10.9	− 0.9	− 7.8
7	5	448.0	22.2	5.0	15.8	3.5	− 1.5	−27.0
7	6	1,884.1	107.0	5.7	127.2	6.8	+ 1.1	+18.7
7	7	20,788.9	4,955.0	23.8	2,242.2	10.8	−13.0	−54.8
7	8	2,405.4	158.4	6.6	81.4	3.4	− 3.2	−48.6
8	0	17,338.0	5,915.4	34.1	4,579.7	26.4	− 7.7	−22.6
8	1	911.0	102.4	11:2	19.0	2.1	− 9.1	−81.0
8	2	1,029.1	55.0	5.3	58.5	5.7	+ 0.4	+ 5.4
8	3	738.3	22.2	3.0	62.2	8.4	+ 5.4	+180.2
8	4	447.3	22.7	5.1	41.8	9.3	+ 4.2	+83.7
8	5	175.7	0.0	0.0	4.0	2.3	+ 2.3	-------
8	6	1,447.5	34.0	2.3	55.9	3.9	+ 1.6	+64.7
8	7	11,169.4	1,833.4	16.4	584.1	5.2	−11.2	−68.1
8	8	6,435.4	541.2	8.4	255.1	4.0	− 4.4	−52.8

Sensitivity test *C*

In sensitivity test *C*, 1 minute was added to both the parking delay time at the destination and the time spent walking from the parking space to the ultimate destination. These two items constitute the denominator (excess time via automobile) in the level of service ratio.

Sensitivity test *D*

The time spent waiting for transit in the origin zone and the time spent transferring between transit vehicles was factored by 1.5 in sensitivity test *D*. This was equivalent to a drastic cutback in transit service. This change had a large effect on the level of service ratio and a lesser effect on the traveltime ratio.

Sensitivity test *E*

Parking costs, which were applied only to zero sector zones, were doubled for sensitivity test *E*.

Sensitivity test *F*

In sensitivity test *F*, the transit vehicle traveltime between all zones was factored by 0.75, this in effect speeded up all transit vehicles.

Sensitivity test *G*

For sensitivity test *G*, the automobile time on the highway system was factored by 0.75, this in effect increased the speed of automobile travel between all zones.

Sensitivity test *H*

Transit fares were doubled for sensitivity test *H*. This run, which parallels sensitivity test *A*, was designed to evaluate the range of application of the cost ratio curves.

Sensitivity test *I*

The excess automobile times for 1980 were replaced in sensitivity test *I*, by the 1955 estimates of these times used for development of the modal split curves.

Sensitivity test *J*

The transit vehicle traveltime was factored by 1.5 in sensitivity test *J*.

Sensitivity test *K*

In sensitivity test *K*, the 1980 estimates of parking costs, parking delay time, and walking time to the ultimate destination from the parking place were replaced by 1955 O–D survey data used for the development of the relationships. This test was designed to determine the effect on transit usage caused by changes in automobile terminal conditions (1955–1980).

Sensitivity test *L*

In sensitivity test *L*, highway traveltimes were factored by 0.75, parking cost by 0.66, and walking time from the automobile parking place by 0.66. This test was designed to evaluate the effect of changes favorable to highway travel.

Sensitivity test *M*

Median incomes (1980) were factored by 1.2 for sensitivity test *M*. This run paralleled sensitivity test *B* and was designed to evaluate the procedure's sensitivity to a modest increase in median incomes.

Table 6.—Modal split between each of survey area sectors nonwork trips

Sector		All modes	1955 O–D data		BPR test estimates		Percentage point difference	Percent trip difference
Origin	Destination		Transit trips	Percent transit usage	Transit trips	Percent transit usage		
				Percent		*Percent*	*Percent*	*Percent*
0	0	2,376.4	803.8	33.8	1,206.9	50.8	+17.0	+50.2
0	1	112.4	0.0	0.0	39.3	35.0	+35.0	--------
0	2	224.6	39.8	17.7	110.2	49.1	+31.4	+176.9
0	3	650.5	372.0	57.2	343.3	52.8	−4.4	−7.7
0	4	251.1	40.3	16.0	146.2	58.2	+42.2	+262.0
0	5	204.2	74.9	36.7	87.9	43.0	+6.3	+17.4
0	6	339.4	75.4	22.2	156.5	46.1	+23.9	+107.6
0	7	199.7	63.8	31.9	152.3	76.3	+44.4	+138.7
0	8	141.6	0.0	0.0	65.1	46.0	+46.0	--------
1	0	240.7	67.2	27.9	91.1	37.8	+9.9	+35.6
1	1	407.7	0.0	0.0	1.2	0.3	+0.3	--------
1	2	258.7	0.0	0.0	8.0	3.1	+3.1	--------
1	3	10.8	0.0	0.0	0.0	0.0	0.0	--------
1	4	47.4	0.0	0.0	0.5	1.0	+1.0	--------
1	5	--------	--------	--------	--------	--------	--------	--------
1	6	--------	--------	--------	--------	--------	--------	--------
1	7	--------	--------	--------	--------	--------	--------	--------
1	8	59.3	0.0	0.0	0.2	0.0	0.0	--------
2	0	601.2	108.8	18.1	142.6	23.7	+5.6	+31.1
2	1	334.7	12.0	3.6	6.4	1.9	−1.7	−46.7
2	2	2,522.3	57.3	2.3	0.0	0.0	−2.3	--------
2	3	524.1	0.0	0.0	0.6	0.0	0.0	--------
2	4	131.5	0.0	0.0	0.0	0.0	0.0	--------
2	5	11.1	0.0	0.0	0.0	0.0	0.0	--------
2	6	10.0	0.0	0.0	0.0	0.0	0.0	--------
2	7	50.8	0.0	0.0	1.2	2.4	+2.4	--------
2	8	44.8	0.0	0.0	0.0	0.0	0.0	--------
3	0	1,663.8	821.1	49.4	969.8	58.3	+8.9	+18.1
3	1	75.2	35.6	47.3	42.6	56.6	+9.3	+19.7
3	2	297.7	0.0	0.0	38.2	12.8	+12.8	--------
3	3	3,113.5	356.0	11.4	399.4	12.8	+1.4	+12.2
3	4	402.6	68.6	17.0	99.8	24.8	+7.8	+45.6
3	5	131.1	76.1	58.0	94.5	72.1	+14.1	+24.2
3	6	204.4	155.6	76.1	66.2	32.4	−43.7	−57.5
3	7	139.3	0.0	0.0	48.5	34.8	+34.8	--------
3	8	11.3	0.0	0.0	0.0	0.0	0.0	0.0
4	0	626.8	326.2	52.0	354.8	56.6	+4.6	+8.9
4	1	9.9	0.0	0.0	0.0	0.0	0.0	--------
4	2	162.3	0.0	0.0	0.0	0.0	0.0	--------
4	3	808.4	92.7	11.5	223.1	27.6	+16.1	+140.8
4	4	1,668.5	57.3	3.4	67.9	4.1	+0.7	+19.2
4	5	133.5	0.0	0.0	17.1	12.8	+12.8	--------
4	6	168.5	0.0	0.0	50.7	30.1	+30.1	--------
4	7	31.8	0.0	0.0	7.4	23.2	+23.2	--------
4	8	39.0	39.0	100.0	28.8	73.8	−26.2	−25.6
5	0	569.5	369.5	64.9	306.6	53.8	−11.1	−17.0
5	1	11.6	0.0	0.0	0.1	0.0	0.0	--------
5	2	--------	--------	--------	--------	--------	--------	--------
5	3	221.3	77.8	35.2	67.5	30.5	−4.7	−12.8
5	4	319.8	33.6	10.5	148.0	46.3	+35.8	+339.3
5	5	458.4	71.8	15.7	2.9	0.6	−15.1	−96.1
5	6	315.5	11.6	3.7	20.7	6.6	+2.9	+77.6
5	7	50.7	0.0	0.0	25.6	50.5	+50.5	--------
5	8	33.6	0.0	0.0	26.4	78.5	+78.5	--------
6	0	712.4	339.8	47.6	355.6	49.9	+2.3	+4.7
6	1	39.8	39.8	100.0	3.6	9.0	−91.0	−90.5
6	2	57.4	11.4	19.9	11.1	19.3	−0.6	0.0
6	3	300.4	158.0	52.6	184.4	61.4	+8.8	+16.5
6	4	367.3	11.7	3.2	110.2	30.0	+26.8	+837.6
6	5	487.4	86.2	17.7	142.0	29.1	+11.4	+65.0
6	6	1,111.6	171.1	15.4	147.9	13.3	−2.1	−13.5
6	7	134.2	0.0	0.0	34.5	25.7	+25.7	--------
6	8	22.0	11.0	50.0	15.7	71.4	+21.4	+45.5
7	0	368.8	105.5	28.6	140.8	38.2	+9.6	+33.0
7	1	21.1	0.0	0.0	6.8	32.2	+32.2	--------
7	2	34.4	10.9	31.7	1.4	4.1	−27.6	−87.2
7	3	86.3	21.9	25.4	11.2	13.0	−12.4	−48.9
7	4	74.6	12.3	16.5	0.0	0.0	−16.5	−100.0
7	5	10.7	0.0	0.0	0.0	0.0	0.0	0.0
7	6	43.1	21.2	49.2	17.5	40.6	−8.6	−17.5
7	7	2,015.5	85.2	4.2	115.9	5.8	+1.6	+36.4
7	8	229.0	0.0	0.0	12.1	5.3	+5.3	--------
8	0	357.8	65.4	18.3	48.7	13.6	−4.7	−26.0
8	1	57.3	0.0	0.0	0.0	0.0	0.0	0.0
8	2	108.3	31.5	29.1	0.0	0.0	−29.1	−100.0
8	3	45.9	23.6	51.4	0.5	1.1	−50.3	−100.0
8	4	11.6	0.0	0.0	0.0	0.0	0.0	0.0
8	5	11.3	0.0	0.0	0.0	0.0	0.0	0.0
8	6	33.2	0.0	0.0	0.0	0.0	0.0	0.0
8	7	433.3	0.0	0.0	1.8	0.4	+0.4	--------
8	8	1,696.3	100.1	5.9	12.9	0.8	−5.1	−86.9

Results

Table 10 details the results of the 13 sensitivity runs. Results from each run are not discussed individually, but the runs have been related to the four main modal split variables. Trip purpose was not considered as only work trips were evaluated.

Economic Status

The economic status variable indexes th set of 16 out of 80 diversion curves for eac purpose that will determine the modal spli The five levels of economic status were deter mined by the following groupings of media income of workers.

Economic status	*Income ($)*
1	0–2, 499
2	2, 500–3, 999
3	4, 000–5, 499
4	5, 500–6, 999
5	7, 000+

Tests *B* and *M* were designed to analyze the nsitivity of the modal split procedure to riations in economic status. The results ow that the modal split procedure is rela-vely insensitive to changes in economic atus. The number of transit passengers clined 2.4 and 4.5 percent respectively in lation to increases of 20.0 and 50.0 percent median income.

Figure 4 illustrates five modal split curves ercent transit usage vs. traveltime ratio) for e five levels of economic status when the her variables were not changed—level of rvice ratio 1.25, cost ratio 2.50. For time tios favorable to transit—shown to the left the vertical dashed line (traveltime ratio of 00) in figure 4—economic status five exhibits higher split to transit than economic status oups two, three, or four. As time ratios came less favorable for transit, the split to ansit became inversely related to income vel. In other words, the relationships veloped indicate that people having higher comes are more apt to use good transit than ose having low incomes; conversely, people aving high incomes are less apt to use poor ansit than those having low incomes.

The characteristics noted of these particular odal split relationships tend to explain e relatively small areawide change in modal lit in relation to large changes in median come. The modal split procedure indi-ates that for the zonal interchanges having me ratios favorable to transit, an increase the split to transit usage occurs according increases in economic status, as more ones fall into the economic status group ve. Conversely, for those interchanges aving less favorable time ratios, a decrease transit usage occurs as median incomes crease. This finding was confirmed by he analysis showing the higher decline in on-CBD oriented trips, 15.4 percent, as pposed to the trips that were CBD oriented, .7 percent. These joint effects tended to ancel areawide variation in modal split aused by changes in median income. The nodal split procedure appeared to be sensi-ive to changes in economic status on a onal basis, but such sensitivity was not pparent on an areawide basis.

Cost Ratio

The cost ratio variable was the ratio of he out-of-pocket costs via each mode. Sensitivity tests *A*, *E*, and *H* were designed o evaluate the sensitivity of the modal plit technique to the cost ratio. Results of tests *A* and *H* showed that the range of sensitivity of the cost ratio is fairly narrow; this narrow range was caused by the me-chanics of the cost ratio calculation. Four levels of cost ratio are specified by the modal split procedure. Between the first and the fourth levels, the cost ratios were in effect continuous because of interpolation between levels. However, cost ratios lower than those of the lowest level (0.25) or higher than the highest level (3.00) were considered to be equal to the high and low ratios. In other words, a cost ratio of 6.00 or 12.00 was considered to be no different than a a cost ratio of 3.00.

Table 7.—Root-mean-square-error analysis of district to district transit work trips

Volume group	Frequency	Total[1]		Mean		RMS error	Percent RMS error
		O–D trips	BPR test estimates	O–D trips	BPR test estimates		
5.0–9.9	13	125. 2	99. 4	9. 6	7. 6	13. 7	142. 4
10.0–14. 9	203	2, 237. 6	1, 229. 6	11. 0	6. 1	12. 9	117. 2
15.0–19.9	3	55. 7	103. 7	8. 6	34. 6	24. 4	131. 3
20.0–24.9	72	1, 589. 3	1, 127. 3	22. 1	15. 7	22. 9	103. 9
25.0–29.9	10	277. 2	382. 8	27. 7	38. 3	43. 3	156. 3
30.0–39.9	274	9, 711. 9	8, 353. 0	35. 4	30. 5	31. 5	88. 8
40.0–49.9	112	4, 746. 6	3, 389. 2	42. 4	30. 3	29. 6	69. 9
50.0–59.9	33	1, 822. 4	1, 186. 3	55. 2	36. 0	34. 0	61. 6
60.0–74.9	98	6, 624. 1	6, 345. 5	67. 6	64. 8	54. 2	80. 2
75.0–99.9	90	7, 366. 9	5, 454. 5	81. 8	60. 6	47. 5	58. 0
100.0–124.9	79	8, 961. 4	7, 914. 1	113. 4	100. 2	62. 8	55. 4
125.0–149.9	31	4, 319. 7	3, 130. 6	139. 4	101. 0	64. 2	46. 1
150.0–499.9	187	48, 308. 0	44, 268. 4	258. 3	236. 7	102. 0	39. 5
500.0 and more	43	34, 910. 4	31, 973. 1	811. 9	743. 6	239. 2	29. 5
TOTAL	1, 248	131, 056. 4	114, 957. 5	--------	--------	--------	--------

[1] Difference in totals caused by certain movements having zero O–D trips and some model trips.

Increases in transit fares had only a minor effect on the modal split. When a 15-cent increase in fares was applied to each zonal interchange—from an average base of 35 cents—transit patronage dropped 5.0 percent overall. An examination of the cost ratios from this test indicated that the resultant ratios were predominantly on the maximum level. To prove this, fares were doubled for test *H*, and the decline in patronage from the base was 7.8 percent, or only 2.8 percentage points more than the decline caused by the 15-cent increase. This decline of 7.8 percent probably closely approaches the maximum decline in patronage caused by fare increases that the model would predict. When transit costs were held constant and parking costs in the downtown area were doubled (test *E*), estimates for transit trips to downtown increased 7.7 percent. The modal split procedure was sensitive to changes in the cost ratio only in a very limited range. From the drastic changes in the cost ratio variable—doubled transit fares to double parking costs—the number of estimated riders ranged only from 99,752 to 115,972.

Service Ratio

The service ratio, also termed the excess time ratio, relates the service provided by transit to the service available by private automobile in terms of the portion of the trip time spent outside the means of conveyance (automobile or transit). Tests *C*, *D*, and *I* were designed to evaluate the sensitivity of the modal split technique to changes in the level of service ratio. By factoring the waiting and transfer times for transit by 1.5 (test *D*), transit service was in effect reduced. For example, trains running on 10-minute headways would have 15-minute headways. This change caused a decline in the estimate for transit trips of 15.1 percent. To show the possible variation in estimates of this type, a

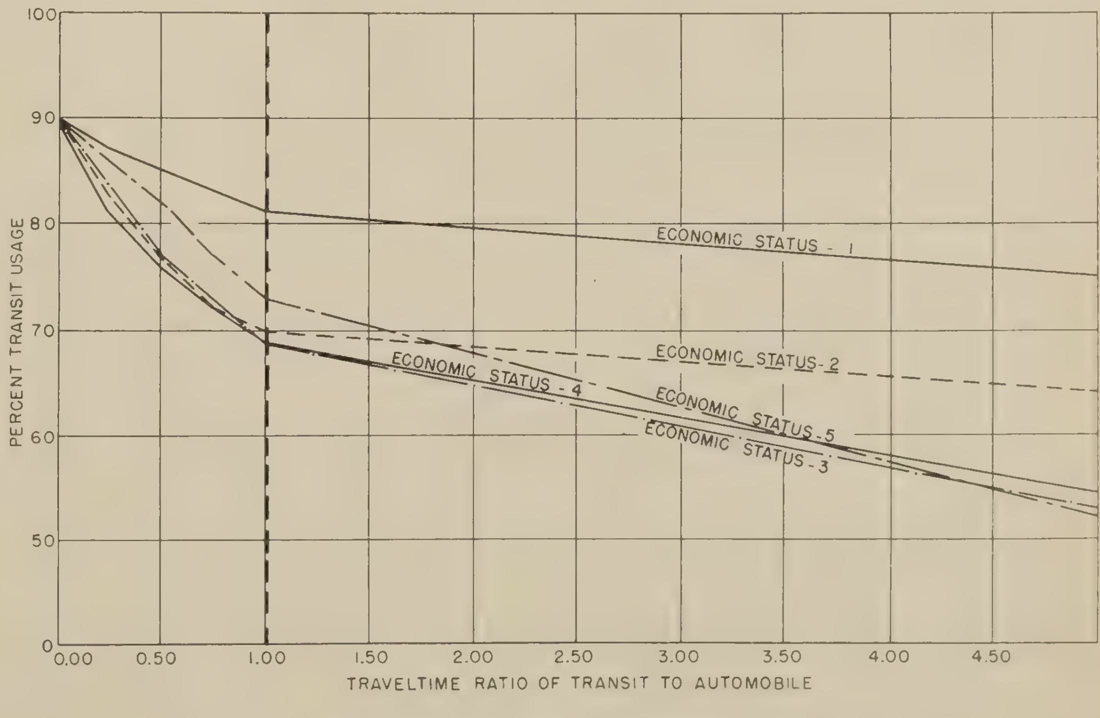

Figure 4.—Variation in modal split related to economic status.

Table 8.—Root-mean-square-error analysis of district-to-district transit nonwork trips

Volume group	Frequency	Total[1]		Mean		RMS error	Percent RMS error
		O–D trips	BPR test estimates	O–D trips	BPR test estimates		
5.0–9.9	4	38.2	34.1	9.6	8.5	11.7	122.3
10.0–14.9	60	660.7	280.7	11.0	4.7	11.0	99.4
15.0–19.9	1	18.2	0	18.2	0	18.2	100.0
20.0–24.9	11	239.7	123.7	21.8	11.2	13.1	59.9
25.0–29.9	3	89.1	58.1	29.7	19.4	18.4	62.1
30.0–39.9	58	2,127.3	1,328.7	36.7	22.9	22.1	60.3
40.0–49.9	18	741.6	609.6	41.2	33.9	23.5	57.0
50.0–59.9	1	56.6	65.4	56.6	65.4	8.8	15.5
60.0–74.9	4	277.1	158.9	69.3	39.7	31.8	46.0
75.0–99.9	7	565.2	347.1	80.7	49.6	36.2	44.8
100.0–124.9	4	452.8	566.9	113.2	141.7	38.7	34.2
125.0–149.9	0	--------	--------	--------	--------	--------	--------
150.0–499.9	2	347.9	294.9	174.0	147.4	37.8	21.7
500.0 and above	0	--------	--------	--------	--------	--------	--------
TOTAL	173	5,614.4	3,868.1	--------	--------	--------	--------

[1] Difference in totals caused by certain movements having zero O–D trips and some model trips.

Table 9.—Cumulative trip length frequency data

Time increment	Accumulated percent of transit trips		Percentage point difference
	1955 O–D data	BPR test estimates	
Minute	*Percent*	*Percent*	*Percent*
0–9	10.85	10.57	−0.28
0–19	41.25	37.90	−3.35
0–29	71.27	69.00	−2.27
0–39	90.93	90.01	−0.92
0–49	97.27	97.60	+0.33
0–59	99.34	99.50	+0.16
0–69	99.89	99.90	+0.01

comparison was made of selected district transit waiting time estimates developed for the 1980 application with estimates developed for the tests applying 1955 data and is shown in table 11. Each of the estimates was made by the same person but at different times.

It is emphasized, however, that the estimates for the BPR test against 1955 O–D data were adjusted to the curve development estimates prior to their use for the test, as previously explained in the material on input factors. To test the sensitivity of the denominator of the service ratio, 1 minute was added to both the automobile parking delay time and the walking time from parking place to ultimate destination (test *C*). This change had drastic effects; transit patronage estimates were increased by 32.7 percent. CBD oriented trip estimates were increased by 10.3 percent. As the waiting and walking times for automobile trips to non-CBD areas were assumed to be 1 minute each for all other tests, only CBD oriented trips are discussed here.

Test *C* indicated such a high sensitivity of the procedure to automobile associated waiting and walking time that an additional test was designed. The parameters developed for these times in the test of the 1955 O–D survey data were substituted for the 1980 estimated times in test *I*. When these 1955 test parameters were used, the estimation for transit trips to the CBD declined 20.8 percent.

The results of these tests indicate that the modal split procedure is highly sensitive to the service ratio within the range of realistic input variables. Because of the relative difficulty in accurately estimating waiting and walking times, the procedure may be too sensitive to this parameter. A determination must be made as to whether walking and waiting times are as pivotal a factor in the choice of a mode of travel as indicated by the sensitivity test results.

As for the cost ratio, fixed limits for upper and lower levels were established for the service ratio. However, unlike the cost ratio, the range of percent transit usage was extremely broad between limits. For example, when the other parameters were held constant at given levels, the modal split might vary from 70 to 50 percent in relation to the maximum change in cost ratio. By varying the level of service ratio between its maximum and minimum values and holding all other parameters constant, a typical range in modal split might be from 70 to 30 percent.

Traveltime Ratio

The traveltime ratio consists of the portal-to-portal time via each mode, including waiting, walking, and transfer times. Sensitivit tests *F*, *G*, and *J* were designed to evaluat the sensitivity of the procedure to traveltim ratio. A review of all three outputs showe that the model was adequately sensitive t changes in traveltime. For trips in the les favorable time ratios, that is, those charac terized by the non-CBD oriented trips, th procedure was more sensitive to the travel time ratio than in the areas having ratio favorable to transit. The maximum areawid change of 13.8 percent in patronage estimate occurred when transit times were factore by 1.5. These output figures showed that th procedure was sensitive to traveltime ratio but that the effects of minor time changes such as varying speeds on a given route sectior would be very hard to detect.

Combined Variables

Sensitivity tests *K* and *L* were designed t determine the joint effect of varying severa parameters at the same time. Changing a individual parameter provided a good pictur of the relative sensitivity of the procedure t the change in the variable. However, becaus the modal split procedure exhibited differen degrees of sensitivity over certain ranges, was very difficult to evaluate the joint effe of changes in more than one paramete

Table 10.—Modal split sensitivity analysis

	Base[1]	A[2]	B[3]	C[4]	D[5]	E[6]	F[7]	G[8]	H[9]	I[10]	J[11]	K[12]	L[13]	M[14]
Total person trips	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825	465,825
Number via transit	108,169	102,731	103,265	143,586	91,864	115,972	117,287	93,848	99,752	90,308	93,249	76,133	80,571	10,552
Percent diversion	0.2322	0.2205	0.2217	0.3082	0.1972	0.2490	0.2517	0.2015	0.2141	0.1939	0.2002	0.1634	0.1730	0.2265
Percent change	----------	−5.0	−4.5	+32.7	−15.1	+7.2	+8.4	−13.2	−7.8	−16.5	−13.8	−29.6	−25.5	−2.4
Person trips to CBD	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390	148,390
Number via transit	85,952	82,185	84,463	94,841	76,205	92,609	88,931	81,302	80,078	68,091	80,447	53,915	68,025	84,633
Percent diversion	0.5794	0.5538	0.5692	0.6391	0.5135	0.6241	0.5993	0.5479	0.5396	0.4589	0.5421	0.3633	0.4584	0.5703
Percent change	----------	−4.4	−1.7	+10.3	−11.3	+7.7	+3.5	−5.4	−6.8	−20.8	−6.4	−37.3	−20.9	−1.5
Non-CBD oriented person trips	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435	317,435
Number via transit	22,217	20,546	18,802	48,744	15,659	----------	28,356	12,546	19,674	22,217	12,802	22,217	12,546	20,889
Percent diversion	0.0700	0.0647	0.0592	0.1536	0.0493	0.0700	0.0893	0.0395	0.0620	0.0700	0.0403	0.0700	0.0395	0.0658
Percent change	------	−7.5	−15.4	+119.4	−29.5	--------	+27.6	−43.5	−11.4	----------	−42.4	----------	−43.5	−6.0
TOTAL REVENUE	$37,337	$51,030	$35,984	$48,987	$31,647	$39,623	$40,781	$32,009	$68,545	$31,076	$31,634	$26,315	$27,401	$36,564

[1] Base, NCTA run 23, a.m. peak traffic hours, work trips only.
[2] $0.15 added to base fares.
[3] 1.5×median incomes.
[4] 2 minutes added to auto parking and walking times.
[5] 1.5×waiting and transfer times.
[6] 2.0×parking costs.
[7] Transit times factored by 0.75.
[8] Highway times factored by 0.75.
[9] Base fares doubled.
[10] 1955 auto parking and walking times used.
[11] Transit times factored by 1.5.
[12] 1955 parking costs and auto waiting and walking tim used.
[13] 0.75×highway times, 0.66×parking costs, 0.66×au walking time.
[14] 1.2×median incomes.

ible 11.—Comparison of alternate estimates of transit waiting times

District	Transit waiting time estimates from—	
	Curve development	Test made with 1955 O–D data
1	1.2	3.9
6	2.7	4.0
11	3.0	4.7
16	4.6	4.2
22	4.0	2.0
27	7.2	5.6
32	1.7	4.1
37	7.8	8.5

›r example, a 25 percent decrease in transit ›nes might cause an 8 percent increase in ›e estimate for transit patronage if the aver- ›e cost ratio were 1.5. The same decrease transit time might have an entirely different ›ect if, because of changes in fare structure, ›e average cost ratio were 2.0.

When parameters used in the test of 1955 ›ta for parking costs and automobile waiting ›d walking times were substituted (test K), ›e estimated transit usage of CBD oriented ›ps dropped to 36.3 percent from the 1980 ›se estimate of 57.9 percent. It is difficult draw conclusions from this particular test the estimate for CBD oriented transit usage dropped below the level reported in the 1955 O–D survey. In other words, despite the assumptions regarding improved transit, when the 1955 terminal parameters for automobiles were used, the 1980 estimated percent of transit usage was less than the actual 1955 level.

Test L, which contained more favorable assumptions regarding 1980 automobile travel conditions—higher automobile speeds, lower parking costs, and shorter walking times—showed a 25.5 percent areawide drop in estimated transit trips. Approximately one-half of this change can be related to the factoring of highway times as test G, in which the same highway time change was isolated, showed a patronage decline of 13.2 percent. Because the procedure is much more sensitive to the level of service ratio than the cost ratio, the bulk of the remaining decline can be related to the more favorable assumptions made regarding the walking time from the automobile at the destination.

The results of the analyses for combined variables showed the same key trends as the analyses of individual variables. The trends shown are: (1) The level of service ratio far outweighs the other variables in importance, (2) cost ratio plays a minor role, and (3) travel-time ratio exhibits adequate sensitivity over its entire range.

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(6) *Reconciliation and Corroboration of Washington Modal Split Relationships*, by Traffic Research Corporation, August 1962.

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Comments on Evaluation of New Modal Split Procedure

Comments of three transportation planning ›ficials on the BPR test evaluation made of ›e new modal split procedure were also pre- ›nted at the 43d annual meeting of the High- ›ay Research Board, Washington, D.C., ›nuary 1964. The comments are presented ›re to provide additional information on the ›oblems being encountered by highway and ›ban transportation planners in anticipating ›ture needs.

The following material is the comments ›ade by: Thomas B. Deen, Acting Director the Office of Planning, National Capital ›ransportation Agency; William L. Mertz, ›echnical Director, Tri-State Transportation ›ommittee; and George B. Wickstrom, ›eputy Director, Penn-Jersey Transportation ›udy.

Mr. Deen's Comments

A procedure for estimating the relative usage ›f private and public transportation systems, ›hich is both rational and practical, has long ›een a pressing need in the urban transporta- ›on planning process. The modal split pro- ›edure developed for NCTA appears to be a ›gnificant step forward in filling this theoreti- ›al and methodological gap. The Sosslau- ›leanue-Balek article makes a valuable and ›ecessary contribution to a fuller understand- ›g of this procedure, to the implications ›volved in its application to specific planning problems, and to the subtle interrelationships of the variables affecting transit usage. The authors have treated this complicated and—unfortunately—controversial subject with objectivity and fairness.

Of fundamental importance as a test of its basic validity is the fact that the modal split procedure accurately reproduced the transit usage actually observed in 1955 as regards total areawide transit use, CBD transit use, interdistrict transit use, and transit trip length. It is axiomatic that public transit's greatest strength is in the delivery of work trips to and from the CBD. Estimating transit's ability then to attract CBD-bound workers is essential in proper planning of urban transit and highways systems. The modal split procedure estimated these trips as 75,678, missing the observed O–D survey by only 46 trips, an error so small that it must be considered at least partially coincidence. Total CBD trips, estimated by the procedure were in error by only one percent.

The authors properly point out that non-CBD trips were not so precisely estimated, and follow with the suggestion of development of separate non-CBD modal split relationships and separate handling of such trips. As the model in its present state is a costly and time-consuming procedure, to complicate it further by additional stratification of the thinly-sampled data and to raise the number of modal split curves above the present 160, might not be the most promising approach. Particularly so, as factors other than the need for separate non-CBD modal split relationships may well be more important causes of the lesser accuracy of the non-CBD estimate. These would include the inadequate representation of zonal parameters, such as walking distances and waiting times to employment areas in the larger nonsector zero zones. For example, walking distances to bus stops for each zone—CBD or non-CBD—were estimated so as to represent average conditions to and from trip generation points within the zone. For most nonsector zero zones, such points are primarily residential. However, walking distances to employment or commercial areas within these zones might be quite different from those representing the residential trip generation points.

One disappointing aspect of the model's performance concerns the geographical bias observed in the synthesis of 1955 transit travel. The consistent underestimate of transit usage from the western side of the city and the overestimate on the eastern side are problems of real concern. In order to see the problem in perspective, however, two elements should be considered:

The gravity model trip distribution process used in Washington has been observed to produce a similar bias.[1] Work trips to the

[1] *Evaluation of Gravity Model Trip Distribution Procedures*, by Walter G. Hansen, Trip Characteristics and Traffic Assignment, Highway Research Board Bulletin No. 347, 1962, pp. 67–76.

CBD from the western side of the city were consistently underestimated by the gravity model until adjustment factors were applied. This behavior by the gravity model has been considered a result of unequal distribution of income or other socio-economic factors between the eastern and western sides of the city. No such simple explanation suggests itself in the case of the modal split model as income is one of the input parameters.

The largest percentage of error for any corridor (as indicated by comparison of the 1955 actual and computed figures) was 22.6 percent. However, the largest absolute error was 1,473 trips over a 2.17 hour peak period. If 60 percent of these trips are assumed to occur during the peak hour and the observed peak hour downtown Washington car occupancy (1.8) is used, the error becomes

$$1{,}473 \times 0.60 \times \frac{1}{1.8} = 490$$

vehicles per hour, less than one-third of a highway lane. Considering the limitations in our abilities to estimate future land use, and trip distribution, this would appear to be well within limits acceptable for transportation planning.

The sensitivity tests are extremely interesting and if studied sufficiently can shed much light on the relative importance of the numerous factors affecting transit usage. I concur with the authors' findings that the model is sensitive to cost ratio only through a very limited range, and to service ratios and travel-time ratio through a much larger range. The limited cost-ratio range is not an inherent characteristic of the procedure, however. If data can be found for a broader cost range, then the observed results may be incorporated into this or a similar process.

One surprising element reported from the sensitivity tests is the high elasticity of transit use relative to auto terminal conditions—specifically to auto walk and delay times. I should like to make several comments in this regard:

- One of the most attractive features of unrestricted auto travel that is almost impossible to duplicate with public transportation is that it begins where you want to begin and takes you directly to where you want to go. If, due to lack of properly located parking space, the auto trip must end some distance from the trip destination, then much of the auto convenience is lost, and public transportation is at once more competitive. Ergo, it is not unreasonable to suppose that auto walking time is in fact an important factor in modal split.
- An equally attractive feature of auto travel is that it goes *when* you want to go. If significant delays are associated with unparking—from a parking garage for instance—then auto convenience is reduced. Therefore parking delay could reasonably be supposed to be an important modal split determinant.
- Even if the preceding two points are accepted, the degree of sensitivity shown by the model to auto-walk-wait times would appear to justify careful scrutiny. Perhaps the problem lies in the use of a ratio to express the relative convenience of auto and transit travel. One of the characteristics of the service ratio is that the denominator is significantly smaller than the numerator. In fact, for the nonsector zero-destined trips, the denominator was 2 minutes, while the numerator was usually 7 to 10 minutes or more. Thus a 2-minute increase represents a 100 percent increase in the denominator and a 50 percent decrease in service ratio. A 2-minute decrease makes the service ratio infinite. The extreme effect of this on the modal split can be seen in test *C* where nonsector zero transit trips increased 120 percent as a result of adding 2 minutes to auto-walk-wait times. The same distorting influence is operating for sector zero trips, though to a lesser degree, because the denominator for such trips is larger. Perhaps the problem could be solved by quantifying the convenience factors into time difference—transit excess time minus auto excess time—instead of a time ratio.

Some comment should be made concerning test *K* in which use of 1955 auto terminal values (parking costs, auto-walk-wait times) along with the other 1980 assumptions, including the proposed rail transit system, produced a modal split below the 1955 level. I concur with the authors that this test is "difficult to interpret." However, before any interpretation can be made, certain other items must be fully understood:

- While in this test the *proportion* of peak-hour commuters using transit to sector zero dropped below the 1955 level, the absolute volume of sector zero transit riders held about the same as in 1955.
- The 1955 auto terminal conditions have long since disappeared. Average parking costs have gone up an estimated 100 percent since 1955 due in part to a 30 percent increase in commercial rates, but more importantly to an increase in the number of parkers using pay facilities and a corresponding decrease in the number parking free.
- Test *K*, in addition to assuming an improved transit service, also assumed a substantially improved highway system over 1955, with significant increases in auto travel speed. An intelligent appraisal of the real meaning of returning to 1955 auto terminal conditions in 1980 cannot be made without evaluation of the effects on auto speeds of the shift of such a large number of transit riders to the highway.
- In fact, it can be fairly stated that the modal split at any moment is the result of a large number of conflicting factors that are in equilibrium. Change in any factor, say, parking costs, causes a shift to auto travel. This in turn causes decreases in auto speed, which tends to shift travelers back to transit. Thus the elasticity of modal split indicated in test *K* along with all the other tests must be viewed as somewhat artificial since the feedback required to reach equilibrium has not been accounted for.

In conclusion it must be noted that while the modal split procedure appears promising, there are many elements concerning its use that are as yet unknown. The sensitivity tests reported on here indicate that within limitations the model responds in a reasonab way to changes in input conditions; the 19 transit use synthesis indicates that the m chanics of the procedure, the method of i putting certain of the variables, and t otherwise questionable procedure of repr senting conditions within fairly large ge graphical areas by means of averages (f example, average walking distances, incom are adequate. But results of these tests s little about the relative importance of oth factors that probably affect transit use, su as schedule adherence, air conditioning, ridi comfort, vehicle esthetics, diesel fumes, su way claustrophobia, station shelters and par ing facilities, kiss-and-ride, etc. Nor do yet know much of the universality of t modal split relationships. Most importa we don't know if modal split relationships main stable over a period of time. Final the entire approach ignores the effect of re tive transit and auto use on trip distributi and generation, though logic would seem say that all these elements are interrelated, least through land-use changes, and probal more directly as well. All things consider there are many unknowns worthy of conc and further study. Yet, when viewed alo side the other unknowns in the field of urb planning—the modal split model is a sign cant advance that contributes much to understanding of the determinants of pul transit usage

Mr. Mertz's Comments

The modal split procedure evaluated Sosslau, Heanue, and Balek, has recei widespread attention in the technical fi Also, the controversy over the future cou of highway and transit development in National Capital Region has assumed natio proportions. I am concerned that the te nician who reads this paper without m background and perspective might assum more pessimistic view of the usefulness of procedure than is warranted. I would, th fore, suggest that the other two pap *Development of a Model for Forecasting Tr Mode Choice in Urban Areas*, by Von Cube Hill, and *Application of a Modal Split M to Travel Estimates for the Washington Area* Deen, Irwin, and Mertz, be studied in c junction with this one.

The problem of mode choice is assun greater proportions each year. Heretof the tools to deal with the problem have b skimpy indeed. The use of time ratio cu alone will no longer suffice. I suggest t the reader make a judgment as to whether significant factors in modal choice have b incorporated into the procedure. By large, I submit that they have. We nee know more about the effect of crowding— standee problem—and other factors in qua fiable terms so more research is certa needed.

If the reader accepts the position that major significant variables have been inco rated, the next question to be answere whether a proper description of the ac d interaction of the variables has been ınd, which is the subject under discussion. review of the article and an inspection of e curves will reveal the different sources of ta and the portions of the curves for which ere were no data at all—the dotted portions. iere is always great difficulty in developing common denominator base both in time d geography for data collected from differ-t sources. This points to the need for the llection of more information in O–D surveys aring on the mode choice problem. Also, believe that changes of variables assumed to fluence mode choice need to be made within nctioning transit-highway systems and re-lts carefully measured and evaluated. The emonstration Grant Program could be the strument for such studies.

The reader must also judge the conclusive-ss of the test against the 1955 O–D data. ie authors state that on a district-to-district asis "the variation between the O–D and odel estimates is less than the variation in e survey." At the same time it is stated at the variation between corridor move-ents is "a particularly critical weakness of e modal split technique." There have been veral tests of transportation planning tech-ques against O–D data in the past. In l cases, the variation has been higher than e would like and leaves moot the question how much variation is due to sampling and ɔw much is due to a procedure's inability to escribe an historical situation.

The sensitivity tests of the model are par-cularly interesting. It should be borne in ind that the sensitivity tests, by their very ature, extend the parameters into the dotted ortions of the curves for which no data were vailable. The configuration and interaction etween variables in these extended ranges, necessity, were based on logic and intuition. ven so, I am not surprised that changes in re proved to be less sensitive than, for ex-nple, automobile terminal conditions such s parking delay, walking time, and parking osts. I am encouraged that the authors ated that the model is "adequately sensitive changes in travel time," which has been ie backbone of mode selection procedures the past.

I would like to emphasize a point that none f the three articles brings out clearly. One f the major objectives of this development as to create a modal split computer program fit into and be compatible with the "so-alled" BPR battery of transportation plan-ing programs. This was achieved. The nodal split relationships (represented by ables) are input to the program just as travel ime matrices, etc. are input. All of the dis-ussion in the article concerns the evaluation f this input. Different sets of relationships vere used for the work and nonwork purposes. The program is operational, is compatible, and s usable by any study. The tabular curve elationships should certainly be evaluated gainst data for the urban area in question and nodified or completely reconstructed in the light of local conditions. This operational capability should not be overlooked.

Mr. Wickstrom's Comments

When one is given the opportunity to comment on a material that is in itself a comment on a previous paper, it is difficult to know where to begin. Comments could be directed to the problem (modal split), the method evaluated (diversion), or the evaluating of the modal test methods and results.

In reviewing the conclusions as stated in the paper, major points included: (1) CBD and non-CBD trips may require stratification, (2) certain input variables (notably excess time) are overly sensitive, and (3) further study is required.

Although it is difficult to disagree with these conclusions, I cannot help but feel that the basic approach taken to solve the problem of predicting modal split should also be examined. The approach investigated was a diversion approach; that is, it attempts to predict the percentage of travelers who choose transit rather than the auto. While it may be possible to mathematically match observed transit choice behavior by this method with aggregates of O–D data available, how does one accurately predict the future total number of travelers between two O–D zones and using all modes of travel from which to take a percentage? Isn't the ultimate answer desired not just the percentage on transit, for each corridor, but *how many* on transit or auto?

It would also seem that the data available from the O–D survey were overly stratified in an attempt to introduce as many of the factors that influence transit use as possible. A 5- or even 10-percent sample of CBD trips simply does not permit so many stratifications, as sample variability plays havoc. If home-interview data are ill-suited for models of this type, shouldn't we collect data at the CBD end of the trip?

One of the major reasons for collecting home-interview data throughout the metropolitan area is the present need to obtain a universe of household characteristics and trip interchanges.

Although the day has not yet come when secondary source data and models have made these basic requirements obsolete, perhaps better models could be developed if data collection were intensified in several parts of the urban area to provide a statistically reliable sample for model development purposes, while collecting a slightly smaller uniform sample elsewhere.

If only conventional origin-destination data are available, one is really forced to predict transit use on an area basis and usually forced to ignore or generalize the effects of changes in system characteristics. Modal splits are made before distributing trips rather than afterward.

There is also some question as to whether diversion curves can ever adequately predict modal split, since they usually tend to overemphasize system characteristics at the expense of more determining factors—such as whether or not the wife needs the family car! In this regard, I notice that the model tested did not *directly* deal with car ownership. Yet, the importance of this variable in estimating transit use is illustrated by the fact that only 14 percent of all trips and 9 percent of nonwork trips were made by persons in families owning one car in the Philadelphia area in 1960. For trips by two-car families these low percentages were halved, while persons not owning a car made 76 percent of their trips by transit. It would seem that the apparent effect of car ownership is important enough not to be even partially ignored.

In the Philadelphia area, only 25 percent of all transit trips have origin or destination in the CBD. A CBD derived relationship could not be readily used to explain the remaining behavior, since 75 percent of the trips would then be estimated on the basis of relationships derived from 25 percent of the trips.

These comments were not directed at criticising the model, but rather to point up the difficulties inherent in deriving models of this type with conventional origin and destination survey data. The fact that the model behaved as well as it did underlines the need for continued study along these lines. This is the only modal split model now available that has been derived and tested with O–D data from several cities and that deals directly with relative transportation system characteristics. If the excess time factor were modified or eliminated, it would serve as an important interim tool while awaiting the results of the further research recommended.

The paper presented by Mr. Sosslau is an excellent example of the type of thorough, painstaking model evaluation required before the problem of modal split can be solved. The authors have done an excellent job.

Motor Vehicle Size and Weight Limits

A comparison of State legal limits of motor-vehicle sizes and weights with standards recommended by the American Association of State Highway Officials is given in the table on pages 10–11. The statutory limits reported in this tabulation, prepared by the Bureau of Public Roads as of December 31, 1963, have been reviewed for accuracy by the appropriate State officials.

Statutory limits are shown for width, height, and length of vehicles; number of towed units; maximum axle loads for single and tandem axles; and maximum gross weights for single-unit truck, truck-tractor semitrailer combinations, and other combinations.

New Publications

Highway Statistics, 1962

The Bureau of Public Roads, U.S. Department of Commerce, has published a new 180-page bulletin, *Highway Statistics, 1962*, the 18th in the annual series that presents statistical and analytical tables of general interest on motor fuel, motor vehicles, highway-user taxation, State and local highway financing, road and street mileage, and Federal aid for highways. This issue also includes several tables giving the legislative provisions that govern the disposition of State highway-user receipts.

Highway Statistics, 1962, may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, for $1.00 a copy. Some of the previous annual issues of the series and the summary to 1955 are also available from the Superintendent of Documents; a list of available issues is carried on the inside back cover of this magazine.

Road-User and Property Taxes on Selected Motor Vehicles, 1964

The publication, *Road-User and Property Taxes on Selected Motor Vehicles, 1964*, is available from the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402, at 45 cents a copy.

This 56-page bulletin has the same objectives as the four previous reports (1950, 1953, 1956, and 1960). Taxes are discussed on each of a group of motor vehicles that had been selected to illustrate and compare the taxes that apply to vehicles of different types in each State. Basic data on road-user taxes and property taxes as of January 1, 1964 are supplied to give both a direct measurement of the impact of the taxes on different vehicles, and place these taxes in proper perspective. No attempt has been made to assess the merits of the taxes imposed nor to indicate support for or opposition to any tax policy.

Calibrating and Testing a Gravity Model With a Small Computer

The Bureau of Public Roads, U.S. Department of Commerce, has published a manual titled *Calibrating and Testing a Gravity Mod With a Small Computer.* This publication e plains and illustrates the theory and use of system of analytical procedures and comput programs for calibrating and testing a gravi model trip distribution for a small or mediu sized urban area using the IBM 1401 (16] computer. The IBM 1401 programs are co pletely compatible for use on the IBM 14 (40K) computer if the IBM 1410 is equipp with a compatability switch. By combini these programs with those concerned wi traffic assignment, it is possible to comple most of the analytical phase of a comprehe sive transportation study. The manual ref ences a compatible set of IBM 7090 compu programs for traffic assignment. The 14 battery does not presently contain tra assignment programs.

Calibrating and Testing a Gravity Mo With a Small Computer, may be purchas from the Superintendent of Documents, U Government Printing Office, Washingt D.C., 20402, for $2.50 a copy.

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