NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 58

COMPARATIVE ANALYSIS OF TRAFFIC ASSIGNMENT TECHNIQUES WITH ACTUAL HIGHWAY USE

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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SUBJECT CLASSIFICATION:
- TRANSPORTATION ADMINISTRATION
- TRAFFIC MEASUREMENTS
- URBAN TRANSPORTATION SYSTEMS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1968

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

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FOREWORD

By Staff

Highway Research Board

This report will be of particular interest to highway and traffic engineers and transportation planners involved in predicting future highway use. Various traffic assignment techniques were tested, and their results were compared with actual ground counts. The merits of the various traffic assignment programs are presented, as well as a discussion of the expected errors associated with assigning an origin-destination table to a network.

Various methods are in current use to forecast and assign traffic in planning of major highway facilities. The project, titled "Predicted Traffic Usage of Major Highway Facility Versus Actual Usage," was initiated because there is a need to determine the validity of these methods and possibly to develop better methods for forecasting traffic assignments. The NCHRP advisory panel stressed that a major emphasis should be placed on studying the effects of a new facility on the traffic pattern of existing networks. The project statement suggests that the desired results "may be achieved by studying one or more major facilities such as expressways or bridges at locations where pertinent variable factors are at a minimum and can be identified, and where previous adequate O-D data and land-use development history of a nature lending itself to traffic forecasting and assignment by various methods are available, and where it is feasible to conduct O-D studies in a manner which will permit direct comparison of the various prediction and assignment methods based on data of the previous studies."

The researchers from the Yale Bureau of Highway Traffic searched for transportation studies that had data that could be used for the project objectives. They could find only a limited number of studies which met the requirements of having a pair of O-D studies made before and after the construction of a new highway facility.

The initial phase of the research computed traffic assignments based on both travel time and distance parameters using various diversion curves. The second phase dealt with network traffic assignment methods with regard to highway capacity restraint functions. The results obtained by the various techniques were compared with the actual travel data.

An analysis is presented of errors related to O-D input with regard to individual links of the network. Further analysis was conducted to relate link assignments to changes in the O-D patterns and to network changes.

This research emphasizes traffic assignment to individual links of a network so that the resulting volumes can be used by highway and traffic engineers in their geometric design computations. Although this project does not arrive at a foolproof or optimum traffic assignment technique, it does present important information on current assignment methods and points out the areas which will require further research.

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ACKNOWLEDGMENTS

The research reported herein was performed by the Bureau of Highway Traffic, Yale University, for which Matthew J. Huber, Harvey B. Boutwell, and David K. Witheford, Research Associates, acted as co-principal investigators. The project was under the general supervision of Fred W. Hurd, Director.

Grateful acknowledgment is made to the many organizations that contributed time and resources to the project.

The Tucson Area Transportation Study, directed by William G. Ealy and a part of the Arizona Highway Department, provided much information and helpful comment when that city was being considered as a study site. The North Dakota State Highway Department, through Chief Engineer R. E. Bradley, and Planning and Research Engineer L. L. Zink, was extremely cooperative in providing data for the O-D studies on I-94 and their background data on the communities served by it. Their cooperation in providing a considerable volume of trip data without cost must be noted. Staff members of the Planning Division, Bureau of Public Roads, contributed information and suggestions regarding data sources that were valuable to the progress of the work. In particular, G. E. Marple, G. E. Brokke, M. Lash, K. E. Heanue, and C. E. Pyers were helpful regarding urban studies, and R. T. Messer, L. Litz and B. B. Petroff provided information on rural sources. The Planning Division, Pennsylvania Department of Highways, provided information on traffic studies in Erie, and several traffic estimates made in the Pittsburgh region. Thanks are due to George R. Britton and Walter G. Carper, Jr., for making these data available. Comparable thanks are due to the Pittsburgh Bureau of Traffic Planning and Anthony F. Miscimarra for making similar reports from the city available.

The following agencies are thanked for assisting in the search for data in the early stages of the work:

Penn-Jersey Transportation Study
Southeastern Wisconsin Regional Planning Study
Minnesota State Highway Department
Massachusetts Department of Public Works

Special acknowledgment must be made to the Connecticut State Highway Department, which provided trip and network data, without which the I-91 studies would have been either impossible or too costly to undertake. Some of the staff members whose assistance in working with the data was greatly appreciated were I. Resnikoff, F. Coleman, and E. Bates.

An acknowledgment is due the Pittsburgh Area Transportation Study. Data were provided in the form of maps, listings, and trip and network data on cards. The Study staff, notably Director R. Kochanowski, T. Soltman, and L. Kwasniewski, spent many hours preparing data and assisting the Bureau staff in the preparation of inputs for computer traffic assignments. The Study also cooperated in setting up arrangements for using the computer facilities of the Gulf Research and Development Corporation, to whom thanks are also due.

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In brief, whatever success may have been achieved within the time and resource limits of this project must be credited largely to the free and voluntary contributions of effort and materials by many public agencies. To them are given most sincere thanks for their necessary and most willing assistance.

COMPARATIVE ANALYSIS OF TRAFFIC ASSIGNMENT TECHNIQUES WITH ACTUAL HIGHWAY USE

SUMMARY

Forecast and assignment were treated in this project as separate aspects of predicting future traffic use. Only a limited number of studies met the requirements for checking forecasts. The major reasons for rejecting studies were as follows:

1. Failure to build or complete the system as planned at the time of the forecast.
2. Scanty information about the base year from which the forecasts were extrapolated.
3. Absence of follow-up studies during or about the year of the forecast.
4. Incompatibility of data where before and after studies had been made.

Data from two States (Connecticut and Pennsylvania) were used in analyzing assignment techniques and making preliminary analyses of forecast techniques.

A pair of origin-destination studies, made before and after the construction of a new Connecticut River crossing (I-91), were used to test assignments to an isolated rural highway facility. Both travel-time and travel-distance assignments were made. The four techniques tested were the AASHO diversion curve, the California diversion curve, the all-or-none method, and a difference-ratio method (called Easy).

Comparisons of assignment results to 1956 survey results for the two then existing bridges indicated that all of the methods used duplicated survey results and that time-based assignments were slightly better than distance-based results.

The assignments were repeated with 1963 data, after the introduction of the I-91 bridge. Because of the marked increase in speed on the new route as compared to the old routes, none of the distance-based assignments were valid. The time-based assignments to the new crossing (I-91) were satisfactory by all methods but the technique used (choosing next-best alternate only) failed to reproduce trips on the remaining two bridges.

A new assignment technique, in which travel times via all three river crossings were considered simultaneously, duplicated the survey volumes on all three bridges.

The analysis substantiated previous observations that travel time is a better parameter than travel distance.

Efforts to project 1956 origin-destination data to 1963 proved unsatisfactory. The only basis for projection over the 7-year period was population growth, and these data were not sufficient to give the desired results. Projections based on the changes in surveyed trip-ends proved satisfactory, but it is noted that such data were not available to the forecaster in 1956.

Data from the Pittsburgh, Pa., area were used to make comparisons between forecast volumes, computer-assigned volumes, and observed volumes on three different expressways. The forecasts had been prepared by different agencies in the period between 1943 and 1949 and projected to 1958 or 1960. The discrepancies between projected, observed, and computer-assigned volumes underline

the problems encountered when comparing older estimates of traffic volume with recent studies. The forecasts show examples of both underforecasting and overforecasting, but further study is required to isolate the sources of error.

Further studies were made subsequent to the introduction of a new bridge near Pittsburgh's Golden Triangle. Computer-assigned volumes on all of the screenline river crossings were compared to survey volumes, before and after the bridge opening. The individual bridge's assignments were not satisfactory, but the screenline volumes were adequately duplicated. The results indicate that gross assignments are more easily made than specific assignments as to a bridge or a single link of a network.

Five different techniques were used to assign an origin-destination table to an urban network. Results of the five traffic assignments were then compared to observed volumes on two networks—Pittsburgh, Pa., and Raleigh, N. C. The five methods compared were:

Smock—developed for use by the Detroit Area Transportation Study.
BPR—developed by the Bureau of Public Roads.
Schneider—developed for use by Chicago Area Transportation Study.
TRC—developed by Traffic Research Corporation for the Toronto study.
Free—all-or-none assignment, no capacity limitations.

Three of the techniques—Smock, BPR, and TRC—are iterative, and can be repeated an indefinite number of times. Tests of the Smock technique indicated that a minimum of four iterations was required to obtain the desired results. All iterative methods were repeated four times in the following analysis (the first iteration is the same as the Free assignment).

Errors Related to Origin-Destination Input

No assignment can be more accurate than the information used as input to the assignment process. If all elements of the assignment technique were correct, the errors in assigned volumes will never be less than the errors of estimate within the O-D table.

It is hypothesized that the errors in assignment to any link vary as the ratio of the square root of the volume assigned to the link. The expected relationship is:

$$\text{Percent error} = 100\, E_1/V_2^{0.5}$$

in which E_1 is the absolute error associated with a volume of one vehicle, and V_2 is the volume assigned to the subject links.

Forecast O-D tables for 1975 and 1999 in the New Haven area were treated as a table of random trips. The variance of the entire table was assumed to be the error for any single trip interchange and the resulting errors were related to the assigned volumes. A least-squares fit of these data indicated exponent values of 0.545 for the 1975 data and 0.574 for the 1999 data, compared to the hypothesized exponent value of 0.5. The error based only on the errors associated with a 3.6 percent sample O-D were calculated, as follows:

$$\text{Percent error (1975)} = 2060.67/V_2^{0.545}$$
$$\text{Percent error (1999)} = 3662.34/V_2^{0.574}$$
$$\text{Percent error (3.6\% sample)} = 517/V_2^{0.50}$$

The solution of these three relationships provides a range of errors which might be expected when assigning an O-D table to a network.

Comparison of Assignment Techniques

The total number of vehicle-miles and vehicle-hours assigned to the Pittsburgh network were compared to the observed vehicle-miles and vehicle-hours of travel. All of the methods underestimated the observed values. The TRC method came closest to duplicating the vehicle-miles, the Smock method came closest to duplicating the vehicle-hours of travel. Although all of the methods gave assignments significantly lower than the observed values, the differences between the assignments were not significant. There were no significant differences, by methods, in vehicle-miles or vehicle-hours assigned to the Raleigh network.

Results of screenline analyses in Pittsburgh ranged from a 2 percent over-assignment by the Smock method to a 10 percent underassignment by the TRC method. The Smock method came closest to matching the screenline volumes.

All of the methods tested underestimated the screenline volumes for the Raleigh data, but there was little or no difference between the assignment techniques.

When the number of links by volume category was compared for the Raleigh data there was no significant difference between the assignment techniques.

The same comparisons for the Pittsburgh network indicated that the BPR and Free assignments overestimated the number of zero-volume links but gave the best estimates of the number of high-volume links. The remaining three techniques (Schneider, Smock, and TRC) gave similar estimates of the number of links over all volume ranges.

An analysis of the 100 highest volume links (by ground counts) in Pittsburgh indicated that the Smock method gave the best results and the Free assignment gave the poorest.

A "chi-square" analysis of observed volume versus assigned volume over all links showed that the Smock method came closest to reproducing measured volume, followed by TRC, Schneider, BPR, and Free in that order.

Computer time requirements for the Pittsburgh network ranged from 18.75 min for the Free method to 130.48 min for the TRC method. The Schneider technique required 35.48 min and the Smock and BPR techniques both required about 75 min for 4 iterations.

Similar ratios of computer time requirements were found for the Raleigh assignments, the times ranging from 6.34 min for the Free assignment to 108.34 min for the TRC assignment.

The Free assignment, requiring the least computer time, is inferior to the other four techniques. Still, not one of these four is clearly superior to any of the others. By combining computer cost and adequacy of results, it is recommended that the Schneider method be used in making assignments.

Link Assignments Related to Changes in O-D Patterns

The network and the O-D table were held constant, except for all trips to and from a single zone. Two tests were run—in the first test a zone in the center of the New Haven business district was modified, in the second a suburban zone near the periphery of the New Haven network was changed.

The O-D modification had little effect on the distribution of the number of links by volume range.

The maximum volume differences, about equal to the change in number of trip ends, occurred on links directly connected to the subject zones.

Over the range of the 500 maximum-volume links there was no relationship between absolute volume and difference in volume related to the O-D change. When 40,000 trips per day were added at the CBD zone there were only 20 links with volume differences in excess of 4,000 vpd. When 50,000 trips per day were added at the suburban zone there were 13 links that had increases of 10,000 vpd and 33 links with increases of from 4,000 to 10,000 vpd. The suburban zone is located in a portion of the network with fewer zones per mile and fewer alternate routes, so that the impact of the change is accommodated by fewer links.

A cordon-line analysis of the O-D change at the CBD showed that the volume change at the cordon line adjacent to the CBD was nearly equal to the O-D change, but that at a second cordon line (the boundaries of the City of New Haven) the cordon-line volume change was one-half of the O-D change.

A further analysis of volume change related to distance from point of change indicated that the mean volume per link was little affected beyond 5 to 6 min from the point of change in the CBD and beyond 10 min from the point of change in the suburban zone.

A trace of the differences in assigned volume indicated that the differences occur along the expressway portion of the network, and that arterial streets are little affected, except those adjacent to the point of change.

Network Changes and Assigned Volumes

A portion of the expressway network adjacent to the center of New Haven was deleted from the system and the same O-D table was assigned to the network before and after the change.

The differences in volume assignments before and after a network change are more far-reaching than changes in an O-D pattern. The changes in assignment were evident up to 16 min from the point of change in the network and were of greater magnitude than the volume differences associated with an O-D change.

The results suggest that a serious change in trip ends at a given zone could be corrected by hand calculating the distribution of added trips and modifying the computer assignment accordingly. It does not appear that there is any method other than a complete computer assignment to evaluate the effects of a network change.

Changes in Travel Related to Construction of a Major Facility

Two O-D surveys, made before and after the construction of a new river crossing in Norfolk, Va., were compared to isolate the effect of the new river crossing.

The degree of circuity is proposed as a measure of network changes. Two models, one independent of origins and destinations, the other weighted by trip ends, were examined.

The degree of circuity is based on the relationship between actual travel distance and ideal distance between zones. The measure reflected the addition of the new river crossing and was sensitive to a network change, considering the total network. When specific pairs of trip interchanges were compared to changes in circuity introduced by the new facility there was only fair correlation of the expected and observed results.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

This report describes research into traffic assignment and forecasting techniques undertaken for NCHRP Project 7-5, which is concerned with a comparison between predicted and actual traffic use. As noted in the problem statement: "Various methods are in current use to forecast and assign traffic in the planning of major highway facilities. There is need to determine the validity of these methods or to develop better methods for such forecasting and assignment.

The study objectives for the work, therefore, were:

1. To compare the accuracy of predicted use with the actual use, testing the method used and other current methods being used.
2. To prepare a plan for further testing of forecasting and assignment procedures, including development of measures of change in traffic patterns of a network brought about by a new facility.

This report details the standards set up in the search for field data required to test both forecasting and assignment. Because neither time nor funds were available to collect field data on origin-destination and traffic volumes, it was necessary to check existing data for suitable material. Much of the first year's effort was devoted to this search for data.

Two principal sources of data were used in the analysis for the first year. Data from the first of these sources, the Connecticut Highway Department, were used to test assignment techniques to relatively isolated, rural facilities.

Data from the second source, the Pittsburgh Area Transportation Study, were used to make exploratory analyses of network forecasts and assignments. This was accomplished by comparing earlier forecasts of traffic volumes on several sections of the Pittsburgh network against a computer-generated network assignment. This exploratory work suggested that a more thorough examination of volume/capacity restraint functions and an analysis of probable errors inherent to traffic assignment should be conducted.

Five assignment models, four of which employed a volume/capacity restraint function, were tested and evaluated using common networks and common origin-destination trip tables. These results were then compared to existing ground counts where available.

A further objective was to evaluate the errors in assignment as they relate to the sampling errors of an origin-destination survey, and the variation in assignments introduced by a network change or changes in the origin-destination pattern. A simple relationship between sampling error and assignment error has been developed, together with an analysis of the differences in assignment caused by the network or origin-destination changes.

A final section of the study relates changes in origin-destination patterns to changes in the highway network. In this section the observed travel changes are evaluated, together with the changes in the "degree of circuity," a measure of the efficiency of transportation networks.

RESEARCH APPROACH

Although a review of previous studies and publications uncovered many discussions of techniques, it disclosed a very limited number of evaluations of traffic forecasts and assignments—and these were more likely qualitative analyses rather than performance tests.

In reviewing these studies, a distinction was made between forecast and assignment, as follows:

A *forecast* is treated as a projection, to some future date, of travel in a given corridor or area, generally presented as a zone-to-zone trip table. This trip table in turn may be modified by the transportation system to which it will be assigned, as, for example, a shift in emphasis to a new transit or an expanded highway system.

Assignment, as used here, refers to the process of loading a zone-to-zone trip table on the route or network under consideration. In the case of two or more alternates, it is a matter of determining the proportions of the zone-to-zone movements that will use the given routes. In the case of a system or network, it is the process of determining the aggregate use of individual links by the body of zone-to-zone movements.

Data Requirements for Forecasts

The search for data was based on three major requirements for forecasts, as follows:

1. A completed forecast with sufficient description and detail to permit understanding the process employed.
2. Data available to measure the actual conditions in the forecast year.
3. Events between the making of the forecast and the forecast year should have taken place as they were assumed to, and the occurrence of other events should not have invalidated the forecast assumptions.

Beginning with the third assumption, events such as wars or major economic crises occurring between the study and forecast years would obviously invalidate any study. Less obviously, major changes in the pattern of social and economic development, such as relocation of old industries or introduction of new ones, would equally affect results. Changes in the transportation system should conform to forecast assumptions. Many studies made during World War II and earlier were ruled out by the third assumption.

The second condition immediately restricted the potential data sources to locations where two studies had been conducted, because data would be needed from the second study to match the forecast data. The more recent study should match or be reasonably close in time to the year of the forecast. With a 10-, 15, or 20-year gap between the date of the typical study and its target year, evaluation of the most recent repeat studies meant that the forecasts would have been made in the early 1950's or late 1940's.

A frequent problem with old forecasts was scanty data for the base year from which the forecast was extrapolated. Most studies were made in the intermediate periods between census years, so the prevailing population, vehicle registration, and other statistics were based on estimates. More critical was the problem of finding sufficient other data, such as land-use inventories, population distribution, and car ownership. Compatibility of data between the old and new studies was a further requirement. Compatibility was necessary in definitions of data, for instance, in matching home interview data on demographic as well as in geographic definitions, such as corporate boundaries, the survey zones, or the locations of survey stations to which data would be related.

Data Requirements for Assignments

Evaluation of assignments requires a different set of conditions from those outlined previously for forecasts. The two principal requirements for assignment testing were as follows:

1. Detailed descriptions of a major highway facility and the highway system of which it was a part.
2. Travel data in the form of a zone-to-zone table, assignable to the route or system.

In order to make assignments with customary techniques, sufficient detail to develop parameters of travel time, distances, and/or costs between trip terminals was necessary, so that descriptions of the street system had to include link lengths, operating speeds, capacity (in turn requiring type of area, roadway width, grades, etc.)

Travel data sources considered were home interview data from urban area studies, the use of cordon line surveys from such studies, and the use of regional or statewide screenline surveys. The use of screenline studies provided the advantage of data with larger sampling rates than were available in home interview data. Such surveys would report the zone-to-zone movements actually found to be using certain segments of the highway system.

Desirably, two O-D surveys would be needed, one made before the opening of a new facility and one after, so that the new volume could be measured and the effect of the new facility could be evaluated. The time span between the two studies should be brief and no other highway system changes should have taken place, unless their effects could be separately evaluated. Alternately, assignment tests could be made with data from just one survey, if these were screenline trip data taken at several points. In such a situation, a variety of assignment techniques could be tested for their effectiveness in reproducing the survey trip volumes at the different survey stations of the screenline.

Sources of Data

Upon the inception of this study a detailed search was conducted for sources of data necessary for analysis. Because neither time nor funds were available to collect field data on origin-destination and traffic volumes, it was proposed to check the resources of state and urban highway planning agencies for existing data suitable for the project. Approximately 100 published reports (listed in Appendix B) were reviewed and personal contact was made with 9 state highway agencies, 4 offices of the Bureau of Public Roads, 8 urban area transportation study groups, and 3 consulting traffic engineer firms.

It developed that an extremely limited number of studies met the data requirements for checking traffic forecasts, and most were rejected for one or more of the following reasons:

1. Failure to build or complete the system as planned at the time of forecast.
2. Scanty information about the base year from which forecasts were extrapolated.
3. Absence of follow-up studies during or about the year of the forecast.
4. Incompatibility of data where before and after studies had been made.

An analysis of the published reports showed that forecasts were prepared for a variety of data types and projected to various years, as noted (to the nearest 5-year date) in Table 1. In only one-half of the studies had the target year been reached, and in most instances no follow-up studies have been made. For a variety of reasons, as previously noted, the data failed to satisfy the requirements of this study.

Two Urban Area Examples

Two examples are given to demonstrate the nature of the available studies and the difficulty in evaluating them. Neither study is cited as being particularly successful or for any shortcomings, but each study is typical of techniques employed at the time, and the actual events that took place between the study date and 1960 are not extraordinary.

ROCHESTER, N.Y.

In 1947, the New York Department of Public Works made an excellent comprehensive traffic study in Rochester as one of a series being made in the postwar years. The study (*1*) recommended major highway changes and additions, such as a central business district boulevard loop. One part of the report showed 12-hr volumes on downtown arterials in both 1947 and projected 1960, another section discussed forecasts of population and vehicle registrations, and a third section evaluated the study recommendations vis-a-vis the generalized principal land uses existing in 1947. Table 2 summarizes some major statistics for 1947 and for 1960, and for the anticipated 1960 conditions.

Population has been separated into categories permitting comparison between three groups—the City of Rochester,

TABLE 1

DISTRIBUTION OF FORECAST DATA IN PUBLISHED REPORTS STUDIED

PROJECTED DATE OF FORECAST [a]	STUDIES (NO.) FORECASTING					
	POPULATION	VEHICLE REGIS.	TRAFFIC VOLUME	FUEL CONS.	VEHICLE-MILES	LAND USE
1960	14	15	15	0	3	0
1965	29	27	30	0	0	1
1970	28	14	29	4	4	6
1975	9	10	13	1	1	0
1980	6	4	3	3	0	0
All	86	70	90	8	8	7

[a] To nearest 5-year date.

TABLE 2

SUMMARY OF MAJOR STATISTICS IN ROCHESTER, N.Y., TRAFFIC STUDY

STUDY DATE	POPULATION (1,000's)			POPULATION CHANGE (%)			COUNTY REGISTRATIONS (1,000's)			VEH. REG. CHANGE (%)	PERSONS PER CAR
	MONROE COUNTY	ROCHESTER	SUBURB-RURAL	MONROE COUNTY	ROCHESTER	SUBURB-RURAL	CARS	TRUCKS	TOTAL		
1947	450	330	120	—	—	—	120	12	132	—	3.4
1960, forecast	500	350	150	+11.1	+6.1	+25.0	167	17	184	+39	2.7
1960, actual [a]	586	319	267	+30.2	−3.3	+122.5	194	18	212	+61	3.0

[a] Ref. (2).

the remaining Monroe County area, and the County total. Vehicle registrations were estimated from a graph in the report for the 1947 data. It is not known, but it is considered likely that the 1947 population figures were extrapolated from 1940 census data, perhaps on the basis of some later demographic study.

The most readily apparent divergence between the 1960 forecast and actuality was in population estimates. Where the forecast predicted a modest 6 percent gain for the city of Rochester, the actual result was a 3 percent loss. For the County as a whole, the forecast of 11 percent increase was only one-third of that taking place. Where a gain of 30,0000 people (25 percent of 1947 population) was expected for Monroe County exclusive of Rochester, a gain of 147,000 people (123 percent) materialized. The problem here was not only one of underestimating gross population gains, but one of locating the gains appropriately.

The underestimate of population was offset to some degree by an overestimate of car ownership levels. From a level of 3.4 persons per vehicle in 1947, car ownership was expected to increase to a level of 2.7 persons per vehicle. A little over one-half of that gain was actually achieved. Even so, vehicle registrations were 28,000 more than forecasted, the actual gain being 61 percent over levels compared with the 39 percent predicted. Though vehicle registrations could not be distributed between the City and the remainder of the County, it is obvious that the suburban-rural areas were greatly underestimated on vehicle registrations.

What could not be determined from the Rochester report was how the forecast data were applied to obtain the 12-hr and peak-hour data for downtown Rochester streets in 1960. This inquiry was not pursued, even though it was noted that many of the study recommendations had been put into effect, because it was felt that the wide difference in population between the forecast and 1960 census invalidated further comparisons.

TUCSON, ARIZ.

A similar type of study for Tucson, Ariz. (*3*), published in 1951, was based on a home interview travel survey made in 1949 by the Arizona State Highway Department. A forecast of traffic volumes on a freeway bypassing the central business district was included in the study and the freeway had been built as planned prior to 1960. Plans to compare the 1970 forecasts made in this report with the results of a 1960 repeat study (*4*) were frustrated by difficulties in matching 1949 study zones with those of the much larger 1960 area. Further, the large population increase between 1949 and 1960 negated many of the comparisons that might have been made.

A comparison similar to the earlier one for Rochester gave evidence of the situation (Table 3); in this case, the three years for comparison were 1948, actual 1960, and

TABLE 3

SUMMARY OF MAJOR STATISTICS IN TUCSON, ARIZ., TRAFFIC STUDY

STUDY DATE	POPULATION (1,000's) METRO AREA	POPULATION (1,000's) PIMA COUNTY	POP. CHANGE (%) COUNTY	POP. CHANGE (%) PER YEAR[a]	VEHICLE REGIS., PIMA COUNTY[b]	CHANGE IN VEHICLE REGIS. (%)	PERSONS PER VEHICLE
1948	126	133	—	—	40,200	—	3.3
1960, actual	213	266	+100	5.9	97,000	141	2.7
1970, forecast	213	227	+70	2.5	76,000	89	3.0

[a] Percent change per year, compounded. [b] Passenger cars.

forecast 1970. Population is given for the metropolitan area rather than for either the City or the study areas, because the corporate boundaries were also extended between the two studies.

Most startling was that the 1960 population surpassed that forecast for 1970. This was not a case of changing political boundaries affecting the statistics, the effect can be seen for the entire county. If the corporate boundaries, however, had not been enlarged, it could have been demonstrated that most of this phenomenal population growth took place in suburban fringes as it did in Rochester. The forecasted 70 percent gain was extremely low, and applied as an average growth factor to the 1948 assigned volumes on the proposed freeway, was obviously low on forecasted volumes. One contrast with Rochester may be pointed out. The car ownership levels were forecasted to change from 3.3 to 3.0 between 1948 and 1970. The actual 1960 ratio was 2.7, or exactly what Rochester had forecast but not obtained. Where Rochester had overestimated the rate-of-change in car ownership, Tucson had underestimated.

Forecasts on a National Scale

The growth in highway travel during the decade of the 1950's may best be summed up by a review of a national forecast. Holmes in 1950 predicted (*5*) a 4 percent compounded growth rate in travel for the nation's next decade. Starting with a 1950 figure of 450 billion vehicle-miles, a figure of 666 billion was forecast for 1960. Actual travel was estimated by the Bureau of Public Roads at 719 billion vehicle-miles, a total gain of 60 percent rather than 48 percent. Vehicle registrations grew from 48.5 million to 73.8 million over the same period. Though this registration forecast was only slightly low, the Rochester and Tucson studies, as would most others, disclose that this growth was least within the cities and most marked in the suburban fringes. Rural state highway surveys across the nation probably would show, collectively, about an average rate of growth. The difficulty in making an accurate forecast for 20 years ahead for one urban area or one route is clearly apparent. When national forecasts fall short on a 10-year look ahead, forecasts based on smaller areas, fewer basic data, less stable trends, and longer time periods must be subject to question.

The Data Analyzed

As a result of the extensive literature search and the visits to the 24 highway agencies, only two usable sources of data were discovered. These involved the following:

1. Before and after origin-destination data relative to traffic volumes on a new river crossing (Interstate 91) of the Connecticut River. Origin-destination data for 1956 and 1963 were available from the Connecticut State Highway Department. Network coding information was available from the Connecticut State Highway Department and the Massachusetts Department of Public Works. These data were used to check assignment techniques and to make elementary tests of forecasting techniques.
2. The Pennsylvania Highway Department provided data on traffic studies and facilities in the vicinity of Pittsburgh. Subsequent studies of the same area by the Pittsburgh Area Transportation Study were made available so that the results of earlier studies could be compared with actual volumes and O-D patterns after construction had been completed. The Pittsburgh Area Transportation Study data were also used in analysis of assignment techniques to a network.

Chapters Two and Seven describe the studies undertaken with the Connecticut and Pittsburgh data.

TRAFFIC ASSIGNMENT

Historical Review

Realism in traffic assignment techniques has been a long sought for ideal by highway planners; the prediction of future highway use has been attempted by them for more than 40 years. Hooper (*6*), in 1952, described the inadequacy of the then current methods. Assignment of trip tables to a route or a network became feasible with the advent of large-scale digital computers and the discovery of minimum-path algorithms (*7*). From a simple and practical aspect, the all-or-none approach to network assignment has been in general use for more than 10 years.

The Detroit Transportation Study (*8*) in 1958 is generally credited with the first technique to depart from the traditional diversion curve method. Almost simultaneously with the Detroit study, the Chicago Area Transportation Study (*9*) developed a different technique. The Washington

(D. C.) Regional Highway Planning Committee, in cooperation with the General Electric Company and the BPR (*10*), developed a third method, and Irwin, Dodd, and Von Cube, of Traffic Research Corporation, working on a Toronto study (*11*), developed still a fourth technique.

Martin (*12*) in 1963-64 developed a pilot program to enable comparisons to be made of these various techniques. Due to the many differences in hardware and software configurations, it was not possible to borrow the various computer programs and just feed them into a single machine. Martin's approach was to borrow assignment techniques from the previously mentioned works and use a set of volume-delay curves to determine the restraints in each case.

The current study expanded on this thought of using the same network and trip table to determine the effectiveness of each technique. Thus, it incorporated the volume/capacity functions as published for each technique, with the exception of the TRC method, which had utilized volume-delay curves. Martin initially employed a rather small theoretical network, whereas the current study utilized trip tables and coded networks obtained from actual study areas. In effect, the major differences between Martin's work at MIT and this report are the choice of networks and O-D data, the restraint functions, and the application of each technique considered. Martin also developed a fifth technique called "incremental loading." This technique, although interesting, requires so much computer space that all of the networks obtained from the various transportation study groups were simply too large to permit testing.

A more complete history of traffic assignment may be found in the BPR *Traffic Assignment Manual* (*10*).

Uses of Information

Traffic assignment is a tool which provides information to both the highway planner and the designer, each of whom has a different application for the information supplied by traffic assignment results. The traffic planner is interested in the evaluation of a proposed system of roadways and freeways, in the transportation services provided to different portions of the region being analyzed, and in a total evaluation of how well his goals are being met by the plan being tested.

The highway designer is interested in obtaining estimates of volume on a particular facility with which he is concerned, which may be a length of freeway, a particular interchange, or turning movements at an existing intersection. The designer is interested in individual link loads, using these as a guide in the geometric design of the facility under consideration. Witheford (*13*) and Schneider (*14*) have pointed out the difficulties in applying the results of network assignments to specific design problems. This study is an analysis of traffic assignments with particular emphasis on link assignments and their use by the highway designer.

Requirements for Design

The major determinant for the geometric design of a facility is the number of lanes needed to satisfy the volume expected on a roadway. The number of lanes which must be provided is obviously a function of the expected volume on a link. Lanes are added in increments, so that capacities are increased by increments. For example, a 4-lane expressway with 11-ft lanes, on level terrain, some at-grade intersections, 8 percent trucks, and 6 percent intercity buses will have a level D capacity in either direction of 2,755 vph between intersections (*15*).

Assuming the peak-hour flow is 12 percent of the ADT, the expressway capacity is 23,000 vpd. Three lanes will accomodate 34,500 and four lanes will accomodate 46,000 vpd.

Similarily, for major streets in urban areas, the AASHO publication on arterial highways in urban areas (*16*) indicates that the two-way ADT capacity of a major street with 6 lanes may vary from 21,000 vpd to 40,000 vpd when there is no parking and a low volume of cross and turning traffic. With a high volume of cross and turning traffic, the same facility may have a two-way ADT capacity ranging from 9,000 to 20,000 vpd.

The net effect is that whereas assignments may result in as much as a 15 percent variation from an expected value, as shown later, the latitude in capacity for a particular design may compensate for these assignment errors. At the same time the assignment results are the most likely estimate of what can be expected along any particular link of the network.

It is evident that as far as the relationship between capacity and volume is concerned there is a wide latitude in forecast volumes that will be accommodated by a given number of lanes, and that the addition of a single lane gives a large step increase in capacity.

CHAPTER TWO

CONNECTICUT RIVER BRIDGE STUDIES

The tests made with the Connecticut Highway Department data compared assigned volumes to observed volumes, before and after the installation of a major river crossing facility. The study was conducted in three phases, as follows:

1. A test of four different assignment techniques, comparing results of assigning the 1956 O-D trips to 1956 observed volumes on two Connecticut River bridges.
2. Evaluation of the same four assignment techniques after the introduction of a third river crossing, comparing the results of assigning the 1963 O-D trips to 1963 observed volumes. Tests of a new technique for simultaneous assignment to all three bridges were also made.
3. Expansion of the 1956 table to a 1963 forecast and comparison of the results of assigning these trips with 1963 observed volumes.

A map of the study area as it relates to Connecticut and Massachusetts, and the details of the bridge locations and major highway network are presented in Figure 1. The three bridges are, respectively, 2.18 miles, 7.10 miles, and 7.76 miles south of the Massachusetts-Connecticut boundary. The newest bridge, carrying I-91, is south of the two older bridges. The ADT volumes for 1956 and 1963 are given in Table 4.

Much of the increase in traffic volume across the river between 1956 and 1963 resulted from a diversion of north-south traffic from either Route 5 or 5A to I-91, in which case trips that formerly stayed on one side of the river or the other now cross the river within the limits of the study area. The remainder of the increase in traffic volumes was a result of traffic expansion in the study area

AVAILABLE DATA

Network data consisting of link lengths to hundredths of miles and speeds to the nearest mile per hour were available from the Connecticut Highway Department. The network description was extended to incorporate the Massachusetts highway system as far as Springfield, and all river crossing links other than those associated with the study bridges were deleted from the network. This last step insured that assigned trips had no more choices than those indicated in the roadside survey. The 1963 network differed only in the added coding for Interstate Route 91 and its associated ramps.

ORIGIN-DESTINATION INFORMATION

The 1956 study had been made on six Connecticut River bridges for the Greater Hartford Bridge Authority. Interview stations were operated 24 hr a day for four days on each bridge and the interviews were factored to 24-hr ADT values. These data were arranged for trips between 89 zones on the east side of the river to 33 zones on the west side of the river for the purpose of this study. Points of entry to or departure from the study area were selected by judgment according to the major highways serving the region.

The 1963 O-D data were collected as part of a statewide transportation study, in contrast to the limited area of the 1956 study. As a result, the 1963 data were less extensive than the 1956 data. The Thompsonville and Windsor Locks interview stations were operated for only 8 hr, and each town was coded as one zone rather than several as in the earlier study. The details reconciling the two origin-destination studies to a common basis are included in Appendix C.

Prior to testing the assignment techniques, tables of observed two-way trips were prepared, as follows:

1956

A. Between east zones and west zones, north bridge (Thompsonville).

B, Between east zones and west zones, south bridge (Windsor Locks).

C. Between east zones and west zones, both bridges combined.

1963

D. Between east zones and west zones, north bridge.

E. Between east zones and west zones, south bridge.

F. Between east zones and west zones, I-91 bridge.

G. Between east zones and west zones, three bridges combined.

Tables C and G were used as the sources for assigning trips in 1956 and 1963 and the remaining tables were used in comparing the actual zone-by-zone trips assigned to each bridge.

ASSIGNMENT TECHNIQUES TESTED

Four assignment methods were written into the overall program so that results could be presented and evaluated simultaneously. These were: (1) the AASHO diversion curve; (2) the California time and distance curves; (3) a ratio method designated here as the "easy method"; and (4) the all-or-nothing minimum path. The formulations employed are described in Appendix C.

RESULTS OF 1956 ASSIGNMENT

The results of assignments to the two bridges by different methods (four assignment techniques, both time and distance) are given in Table 5, which compares assigned volumes to surveyed volumes, and gives the standard error. A full discussion of the error calculation is given in

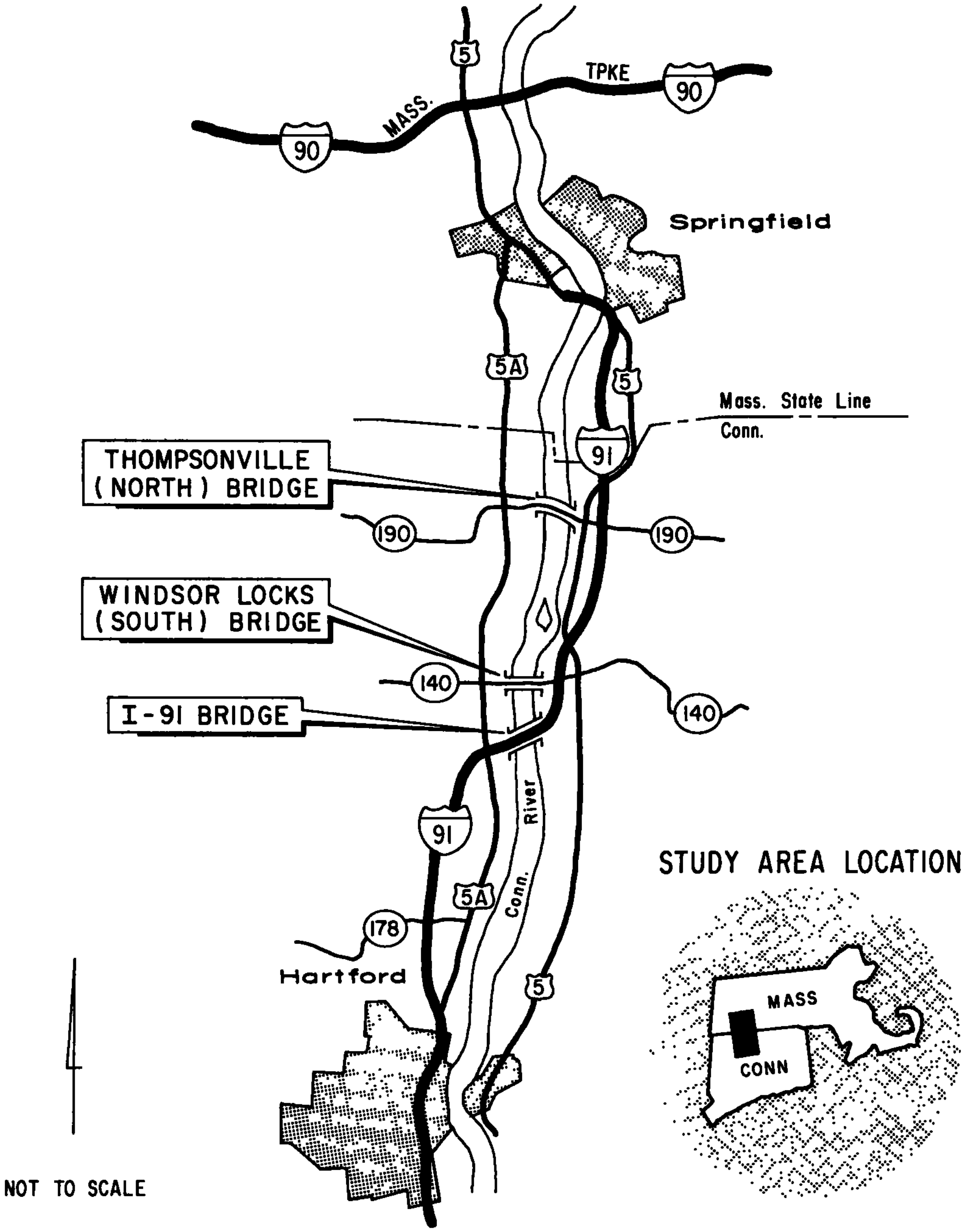

Figure 1. Map of Connecticut River study area.

Appendix C. It is simply stated that approximately two-thirds of the time the difference between actual and assigned volumes from any one zone to all others will range between ± one standard error, thus the lesser values indicate better precision. Volumes assigned to the south bridge ranged on both sides of the survey volume, from a low of 9,243 to a high of 12,186. This is a variation from 90 to 119 percent of the survey volume. Of the eight assignment techniques, five produced results within 7 percent of the survey data on the south bridge. The only assignment with a significantly broad variation from the survey is the all-or-none time assignment, for which the standard error is the greatest.

TABLE 4

SUMMARY OF ADT VOLUMES,[a] CONNECTICUT RIVER BRIDGE STUDY

	ADT (VPD)	
BRIDGE	1956	1963
Thompsonville	6,501	5,400
Windsor Locks	11,245	6,600
I–91	—	24,600
All	17,746	36,600

[a] Source: Bureau of Planning and Design, Connecticut State Highway Dept. (unpublished data).

TABLE 5

SUMMARY OF 1956 ASSIGNMENT RESULTS, CONNECTICUT RIVER BRIDGE STUDY

		TRAFFIC DISTRIBUTION (VPD)								
			AASHO [b]		CALIF. [c]		EASY		ALL-OR-NONE	
BRIDGE	PARAMETER	1956 SURVEY [a]	NO.	STD. ERROR	NO.	STD. ERROR	NO.	STD. ERROR	NO.	STD. ERROR
South	Time	10,222	9,647	42.3	10,659	64.8	9,646	45.8	12,186	149.2
	Dist.		9,243	51.3	10,649	64.1	9,306	49.2	10,859	99.9
North	Time	5,717	6,292	—	5,280	—	6,293	—	3,753	—
	Dist.		6,696	—	5,290	—	6,633	—	5,080	—

[a] Actual. [b] AASHO diversion curve. [c] California time and distance curves.

The lowest standard error is for the AASHO time assignment, although the California method best matched the aggregate assigned and survey volume.

Further detailed examinations of the assignments were made in order to detect any inherent bias. These are presented in detail in the Appendix C.

A summary of the analysis of the number of possible pairs of interchanges by volume groups and the total volumes in these groups is given in Table 6. All told there are 2,937 (89 x 33) possible interchanges between the east and west side of the river, but the study reported 406 interzonal transfers and only 359 of these were actually observed on the south bridge. The eight methods assigned from 322 to 377 of the combinations to the south bridge. Similar good results were obtained by zone-to-zone volume groupings and stratified trip volumes.

Figure C-7 shows the relationship between trip length and assignment results for the south bridge. This display was prepared to detect whether any bias crept into assigned volumes because one technique might tend to assign shorter trips while another assigned long trips. For example, because point-of-choice alternate routes were not used, diversions based on time or distance ratios from origin to destination would tend to divide trips more evenly between bridges as trips got longer, because ratios would be closer to unity. A brief summary of Figure C-7 is presented in Table 7, which gives the calculated average trip length, the number of survey and assigned zone-to-zone movements, and the trip volume in the ranges of 0-20 miles and 50-60 miles. Only the maximum and minimum values are indicated. It is apparent that there are no major distortions by the assignments in these respects. A similar conclusion is provided from an analysis of travel time distributions (Fig. C-13).

Inasmuch as ratios are determinates in the AASHO technique, a comparison of results by time-ratio stratification was undertaken. Trips were first stratified by travel time via the south bridge. The results are summarized in Table 8. The AASHO diversion curves provided a good simulation of survey findings in this respect. As might be expected, the bulk of the zone-to-zone interchanges had time ratios between 0.6 and 1.2. A similar series of tabulations using distance parameters gave much the same results.

In summary, it appears that for 1956 data all of the techniques tested have produced reasonable results. In terms of volumes and major movements, all the techniques appeared reliable, as they did in subsequent analysis by stratifications of trip movements. Inasmuch as the 1963 assignments were analyzed in a similar manner, it was possible to determine whether similar results were to be found.

TABLE 6

SUMMARY OF RESULTS OF 1956 VOLUME CHARACTERISTICS ANALYSIS FOR THE SOUTH BRIDGE,[a] CONNECTICUT RIVER BRIDGE STUDY

	ZONE TO ZONE MOVEMENTS (NO.)	MOVEMENTS (NO.) IN		TRIPS (NO.) IN	
STUDY GROUP		1-10 VOLUME	200 OR MORE	1-10 RANGE	200 OR MORE
1956 survey	359	246	10	822	5188
Computer assignment:					
Max.	377	275	11	863	6602
Min.	322	204	8	698	4528

[a] Source: Figure C-1.

TABLE 7

SUMMARY OF RESULTS OF 1956 ANALYSIS OF TRIP LENGTH AND ASSIGNMENT FOR THE SOUTH BRIDGE,[a] CONNECTICUT RIVER BRIDGE STUDY

		TRIP LENGTH 0-20 MILES		TRIP LENGTH 50-60 MILES	
STUDY GROUP	AVG. TRIP LENGTH (MI)	NO. OF MOVEMENTS	ASSIGNED TRIP VOL.	NO. OF MOVEMENTS	ASSIGNED TRIP VOL.
1956 survey	16.15	97	7773	34	155
Computer assignment:					
Max.	16.27	100	9274	36	186
Min.	15.32	83	7303	29	108

[a] Source: Figure C-7.

RESULTS OF 1963 O-D DATA ASSIGNMENTS

Two factors contributed to differences between the 1956 and 1963 assignments. One was the coarser zone definition in the more recent study, where location of the one loading node in 1963 had more influence in determining the distribution of assigned trips across the bridges than it had in the 1956 assignment. The other factor was the three-bridge situation. This was treated in two ways. First, for comparison with 1956 data, the assignment which used I-91 as one route and the better of the 1956 crossings as the alternate was used. In some instances, the Interstate crossing would be the least likely choice; yet it was always considered as one of the alternates, while one or the other of the 1956 bridges was always eliminated from consideration. It was felt that this assignment was representative of usual applications and thereby merited evaluation. Second, a new relationship comparing all three routes at once was introduced and the volumes were again assigned.

TABLE 8

SUMMARY OF COMPARISON OF 1956 RESULTS BY TIME-RATIO STRATIFICATION IN AASHO TECHNIQUE FOR THE SOUTH BRIDGE, CONNECTICUT RIVER BRIDGE STUDY

TRAVEL TIME (MIN)	TRIPS ON SOUTH BRIDGE WITH TIME RATIO > 1 (%): 1956 SURVEY	AASHO TIME	AASHO DIST.
0–10	0	0	0
10–20	3.5	3.2	0.8
20–30	4.0	3.7	3.0
30–40	1.4	4.7	3.4
40–50	1.3	1.8	1.7
50–60	2.2	1.9	1.9
60 +	4.6	6.1	6.1

I-91 vs Best Alternate Assignments

The assigned volumes for the eight assignments and the survey are given in Table 9. There is a wide spread between assignment results: three of the assignments based on time provide a close match to the survey, but the California method (as used here) underassigned trips for both time and distance comparisons. All other assignments based on distance were extremely low. The standard errors followed accordingly, with all-or-none time showing the lowest standard error of 118, the next lowest being 201. It was obvious from the results, however, that the south bridge was overassigned with distance techniques because major movements did not obtain any distance advantage by the Interstate crossing. The California method, employing time and distance in both instances, produced results that came closer to the survey volume, but volumes were still low because of the distance function. The three assignments based solely on time produced results within 7 percent or less of the survey volume on the I-91 bridge.

The analyses by volume groups, travel time, and trip length distributions are presented for comparison with 1956 results in Appendix C. A summary of volume characteristics on the I-91 bridge is given in Table 10.

The lower number of zone-to-zone movements was partly a function of the coarse zoning for the 1963 data. The proportion of low-volume interchanges was much lower than in the 1956 conditions. At the other end of the volume group scale, there were both more movements and higher volume. In 1963, 68.6 percent of the survey volume was in interchanges of 200 trips or more. In 1956, the figure was 50.8 percent. The assignments reproduced this situation, although it was masked to some extent by the understating of the distance assignments.

Examination of trip length distribution for 1963 trips assigned to the I-91 bridge (Fig. C-10) showed at least one significant difference from 1956 data; the average survey trip length increased from 16.15 to 25.70 miles. This is due to the greater proportion of Connecticut River Corridor trips (between Hartford and Springfield, for example) that crossed the river within the study section. In the 1956 study area, these trips were probably on either Routes 5 and 5A exclusively, with their crossing points outside of

TABLE 9

SUMMARY OF 1963 ASSIGNED AND SURVEY TRAFFIC VOLUMES, CONNECTICUT RIVER BRIDGE STUDY

BRIDGE	PARAMETER	TRAFFIC DISTRIBUTION (VPD): 1963 SURVEY [a]	AASHO NO.	AASHO STD. ERROR	CALIF. NO.	CALIF. STD. ERROR	EASY NO.	EASY STD. ERROR	ALL-OR-NONE NO.	ALL-OR-NONE STD. ERROR
I-91	Time	17,167	16,167	287.9	14,227	234.7	16,037	290.9	17,007	118.2
	Dist.		10,963	427.6	14,585	201.9	11,109	423.9	10,590	759.1
South	Time	6,062	8,595	—	9,289	—	8,654	—	7,448	—
	Dist.		12,864	—	9,805	—	12,674	—	12,562	—
North	Time	5,079	3,546	—	4,793	—	3,617	—	3,854	—
	Dist.		4,482	—	3,913	—	4,526	—	5,157	—

[a] Actual.

TABLE 10

SUMMARY OF RESULTS OF 1963 VOLUME CHARACTERISTICS ANALYSIS FOR THE I-91 BRIDGE,[a] CONNECTICUT RIVER BRIDGE STUDY

STUDY GROUP	ZONE-TO-ZONE MOVEMENTS (NO.)	MOVEMENTS (NO.) IN 1-10 VOLUME	MOVEMENTS (NO.) IN 200 OR MORE	TRIPS (NO.) IN 1-10 RANGE	TRIPS (NO.) IN 200 OR MORE
1963 survey	204	66	17	385	11,766
Computer assignment:					
Max.	250	149	16	646	11,609
Min.	91	26	14	147	6,588

[a] Source: Figure C-4.

the study area. Approximately 10 times as many trips were found in the longest trip categories in the 1963 study. Figure C-10 shows again a wider range of deviations about the survey data. In general, though, the assignments produced the same percentage distribution across the range of trip lengths. A summary of trip-length distributions assigned to the I-91 bridge is given in Table 11.

The tabulations of zone-to-zone movements by volume groups within the trip-length increments show results similar to the 1956 test. The AASHO and Easy time assignments closely corresponded to the survey data in the spread of trip interchanges and volumes across the volume ranges. All-or-none time did not match by volume groups as it had for 1956 data, but the total trips in each trip-length category were reasonably close to the survey volumes. Distance assignments could not be evaluated realistically because volumes were low.

The study of how individual zone-to-zone assigned volumes compared with their survey counterparts showed at first glance a broader range of errors in the 1963 assignments. For example, although the AASHO time assignment in 1956 had shown 327 out of 359 interchanges having differences of less than 10 from the survey volume, the 1963 assignment showed only 129 out of 204 in the same error bracket. Yet, in 1956, 246 out of 359 survey interchanges were in the 0-10 volume group and in 1963 only 66 out of 204 were in the same volume class.

TABLE 11

SUMMARY OF RESULTS OF 1963 ANALYSIS OF TRIP LENGTH AND ASSIGNMENT FOR THE I-91 BRIDGE,[a] CONNECTICUT RIVER BRIDGE STUDY

STUDY GROUP	AVG. TRIP LENGTH (MI)	TRIP LENGTH 0-20 MILES: NO. OF MOVEMENTS	TRIP LENGTH 0-20 MILES: ASSIGNED TRIP VOL.	TRIP LENGTH 50-60 MILES: NO. OF MOVEMENTS	TRIP LENGTH 50-60 MILES: ASSIGNED TRIP VOL.
1963 survey	25.70	39	9,146	45	1,574
Computer assignment:					
Max.	28.70	44	10,115	52	1,187
Min.	21.68	9	4,622	25	796

[a] Source: Figure C-10.

In summary, except for the distance assignments, the re-run of the assignment techniques on the 1963 network produced I-91 bridge volumes agreeing with the survey values. The technique was that customarily employed of assigning to the major facility, considering only the one best alternate route of the several possible routes. The distance assignments were very poor, obviously because distance alone did not reflect the improved level of service offered by the freeway. This is confirmation, at least, of experience elsewhere. The 1963 assignments suggested, also, that for detailed comparisons on minor stratifications of the trip volume assigned to a facility, the AASHO technique provided better results. All-or-nothing time assignment, however, did provide an excellent match with the overall survey volume.

Use of a Multi-Alternate Model

In the foregoing assignments of trips, the diversion curves were applied between the I-91 bridge and that one of the remaining two bridges which had the shortest travel time (or distance) between the subject zones. For this study it was reasoned that traffic would distribute itself in inverse proportion to the travel time over all three of the alternate routes. For example, assume that the travel times by way of bridges 1, 2 and 3 are 5, 2, and 4 min, respectively. It would be anticipated that the greatest number of drivers would select bridge 2, the next greatest number, bridge 3, and the fewest drivers bridge 1. Assuming 950 trips to be assigned, the results would be as follows:

$$\text{Bridge } 1 = 950 \times \frac{1/5}{1/5 + 1/2 + 1/4} = 200$$

$$\text{Bridge } 2 = 950 \times \frac{1/2}{1/5 + 1/2 + 1/4} = 500$$

$$\text{Bridge } 3 = 950 \times \frac{1/4}{1/5 + 1/2 + 1/4} = 250$$

$$\text{All bridges} = 950$$

The results of assigning the 1963 volumes to the three bridges (Table 12) were only moderately successful. The I-91 bridge, despite a substantial time advantage, received fewer trips than were observed in the survey. The I-91 bridge showed no real advantage over either of the alternate bridges when distance was the parameter. At this point it was decided that to raise the travel time to some power, N, would emphasize the time advantage of the new bridge and the analysis was repeated, for both time and distance.

The effect of using $N = 2$ on the previous example would be as follows:

$$\text{Bridge } 1 = 950 \times \frac{1/5^2}{1/5^2 + 1/2^2 + 1/4^2} = 108$$

$$\text{Bridge } 2 = 950 \times \frac{1/2^2}{1/5^2 + 1/2^2 + 1/4^2} = 674$$

$$\text{Bridge } 3 = 950 \times \frac{1/4^2}{1/5^2 + 1/2^2 + 1/4^2} = 168$$

$$\text{All bridges} = 950$$

The exponent, N, for the power of time and distance was increased in steps of 1 and the difference between survey and assigned volumes for time assignments was plotted against the exponent, as shown in Figure 2. Because the I-91 expressway was at a distance disadvantage, an increase in N exaggerated the errors, and distance assignments were not further analyzed. Also shown is the error term for each of the three bridges; the error term for the north bridge was a minimum at $N = 7$ and for the other two bridges between 11 and 12.

The total difference between assigned volume and survey volume continued to decrease up to $N = 12$ for the south and I-91 bridges, but the differences on the north bridge were minimized when $N = 11$ and then began to increase. The results of the survey vs assigned volume on the 1963 network when $N = 11$ are given in Table 13. These results on I-91 are better than all those obtained in the previous assignment (I-91 vs best alternate) except for the all-or-none method. The results on the north and south bridges are substantially improved by using the multi-alternate method.

The use of a power ($N = 11$) is not the ultimate answer. Further testing, where three or more routes are available as alternates, and at different geographical locations, will be required to determine the optimum value of N. It might be noted that as the value of N is increased, this assignment technique approaches an all-or-none solution.

TABLE 12

SUMMARY OF RESULTS OF ASSIGNING 1963 VOLUMES TO THE THREE BRIDGES,[a] CONNECTICUT RIVER BRIDGE STUDY

BRIDGE	PARAMETER	TRAFFIC DISTRIBUTION (VPD) 1963 SURVEY [b]	ASSIGNED VOLUME NO.	ASSIGNED VOLUME STD. ERROR
I-91	Time	17,167	10,413	630
	Dist.		9,347	683
South	Time	6,062	9,355	389
	Dist.		9,744	387
North	Time	5,079	8,540	490
	Dist.		9,218	498

[a] On 1963 network. [b] Actual.

RESULTS OF THE 1963 FORECAST ASSIGNMENTS

In this phase of the tests, the volumes assigned to the 1963 bridges and network were based on the logical expansion of 1956 O-D data. The choice of techniques to obtain the forecast of future travel was limited. By the nature of the survey data for the base year, the use of gravity or similar type trip models was not feasible. Trip data by zones or towns were limited to river crossing travel; other travel was unknown. Similarly, there was no knowledge of base-year land uses by zone, households by zone, car ownership by zone, or any of the other socio-economic statistics except population and average daily traffic on state highways. Because the only available data were the estimate of the change in population (*17*) between 1956 and 1963, and observed increases in traffic volumes of external stations from 1956 to 1963, some form of growth factor technique was necessarily applied. The Fratar method was selected because a computer program was available.

The growth factors obtained by calculating the ratio of 1963 population to 1956 population were used in the Fratar model and the 1956 O-D table was updated to 1963. The Fratar model was applied to the entire 122 × 122 matrix of trips and then after expansion the river crossings (89 × 33) were assigned to the three bridges, comparing the I-91 bridge with the best of the two alternate bridges. The results are given in Table 14.

The results of expanding the 1956 trips to 1963 in terms of population growth was to produce 22,789 trips across the river, compared to the survey value of 28,308 trips in 1963. Overall, there was a real gain of 78 percent in river crossings between 1956 and 1963, but the forecast based on population growth produced a gain of only 43 percent.

One factor whose influence could not be assessed was the effect of the Interstate route in establishing river crossings that had not taken place in the 1956 study area. For example, a typical 1956 trip from Hartford to Springfield might have crossed the river in either city and passed through the study area entirely on either the east or west side of the river without appearing in the survey data. The same trip in 1963 would be very likely to appear in the survey of the I-91 bridge, so that expanding 1956 survey trips would not reproduce 1963 volumes if the 1963 facility attracted travel from routes not surveyed in 1956. This is most likely to happen for travel on a SW-NE axis through the study area.

A better test of the Fratar technique was performed by setting the growth factors in each zone equal to the ratio of 1963 trip ends to 1956 trip ends, and calculating a new 1963 forecast trip table. Total river crossing trips produced as a result were 27,882, or 98.5 percent of the survey volume. The resulting assignments to the I-91 bridge are given in Table 15.

The assignments have been much improved, but the expansion factors were based on data not available to the planner in 1956.

The difficulties of reproducing a zone-to-zone table by trip forecasting methods were clearly evaluated several years ago by Brokke and Mertz (*18*) reporting on studies of travel in Washington, D.C. The present investigation was undertaken for a different purpose—to find out how well a forecast technique predicted actual volume on a major facility. The first pass, using only population data for growth, was a failure. Using the known growth characteristics, as reported by two O-D surveys, the forecast fared much better. Even so, it appeared that tolerance was necessary for comparison with similarly assigned survey volumes.

TABLE 13

SUMMARY OF RESULTS OF 1963 NETWORK ASSIGNED VOLUMES WHEN $N = 11$, CONNECTICUT RIVER BRIDGE STUDY

	TRAFFIC DISTRIBUTION (VPD)		
BRIDGE	1963 SURVEY	TIME ASSIGNMENT	STD. ERROR
I-91	17,167	16,475	272
South	6,062	6,771	144
North	5,079	5,062	137

TABLE 14

SUMMARY OF 1963 ASSIGNMENTS TO I-91 BRIDGE (POPULATION EXPANSION), CONNECTICUT RIVER BRIDGE STUDY

	TRAFFIC ASSIGNMENT (VPD)				
PARAMETER	1963 SURVEY [a]	AASHO [b]	CALIF. [c]	EASY	ALL-OR-NONE
Time	17,167	11,507	7,870	11,313	11,133
Distance		7,640	8,892	7,803	3,401

[a] Actual. [b] AASHO diversion curves. [c] California curves.

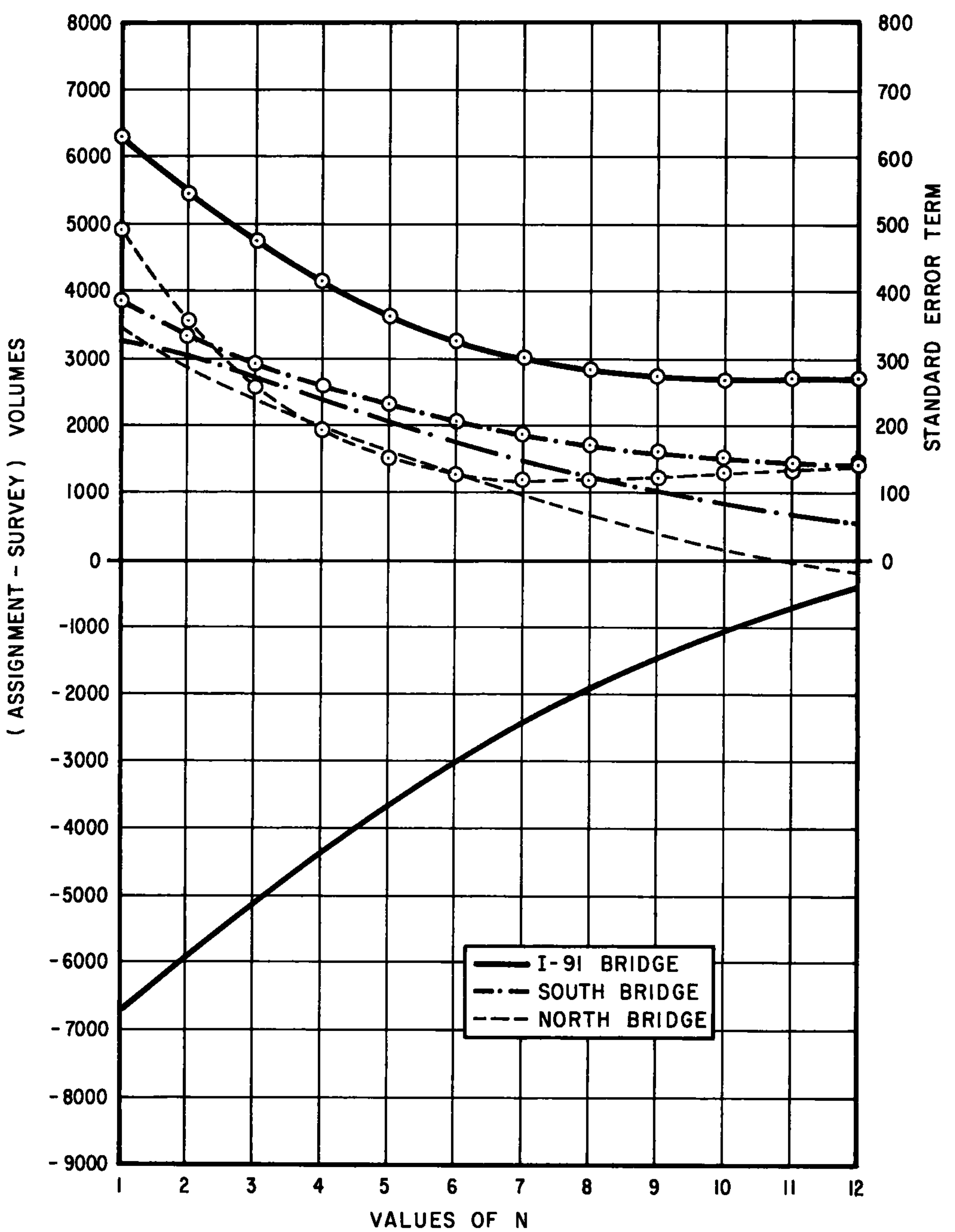

Figure 2. Multi-alternate model used with 1963 Connecticut River O-D data; difference of assigned and survey volumes vs time exponent, N.

Mainly, however, the forecast test indicated the futility of predicting traffic volumes on an isolated facility without adequate knowledge of traffic growth causes. Many forecasts, made as recently as ten years ago, had similar or less information than this example, and used similar or less complex techniques. These techniques, unfortunately, were the only ones that could be evaluated by comparison with current traffic volumes. The newer techniques, based on greater understanding of travel influences, cannot yet be evaluated by current information, and cannot be applied to past situations because of the lack of data so typically shown by this forecast example.

TABLE 15

SUMMARY OF 1963 ASSIGNMENTS TO I-91 BRIDGE (TRIP END EXPANSION), CONNECTICUT RIVER BRIDGE STUDY

PARAM-ETER	TRAFFIC ASSIGNMENT (VPD)				
	1963 SURVEY [a]	AASHO [b]	CALIF.[c]	EASY	NONE ALL-OR-
Time	17,167	16,549	14,609	16,446	17,682
Distance		11,090	15,347	11,141	10,935

[a] Actual. [b] AASHO diversion curves. [c] California curves.

SIGNIFICANCE OF THE CONNECTICUT STUDIES

Several conclusions and observations may be drawn from the results of the Connecticut study. One point that was conclusively demonstrated was the failure of distance parameters to represent the characteristics of route choice made by auto drivers. Although the distance assignment techniques performed well in the 1956 conditions, when all alternate routes were much the same in travel service, introduction of a new facility with markedly different speed attributes cannot be reflected by a distance criterion, even though dramatic differences in route choice took place. Similarly, the adequacy of time alone as the determinant of route choice appears to have been confirmed, inasmuch as the assignments based solely on time gave the best results without exception.

Some of the typical problems highlighted by this investigation can be experienced in similar assignments to isolated facilities. One such problem was that of a new facility which attracts travel from areas beyond the scope of the initial study area. A forecast based on expanding the trips found in a limited study area would consequently always be an underestimate. Second, growth factors based on population are an insufficient measure of future travel increases. If no other data are available, some estimate should be made for increasing car ownership, at the very least. And third, great care must be taken in the coding of networks for computer assignments. The placement of loading nodes can be critical; they should be located at the best estimate of the trip centroid of a zone. Similarly, great care must be taken to represent speeds and distances accurately for all segments of the network.

Perhaps the most interesting result of these assignment tests was the degree of agreement between a variety of techniques. The AASHO technique (a diversion curve based on time ratios), the EASY technique (based on time differentials proportioned to total times), and the all-or-none technique produced virtually the same results. The California assignments were effective with 1956 conditions, less so with 1963. One of the problems with the California techniques was scaling. The method effects great changes in assigned percentages for time or distance differentials of 1 to 2 min or 1 to 2 miles. The network scale in this test often had greater differentials between alternates, forcing an approximation of all-or-none assignments in many situations. Although distance-based assignments were poor where service levels varied, if the highway system did not contain routes of highly different speed characteristics, distance assignments were effective.

This suggests that the assignment phase of the traffic estimating problem can be reduced to simple procedures, if necessary. If time or funds should not permit more extensive studies, it appears that reasonable results can be obtained using whichever of the methods tested is simplest or most economical to employ. There are many situations where traffic estimates are desired but the expense and time of extensive travel and/or land-use surveys cannot be undertaken. The test of O-D data indicated that at least the assignment part of the problem could be handled reliably with less than total transportation study methodology.

The survey trip interchanges were stratified according to the volume sizes, the length of trip in time and distance, and the time and distance ratios for routes via alternate facilities. The assignment results were examined with the same stratifications and the results compared to the survey findings. The AASHO diversion-curve assignments appeared to conform most closely to the matching distributions of survey data, whereas the all-or-none results, not surprisingly, differed most. Yet, within major subgroupings, even the all-or-none assignment results resembled those of the surveys.

Two aspects of this analysis may be speculated upon with some justification. First, although the difference between "point-of-choice" and origin-to-destination time and distance assignments was not explored, it is assumed that the differences would be slight. Certainly, it does not seem likely that any added accuracy, of any real value, would be obtained, inasmuch as assignments without the refinement are well within desirable accuracy levels. The effect of this refinement may well be canceled out by the fact that time or distance ratios less than unity are likely to be matched by those greater, making the refinement self-cancelling for any volume consolidating several trip interchanges. Second, it is likely that ignoring capacity restraint may well be like using the distance parameter without regard for speed differences on alternate routes. Because the trip file in this test did not contain all travel across the bridges, and because other network travel not crossing the bridges was not included, capacity restraint features were meaningless in these tests. The fact that the distance parameter failed to produce the effect of increased service levels strongly suggests, however, that capacity should also be recognized in a total assignment to a 4-lane freeway in a system of 2-lane rural highways or urban arterials. But in a case such as the I-91, or in other evaluations of isolated facilities without knowledge of total travel, it seems that the capacity aspects can be safely ignored.

Finally, the introduction of a multi-alternate technique, which permitted assignments to several alternates simultaneously, greatly improved assignments to the "next-best" routes and gave satisfactory assignments to the best route. No theoretical justification for the increase in time exponent is advanced, but it can be noted that as the exponent of the travel time increases the assignment does approach an all-or-none solution.

CHAPTER THREE

NETWORK ASSIGNMENT

ASSIGNMENT MODELS

Four capacity restraint functions were incorporated into a common computer program to permit a direct comparison of the assignment techniques on a common network and trip table.

1. Smock (*8*) reported in 1962 on the iterative procedure used by the Detroit Area Traffic Study. This technique starts with a free or unrestrained assignment of the trip table to the network, which is the all-or-none approach. The link travel times are then modified according to

$$T_A = T_0 e^{(V/C-1)},\ T_A \leq 5\ T_0 \qquad (1)$$

in which

T_0 = the orginal travel time (a function of the desired operating speed) or the travel time on a link when volume equals capacity;
T_A = the adjusted travel time;
e = the base of napierian logarithms;
V = the assigned volume; and
C = the computed capacity of the link.

This is an exponential curve, as shown in Figure 3, where this function is plotted with (assumed) $T_0 = 1$. The second iteration is accomplished by using the new travel times to determine the minimum paths or trees. The volumes are additive to the results of the previous iteration and the average link load is considered to be the result. Successive iterations recalculate the T_A value based on the model using the average link volume for the value of v. This method is referred to herein as the Smock technique.

2. The Bureau of Public Roads technique (*10*) starts out with the free assignment and then updates the link travel time according to

$$T_N = T_0\,[1 + 0.15(V/C)^4] \qquad (2)$$

in which

T_N = the link travel time at the assigned volume;
T_0 = the base travel time at zero volume, which equals travel time at practical capacity times 0.87

$$T_A = T_0 + (T_N - T_0)/4 \qquad (3)$$

(Only one quarter of the adjusted difference is applied to minimize oscillations in loading through the successive iterations.)

Combining the two equations, the following model was used for this project:

$$T_A = T_0\,[0.87 + 0.13(V/C)^4] \qquad (4)$$

The second iteration is performed using minimum paths based on the calculated T_A after resetting link volume to zero. At the conclusion of this iteration a new estimate of link travel time is made substituting T_A for the T_0 values originally used and the operation repeated through as many iterations as required. In other words this technique builds upon the adjusted time in lieu of the average assigned volumes, as does the Smock procedure.* This curve is shown in Figure 4. The procedure results in volumes being loaded on only the links that are on the minimum path as of the final iteration. This method is referred to herein as the BPR technique.

3. The Schneider model (*14*) is a one-pass technique where only trips from one zone are assigned to the network, based on the original link travel time estimate, and then the travel times are updated by

$$T_A = T_0\,(2)^{V/C},\ T_A \leq 4(T_0) \qquad (5)$$

in which all symbols are as previously described, except T_0 is the travel time at free-flow conditions. In order to use the same estimates for T_0 from the other models, the equation becomes

$$T_A = T_0\,(2)^{(V/C-1)} \qquad (6)$$

This function is shown in Figure 5.

The volumes from the next zone in the loading sequence are then loaded onto the network using new minimum paths based on the revised travel times. This procedure is repeated until the entire trip table has been loaded. The original concept included a trip distribution model as well as the assignment feature. The research of this project utilized only the assignment and volume capacity function. The loading se-

* A recent revision averages link volumes in the reporting phase.

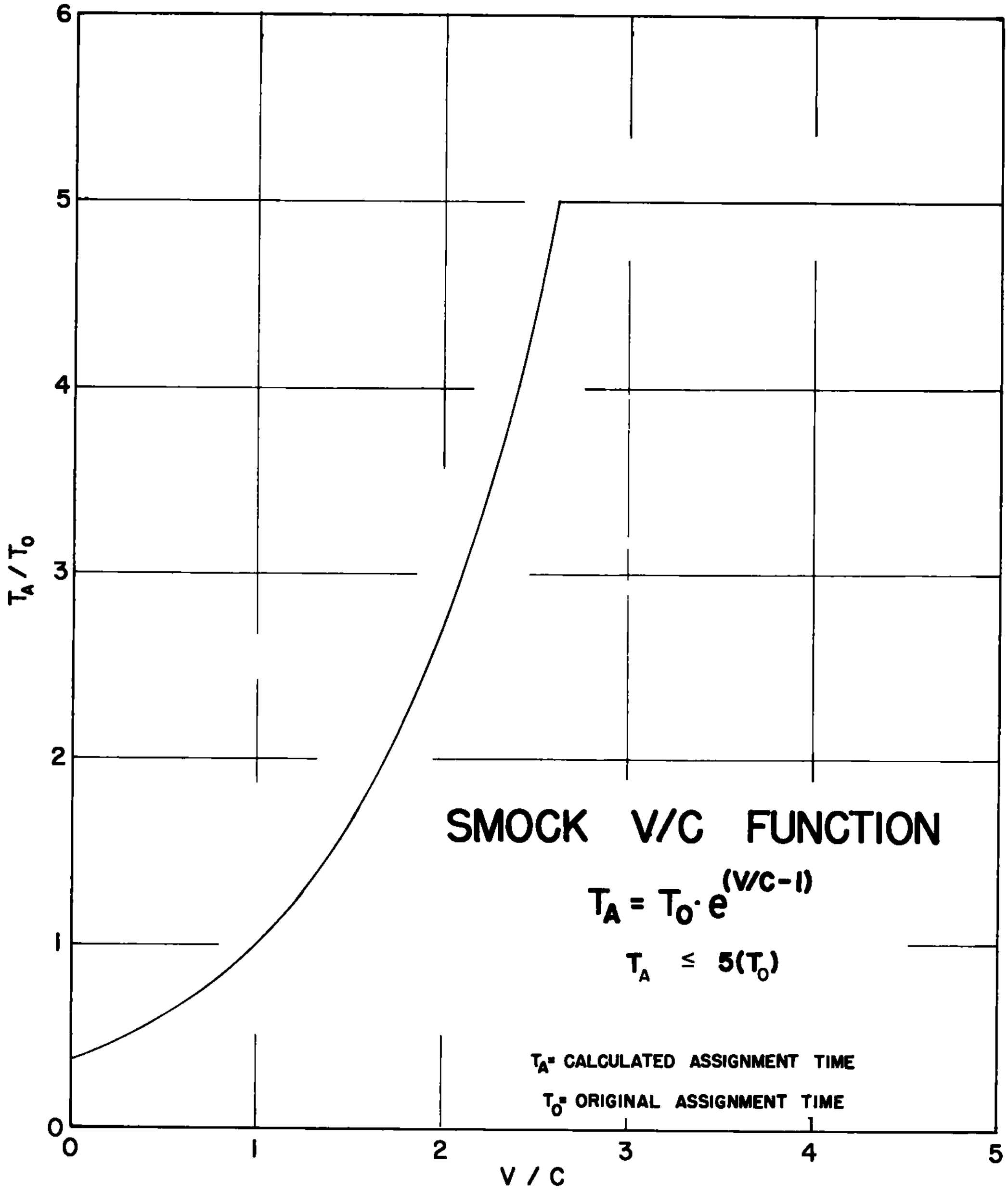

Figure 3.

quence was designed so that zones from different parts of the study area were loaded onto the network in a somewhat random manner. This project used the reverse sequence order as originally proposed by Schneider because all of the networks considered had the centroids numbered in an orderly fashion. A change in loading sequence has little effect on the areawide results, but could produce radically different link volumes. This has been reported by Soltman (*19*) from work done in Pittsburgh.

4. Irwin, Dodd and Von Cube (*11*) reported on a restraint model which used a family of volume-delay curves for various speeds and types of vehicles. A portion of their technique is to assign the trip table on a proportioned split, based on the trees which are accumulated from previous iterations. Smock's volume/capacity model was used in place of the volume-day curves so published. The research program was constructed so that the trees from each iteration could be retained and the trip table applied to the network in the following manner.

First iteration would be a free assignment.

Second and succeeding iterations would be loaded in the following manner:

$$V_{Rij} = V_{ij}\left[\frac{(T_{Rij})^{-1}}{\sum_{R=1}^{n}(T_{Rij})^{-1}}\right] \tag{7}$$

in which

T_{Rij} = the travel time from zone i to zone j in the Rth tree;
V_{ij} = the volume from the trip table between zones i and j;

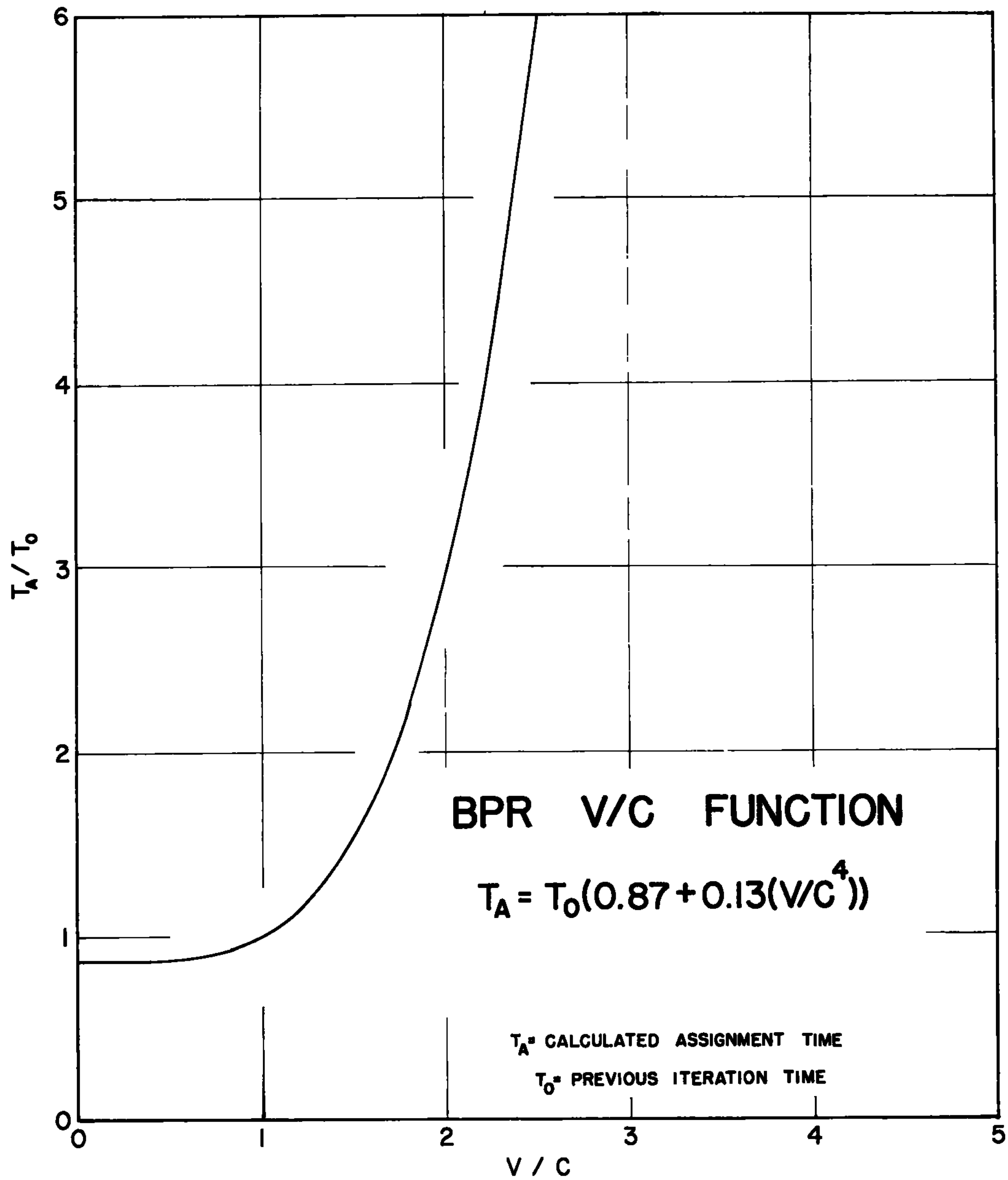

Figure 4.

V_{Rij} = the volume assigned to links on the *R*th tree; and
n = the number of trees available ($1 \leq n \leq 4$).

This model is referred to herein as TRC.

NUMBER OF ITERATIONS

A statistical test was employed that summed the squared difference between the estimated link volume and the assigned link volume, divided by the assigned link volume. In the case of Pittsburgh, the Smock technique was run through seven iterations in an attempt to ascertain how many iterations were necessary. Table 16 gives the value of χ^2 when each iteration was compared to the ground counts.

This analysis demonstrated that there was an insignificant improvement between the next iteration results and the estimated ground counts after the fourth iteration. Further testing of techniques was limited to four iterations for each technique.

DATA SOURCES

A new data search was instituted for this phase of the work. Again, only a few promising replies were received; most leads proved to have gaps for the project's requirements.

The ideal data set required by this project would contain two detailed coded networks, two O-D studies that had been conducted one before and one after an addition of a major

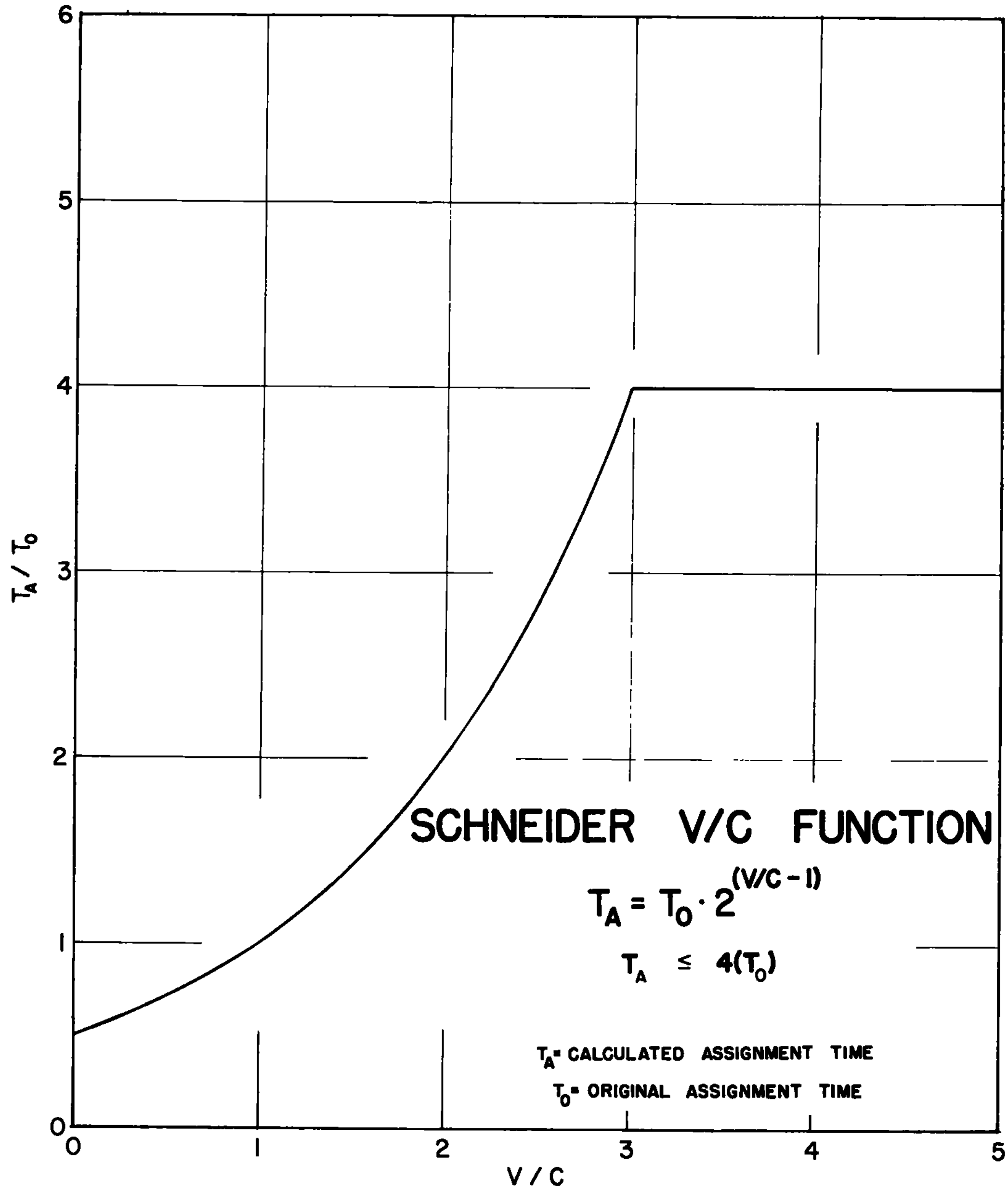

Figure 5.

highway facility, ground counts for all links in the networks both before and after the creation of a major change, with all this accomplished within a short span of time. These requirements were never met in their entirety with any of the data sets investigated by this project. In fact, few areas even came close to meeting them. Data were obtained for the areas given in Table 17.

Pittsburgh data were the most complete, having ground counts and capacities assigned to almost every link in the coded network. New Haven data contained some capacities, but had no ground counts against which to match the assignments. Both the Raleigh and Norfolk data contained ground counts only for the major links. No ground counts or capacities were obtained for Waco; this data set was used for computer program testing.

The origin-destination tables for Pittsburgh and Raleigh were expanded from home interview and supplementary travel information samples for the year of the respective studies. The New Haven origin-destination tables were obtained from gravity model forecasts of 1975 and 1999 (19XX) travel.

The coded networks received from these sources were reformated to uniform arrays of data so that the information would be compatible with the assignment program. This necessitated describing a two-way link as two one-way links. One of the objectives of this study was to compare the assigned link volumes to actual or estimated ground

TABLE 16

VALUES OF χ^2 FOR SUCCESSIVE ITERATIONS OF SMOCK VS GROUND COUNTS ON PITTSBURGH NETWORK

ITERATION	VALUE OF χ^2
1	66.8
2	11.2
3	4.6
4	3.5
5	3.1
6	3.0
7	3.2

counts. Thus, it was reasoned that the capacity for each link should be the ground count volume, to eliminate any bias due to errors in capacity calculation, and the ground counts were substituted for capacity whenever they were available. All volume tables, ground count estimates as well as capacity figures, used in this report are 24-hr values.

The networks varied in coding techniques. The Pittsburgh network had the zone centroids (home nodes) on the network system, whereas the other study areas were coded in such a manner that minimum paths did not pass through a centroid. In each area considered, the expressway and the major arterial systems appeared on the coded network; but the secondary streets were only coded when they were needed as connectors in the Pittsburgh network, whereas a majority of the streets within the core area appeared in the Raleigh network.

The Norfolk data were of particular interest in that a home interview study had been conducted in 1950 and again in 1962 and during this period a bridge and tunnel had been opened to traffic between Norfolk and Portsmouth. Close inspection of the respective zones for the two years showed remarkable compatibility with respect to size and boundaries, so that only minor adjustments were necessary. The continuing feature imposed upon the comprehensive urban area studies by the Highway Act of 1962 should produce valuable sources of this type of data in the future.

It can only be stressed here that the coding systems and study areas be held constant to facilitate compatibility of the before and after situation. The authors' experience indicated that much time is lost in attempting to use data from various sources, as the little quirks that each study group knows about, but actually are not quite uniform or clear, become major obstacles to the researcher later on. Data obtained on magnetic tape may not be readily used if it had been written by an installation using a different computer monitor system or a different type of machine from the one available to the researcher. An example of this would be binary tape files written on an IBM 7094 using the Bell Laboratory's monitor, for which the word count is placed in the right-hand portion of the control word, whereas a Fortran IV program operating under an IBM monitor places this information in the left-hand portion of the control word.

ERRORS IN ASSIGNMENTS RELATED TO ERRORS IN SOURCE DATA

In making comparisons of assigned volumes to ground counts, there are four major variables that enter into the comparison:

1. Ground count volumes.
2. A network description.
3. The assignment technique.
4. The origin-destination table.

The ground count volumes are estimates based on sample counts and are subject to random errors.

The network description does not describe all of the possible routes, but includes the arterial and expressway network with connecting ramps together with some of the streets in the central city. All trips within a given zone are assumed to start at a common point, a very unrealistic assumption, especially for zones that cover a large geographical area.

The differences in the assignment techniques are the subject of this study.

Finally, the initial origin-destination table is based on a sample, again subject to random errors. Even though the network description and the assignment technique were to operate without error, there would still be differences between the measured volumes and the assigned volumes because of the sampling error used as input to the compari-

TABLE 17

SUMMARY OF DATA FOR AREAS USED IN NETWORK ASSIGNMENT STUDY

METROPOLITAN AREA	POPULATION [a]	LAND AREA [a] (SQ MI)	NO. OF ZONES	NETWORK NODES	NETWORK LINKS
Pittsburgh, Pa. [b]	604,332	3051	280	1284	3709
Raleigh, N. C.	169,082	864	288	1027	2923
Norfolk, Va.	578,507	667	250	982	2677
New Haven, Conn.	311,681	200	203	1368	3801
Waco, Tex.	150,091	1034	221	635	1708

[a] 1960 Census data. [b] PATS.

sons. The following section is a discussion of the amount of error which might be expected from assigning a sample origin-destination table.

A Simple Example

Consider a single link—A to B—to which is assigned the following trips:

ZONES	VOLUME	ERROR	VARIANCE
18–34	1000	163.0	26569.00
106–34	2500	272.5	74256.25
106–35	500	115.5	13340.25
112–35	100	51.7	2672.89
18–36	1000	163.0	26569.00
112–36	250	81.7	6674.89
Total	5350		150082.28

The error (standard deviation) is the sampling error for trip interchanges of the size shown based on a 3.6 percent sample rate (used in the Pittsburgh Area Transportation Study). The variance is the square of the error. From statistical theory it is known that the variance of the sum $(x_1 + x_2 + \quad x_n)$ is equal to the sum of the variances $(\sigma_1{}^2 + \sigma_2{}^2 + \quad \sigma_n{}^2)$. Applying this relationship to the link A-B gives an estimated volume of 5,350 vehicles with an error of $\sqrt{150{,}082.28}$, or 387.41. A deviation of less than $\pm 1\sigma$ will occur about 67 percent of the time and deviation of less than $\pm 2\sigma$ will occur about 95 percent of the time.

In this simple example it can be estimated that a volume of 5,350 vehicles will use the link, but because of (sampling) error there is confidence that a range from 4,963 to 5,737 will be correct 67 percent of the time. This error term (387.4) is 7.3 percent of the anticipated volume of 5,350.

Consider, further, that a second link, D-C, serves not 6, but 60 trip interchanges and that each of the 6 volume interchanges magnitudes previously listed is represented ten times. In this case the result will be: total volume, 53,500; total variance, 1,500,823.

The result is that the total volume on the link is estimated to be 53,500 vehicles, with an error term of $\sqrt{1{,}500{,}823}$ (or 1,225 vehicles) This error term (1,225) is 2.3 percent of the anticipated volume of 53,500, with confidence that a range of 52,275 to 54,725 vehicles will be correct 67 percent of the time.

It is observed that as the estimate of volume on the link is increased by a factor of ten (53,500/5,350) the absolute value of the error term is increased by a factor of 3.16 (1,225/387), which is $\sqrt{10}$ (the square root of the ratio of the volume change). It follows that the error term for any link would vary approximately in proportion to the square root of the volume.

This last fact suggests a model for estimating the random error associated with a volume estimated for any link. That is, let

$$E_2/E_1 = \sqrt{V_2}/\sqrt{V_1} \qquad (8a)$$

so that

$$E_2 = E_1\,\sqrt{V_2}/\sqrt{V_1} \qquad (8b)$$

in which

E_1 = error associated with link 1;
E_2 = error associated with link 2;
V_1 = volume associated with link 1; and
V_2 = volume associated with link 2.

Further, if V_1 is assumed to be 1 and a value of E_1 is known, the absolute error is given by

$$E_2 = E_1\,\sqrt{V_2} \qquad (8c)$$

A more convenient form for expressing error is to treat the error as a percentage of the assigned volume, so that the percent error for link 2 is $E_2/V_2 \times 100$. Eq. 8*c* is then modified to the following by multiplying both sides by $100/V_2$

$$\begin{aligned} \%\text{ error} &= E_2/V_2 \times 100 \\ &= (E_1\,\sqrt{V_2} \times 100)/V_2 \\ &= 100\,E_1/V_2{}^{0.5} \end{aligned} \qquad (9)$$

A model of this form was applied to assignments made for the years 1975 and 1999 (19XX) for the New Haven Area Transportation Study.

To test the error model developed in the foregoing, it was necessary to have an estimate of the error term associated with each link in the system. These errors were then expressed as a percentage of the volume and a scatter diagram of the percent error vs volume was prepared. A least-squares regression equation was fitted to the scatter of the points and the validity of the equation was checked.

CALCULATION OF ERROR ON EACH LINK

All assignment techniques calculate volume per link by aggregating the sums of trips for all of the origin-destination pairs using any given link. An ideal estimate of the error term associated with each link could be obtained by aggregating the variance, however calculated or estimated, for all of the origin-destination pairs using any given link. Then for each link, there would be available both an estimate of assigned volume and the estimate of error.

Calculation of errors by the foregoing method would require that for each non-zero origin-destination pair there be an error term available and that there be room within the computer to aggregate these error terms along with the other data stored for each link. The programs and the computer available for this project did not permit such a direct approach to the calculations of errors; a more indirect approach, using an assumed average error, was used as outlined in the following.

For each link in the system, an accumulator kept track of the number of times a link was involved and had volume assigned as part of the minimum path branch. (In a network used for assignment of 203 O-D zones, there are 203 $\times$ 202 = 41,006 minimum path branches calculated and a given link may enter into several thousand of the possible 41,006 minimum path branches.) At the end of the assignment process, it was possible to know both the volume and the number of times a link was used in a minimum path (usage). The usage was in turn used in estimating the error term. It was assumed that each assigned origin-destination pair had the same error term, so that the sum of the variance becomes: usage × variance = total variance per link, and (total variance)$^{\frac{1}{2}}$ is the error term per link.

The variance per origin-destination pair was calculated by treating each entry of the O-D matrix as a single observation of a random variable. The variance of the distribution of all of the non-zero values was then taken as an estimate of the variance for any single trip interchange. For the 203-zone New Haven Area, the results of this calculation are given in Table 18.

The variance calculated by this method is high, because it is based on the average trip interchange for all pairs of zones, with undue weight given to the differences in the size of the zones and the number of origins at each zone. These assumptions were required because it was not possible to keep track of the specific O-D pairs which used any given link, so that it is assumed that any O-D pair may be on a link, each pair with the variance calculated as in the foregoing. As a last step, the percent error was found by dividing the link error term by the link volume.

The percent error vs the volume estimate for 19XX is shown in Figure 6. A least-squares regression fit indicated that the percent error may be expressed as follows:

$$\% \text{ error } (1975) = 100\, E_1 / V_2^{x}$$

$$= 2060.67 / V_2^{0.545} \qquad (10)$$

Coeff. of correlation = 0.86

For 19XX estimates the relationship is:

$$\% \text{ error } (19XX) = 3662.34 / V_2^{0.574} \qquad (11)$$

Coeff. of correlation = 0.86

This relationship is shown as $Y = A\,X^B$ in Figure 6, together with the relationship $Y = A + B/X$ (% error $= A + B/\text{volume}$). This latter curve provides a better fit to the low-volume data (the majority of points), but is high in the greater-volume range; however, no rationale was found for the second relationship (fitted by trial and error).

The expected percent error for the 1975 and 19XX relationship of the form $100\, E_1 / V_2^{x}$ at different volume levels is given in Table 19.

The expected value of the exponent, x, was 0.50 (square root). In the test made with these data the exponent is slightly greater than 0.5, but sufficiently close to suggest some merit in the analysis. It should be emphasized that the estimate of the error term was based on a common variance for each usage and that the total variance was (variance × usage). Had the volume assigned been based on an average volume per usage, the relationship would have been exactly as assumed and the "observed" points would have fitted the theoretical points without deviation. In other words, the test tends to be self-proving as done here, but no way of handling individual variance estimates was available in order to overcome this difficulty.

The estimate of error is a function of the constant multiplier as well as the exponent of the volume. It will be observed that the error for one trip in 1975 is 20.60 and for one trip in 1999 is 36.62. These two values are a function of the high variances calculated by using the entire matrix in calculating the individual variance terms.

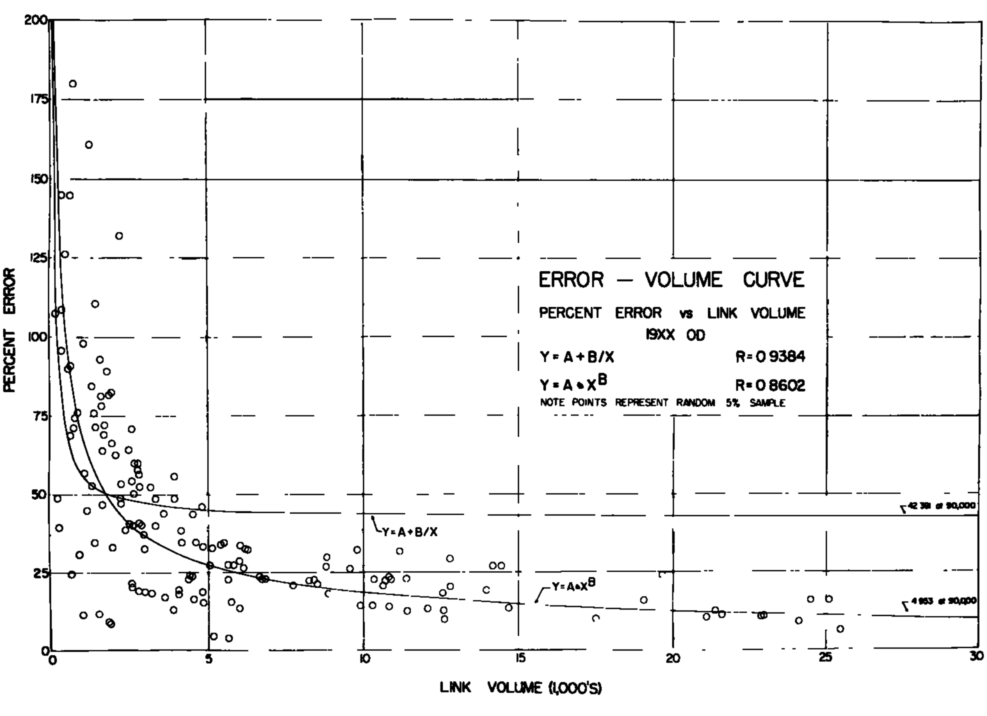

Figure 6.

TABLE 18

CALCULATON OF ASSUMED ERRORS IN ORIGIN-DESTINATION MATRIX

YEAR	NO. OF NON-ZERO ENTRIES	TOTAL TRIPS	MEAN VOL./O-D PAIR	VARI-ANCE
1975	37,638	952,461	25.31	5,268
19xx	37,638	1,277,806	33.95	13,208

Some idea of the relationship that might be expected if the errors were based only on sampling error can be obtained by reconsidering the sampling error predicated upon a 3.6 percent interview sample size as used for home interview in Pittsburgh. The sampling error for 100 trips is given as 51.7 and for 10,000 trips is given as 517 trips. This would indicate that the error term, E_1, for one trip is 5.17 units and that $E_1 \times 100 = 517$, so that the equation for percent error in assignments becomes % error = $517/V_2^{0.5}$. Errors based on an assumed 3.6 percent sample are compared to the errors previously reported for 1975 and 1999 in Table 20. It is obvious that the estimate of the error on an assigned link is very sensitive to the term E_1, the error on a link with a volume of 1.

The percent error of Table 20 is based on the assumption that errors in estimating the O-D matrix are randomly distributed; i.e. underestimation and overestimation are equally likely to occur and are the sole source of error in the assignment process. There is no allowance in the formula for error in the route selection process or for bias in estimating future trip generating characteristics.

The percent error shown for an assumed 3.6 percent O-D interview sample is a minimum error estimate which relates only to the influence of errors in sampling. This value may be thought of as representing the expected error in the assignment process when testing the assignment of an existing O-D table to an existing network and comparing with ground count. Even with a perfect representation of the network, and a perfect assignment system, errors will not be less than those shown for the 3.6 percent sample error.

As the error term within the O-D matrix is increased, for whatever reason (ie., forecasts to some future year, a lesser percent O-D home interview sample, or the tendency for different land uses to generate more or less trips than expected), the errors in the final result will also increase, again assuming that the assignment technique is not a further source of error. A final estimate of error must include an error term which reflects the error in the assignment process along with errors in the O-D matrix. No method of estimating this last error is known nor is one suggested by this study, but the errors of Table 20 for the 1975 volume and the 1999 volume may be indicative of a range of errors which might occur when aggregating all of the error sources.

TABLE 19

CALCULATED PERCENT ERROR FOR VARIOUS VOLUMES

TRAFFIC VOLUME	CALCULATED % ERROR	
	1975 FORMULA	1999 FORMULA
100	167.1	260.0
500	69.5	103.0
1,000	47.6	69.3
2,000	32.6	46.5
5,000	19.8	27.5
10,000	13.6	18.5
15,000	10.9	14.6
20,000	9.3	12.4
25,000	8.2	10.9
30,000	7.5	9.8
35,000	6.8	9.0
40,000	6.4	8.3
50,000	5.6	7.3
60,000	5.1	6.6

TABLE 20

PERCENT ERROR FOR 3.6 PERCENT SAMPLE VS 1975 AND 1999 LEAST-SQUARES CALCULATONS

TRAFFIC VOLUME	PERCENT ERROR		
	3.6% SAMPLE	1975 FORMULA	1999 FORMULA
100	51.7	167.1	260.0
500	23.1	69.5	103.0
1,000	16.4	47.6	69.3
2,000	11.6	32.6	46.5
5,000	7.3	19.8	27.5
10,000	5.2	13.6	18.5
15,000	4.2	10.9	14.6
20,000	3.7	9.3	12.4
25,000	3.3	8.2	10.9
30,000	3.0	7.5	9.8
35,000	2.8	6.8	9.0
40,000	2.6	6.4	8.3
50,000	2.3	5.6	7.3
60,000	2.1	5.1	6.6

OUTLINE OF STUDY

Four items are included in subsequent chapters, as follows:

1. A comparative analysis of the four capacity restraint assignment techniques and the free assignment as applied to Pittsburgh and Raleigh (Chapter Four).
2. Changes in assigned volume as related to isolated changes in origin-destination patterns (Chapter Five).
3. Influence of isolated network changes upon assigned volume (Chapter Six).
4. Evaluation of measured changes in origin-destination patterns as related to the construction of a new river crossing facility in Norfolk (Chapter Eight).

CHAPTER FOUR

COMPARISON OF ASSIGNMENT TECHNIQUES

The coded networks examined in this study include from 1,708 to 3,801 links, so that it was necessary to devise methods to examine the impact of changes in variables on the assignment results. The vehicle-miles and vehicle-hours of travel throughout the network provided an overall picture of the relative merits of the assignment techniques. Accumulated volumes across selected screen lines and cordon lines at different points within the network provide a measure of comparison in more detail than provided by total vehicle-miles or vehicle-hours of travel.

The numbers of links in each assigned volume grouping by each of the assignment techniques were compared to determine if there was a tendency to assign traffic only to certain of the network links or if volumes were distributed in much the same manner by all of the techniques. In particular, a large number of links resulting in zero assigned volume would indicate that the assignment technique is not accurately simulating traffic, and that some links never become part of minimum paths even as other parts of the network become loaded beyond capacity.

The links at the high end of the volume scale were also evaluated to determine the effect of the different assignment techniques at this end of the volume scale. It is assumed that the most critical design problems will occur with the high-volume links and that accuracy is most important in assigning volume to these links.

A final comparison between the techniques is made in terms of computer time needed to accomplish the desired results.

VEHICLE-MILES AND HOURS OF TRAVEL

Two study area data sets—Pittsburgh and Raleigh—were used to compare assignment values obtained by using five different capacity restraint functions. Pittsburgh data were the most complete in respect to actual ground count information by links. However, even in this study area, some 640 external links did not have volume estimates.

The first measure employed was a test of how well any one technique duplicated the ground counts by accumulating the total vehicle-miles of travel assigned to the study network. This item was computed by multiplying the final link volume by the link distance and summing the results for vehicle-miles. Raleigh did not have sufficient ground counts available to make a comparison meaningful between ground count values and the other assignments. In the case of Pittsburgh, the 640 links that did not have an original volume estimate were omitted in the accumulations.

Vehicle-hours of travel in each network were calculated by accumulating the assigned link volume times the original travel time for each link. The vehicle-hours of travel for Pittsburgh have been adjusted to delete the links not having estimates of ground counts. The results are given in Table 21.

A statistical test (the Dixon criterion) was applied to the ground count and assigned vehicle-miles for Pittsburgh to determine if the differences could have occurred by chance alone. The test requires that the values be in rank order from 1 to N. An r value is calculated from $(X_N - X_{N-1})/(X_N - X_1)$. If the r value is greater than the tabulated value of r, the hypothesis that all samples are from the same normally distributed population is rejected. When excluding the ground counts (N=5) there was no basis on which to reject any of the observations (i.e., there was no proof that they were not from the same normally distributed population). When the ground count vehicle-miles were included (N=6) the test indicated that the hypothesis of common population be rejected. In other words, the various assignment techniques gave results which were closer to each other than to the ground count results.

VEHICLE-MILES BY LINK SPEED

To further compare the assignment results, the vehicle-miles were subdivided by link speed (Table 22). It was apparent that the Smock restraint technique, in attempting to load each link up to its capacity, decreased the travel time (increased link speed) for all links which had volumes less than the given capacity. Thus, the vehicle-miles increased in the higher speed groups as the successive iterations proceeded. The same occurrence may be noted with the TRC technique, in which the Smock restraint was also utilized. There was some indication that the higher link speeds tend to recede after the third iteration, presumably because the links with higher speeds had attracted more volume. The shift of link speed was much slower in the case of the BPR function. This was due to the damping feature of this func-

TABLE 21

VEHICLE-MILES AND VEHICLE-HOURS OF TRAVEL BY ASSIGNMENT TECHNIQUE

	PITTSBURGH [a]		RALEIGH	
TYPE OF ASSIGNMENT	VEH-MI (000's)	VEH-HR (000's)	VEH-MI (000's)	VEH-HR (000's)
Ground count	10,131	3,613	—	—
Free	9,250	3,185	1,185	347
Schneider	9,136	3,334	1,175	352
Smock 4th iter.	9,452	3,589	1,178	351
BPR 4th iter.	9,484	3,509	1,118	351
TRC 4th iter.	9,485	3,509	1,180	350

[a] Does not include links where ground count estimates were unavailable.

TABLE 22

SUMMARY OF VEHICLE-MILES, BY LINK SPEED RANGE AND ASSIGNMENT TECHNIQUE, FOR PITTSBURGH AND RALEIGH STUDY AREAS

LINK SPEED RANGE (MPH)	VEHICLE-MILES ASSIGNED (1,000's)										
			SMOCK			BPR			TRC		
	GROUND COUNT	FREE	ITERATION 2	ITERATION 3	ITERATION 4	ITERATION 2	ITERATION 3	ITERATION 4	ITERATION 2	ITERATION 3	ITERATION 4
(a) PITTSBURGH											
0 –10	508	276	2059	1355	1045	529	845	1106	2720	1842	1465
10.1–20	2251	2429	1863	2412	2622	2325	2709	3096	2024	2237	2326
20.1–30	3587	3269	2478	3283	3404	4469	4440	4079	2450	2974	3187
30.1–40	3751	7856	2943	2648	2551	7472	6474	6188	2522	2671	2706
40.1–50	—	1401	3264	3228	3171	1425	1464	1489	3023	3154	3182
50.1–60	—	1	3324	1402	1697	—	—	—	2738	1271	1547
60.1–70	—	—	165	355	579	—	—	—	135	564	383
70.1–80	—	—	34	596	662	—	—	—	23	329	510
80.1–90	—	—	—	362	387	—	—	—	—	278	392
Over 90	—	—	—	727	227	—	—	—	—	599	378
(b) RALEIGH											
0 –10	—	34	42	40	38	35	36	37	45	41	40
10.1–20	—	137	143	140	142	150	153	153	142	139	139
20.1–30	—	263	278	273	269	268	274	268	275	274	269
30.1–40	—	343	340	341	340	333	337	336	342	343	352
40.1–50	—	262	264	228	255	288	293	299	265	275	259
50.1–60	—	131	94	137	115	97	74	73	93	90	101
60.1–70	—	15	20	18	18	14	14	14	19	19	19
70.1–80	—	—	—	2	1	—	—	—	—	2	2

tion, where only one-fourth of the indicated adjustment was applied to the link travel time between any two successive iterations. The Schneider function is not included in Table 22 due to the manner in which the function was applied. Travel time for each link in the network was adjusted after trips from each zone were loaded; thus, the housekeeping problems of reporting the link time for each minimum tree became too complex and would have required more storage space than was available.

SCREENLINE ANALYSIS

A screenline analysis was performed for each study area using previously defined screen lines from the respective studies. The Pittsburgh screen lines were drawn along the three major rivers which abut the so-called "Golden Triangle" (CBD). The volumes across the screen lines for both Pittsburgh and Raleigh are given in Table 23.

More variation in the totals may be observed for the Pittsburgh screen lines than for the Raleigh screen lines. In the Pittsburgh study area, the various assignments displayed total screenline crossings ranging from 2 percent higher to 10 percent lower than ground count. It should be restated here that for the purposes of this study, where the object was to compare computed link volumes with actual volumes, the ground count estimates were used as an estimate of capacity for each link wherever they were available.

The screen lines in Raleigh were of a more arbitrary nature. On the basis of the screen lines all of the techniques produced essentially the same results. Of course, little difference was possible, because each technique utilized the same O-D table as well as the same network; and in the case of Raleigh several of the screen lines were near the external stations, which restricted any possible diversion to alternate routes. Total screenline crossings were matched to the ground count estimate. All techniques tested produced 7 to 8 percent lower aggregate volume across all screen lines than actual count. This would indicate that the O-D table was not entirely complete, particularly in the case of the external stations.

DISTRIBUTION OF LINK VOLUMES BY ASSIGNMENT TECHNIQUE

The distribution of links by volume range is given in Table 24 for Pittsburgh and Raleigh. There was little difference in assignments made to the Raleigh network. Over all ranges of volume the assignment techniques all give results which vary at most by a difference of 1.9 percent (in the 0-1,000 assigned ADT category). For the Raleigh network, there were 224 of the 2,923 links for which ground counts were available. These 224 ground counts were used as the link capacities when the assignments were made; the remaining 2,699 links were not given capacity restraints. The

TABLE 23

SUMMARY OF SCREENLINE VOLUMES, BY ASSIGNMENT TECHNIQUE, FOR PITTSBURGH AND RALEIGH STUDY AREAS

		ASSIGNED VOLUME (1,000's)					
SCREEN LINE	NO. OF LINKS	GROUND COUNT	FREE	SCHNEI-DER	SMOCK 4	BPR 4	TRC 4
			(a) PITTSBURGH				
Ohio R.	10	77	81	85	93	91	82
Allegheny R.	28	183	172	183	204	175	158
Monongahela R.	24	250	217	213	223	222	220
Total dev.[a] (%)	—	—	−8	−5	+2	−4	−10
			(b) RALEIGH				
CBD cordon	46	137.0	129.3	131.6	134.0	133.4	132.7
A	22	80.6	75.1	75.4	75.3	74.9	75.3
B	26	82.1	71.6	69.0	70.7	70.6	70.9
D	14	22.7	20.4	20.3	20.4	20.2	20.4
North	12	16.5	16.2	15.6	16.1	15.8	16.0
N-East	8	37.3	31.8	31.3	31.6	31.6	31.6
S-East	18	44.0	39.4	39.2	40.2	40.7	40.1
Total dev.[a] (%)	—	—	−7.3	−8.5	−7.3	−7.3	−7.3

net effect was that the travel time changed only on those links with a capacity restraint. The other portions of the network were unchanged when used as input to the tree-building program. Under these conditions it was logical that a minimum change in assigned volumes would result from the different assignments.

A different pattern resulted from the Pittsburgh data, where capacity restraints were applied to all of the links in the system. At very low volumes (0-1,000 assigned ADT) the free assignment and the BPR assignment overestimated the number of links in this range. This reflected the techniques themselves, because the results are based only on the final assignment pass (pass 1 for Free), so that any link which is not part of a tree has zero link volume assigned. The other three techniques (Schneider, Smock and TRC) averaged or accumulated volume loadings from the different trees so that the loading was distributed over a greater number of links. All of the assignment methods overestimated the number of links in the lower range (0-5,000 assigned ADT).

In the middle volume range (5,000-10,000 assigned ADT) the Free and BPR assignments are similar and resulted in the most serious underestimates within this volume range. The remaining three assignments differ only slightly from each other and from the ground counts.

All of the techniques result in similar distributions of link volumes in the higher volume range (10,000-15,000 assigned ADT), but all tend to slightly underestimate the ground count distribution.

Finally, in the greatest volume range, the Free and BPR assignments both equaled or exceeded the number of links with volumes over 15,000, while the remaining three techniques were again similar to each other with equal underestimates of the number of high-volume links. This again reflected the characteristic of the three assignment techniques, each of which distributed volumes over a greater number of links, so that there was less concentration of loadings along particular links.

ZERO-VOLUME LINKS

An analysis of the various assignment techniques was made to determine the number of links reported with zero-volume assignment. Table 25 shows the number of zero-volume links by technique.

In the Pittsburgh case, it is dramatically illustrated that the BPR technique may tend to unrealistic answers in that it starts loading the network fresh on each iteration while Smock and TRC techniques build on the previous volumes and the reported link loads are averages of the iterations to date.

The Raleigh networks had 137 links with zero volumes common to all assignments, whereas the Pittsburgh data had 8 common zero links. Table 25 has had its items reduced by the common zero links. It is apparent that any network has some links that are never used and should not have been coded into the system to begin with. This information is only available after the assignments have been made, and is not intended to be a criticism of the previously tabulated network.

HIGH-VOLUME LINKS

A further comparison of the highest-volume links for Pittsburgh and Raleigh is given in Table 26. Again, for Raleigh, all of the methods, including the free assignment, resulted in nearly identical assignments. There was no tendency for any method to overestimate or underestimate the number of links by volume category.

TABLE 24

PERCENTAGE OF LINKS IN VOLUME RANGE, BY ASSIGNMENT TECHNIQUE, FOR PITTSBURGH AND RALEIGH STUDY AREAS

VOLUME RANGE (1,000's)	LINKS IN RANGE (%) GROUND COUNTS	FREE	SCHNEIDER	SMOCK 4	BPR 4	TRC 4
	(a) PITTSBURGH					
0–1	15.2	24.6	17.1	12.5	27.8	13.8
1–2	13.1	11.4	13.6	13.5	10.5	13.3
2–3	10.6	8.9	11.3	15.5	9.0	12.3
3–4	8.7	8.4	10.5	7.4	7.2	9.5
4–5	7.1	7.7	8.2	9.4	5.8	8.9
0–5	*54.7*	*61.0*	*60.7*	*58.3*	*60.3*	*57.8*
5–6	5.9	6.2	6.9	6.9	5.4	7.2
6–7	6.6	6.1	6.6	7.0	6.8	8.1
7–8	4.6	4.5	4.2	6.0	4.0	4.8
8–9	5.2	3.2	4.3	4.2	3.1	4.3
9–10	5.3	2.8	3.3	3.4	2.9	3.4
5–10	*27.6*	*22.8*	*25.3*	*27.5*	*22.2*	*27.8*
10–11	3.9	2.6	3.0	2.6	2.0	3.1
11–12	3.0	2.0	2.7	3.1	3.1	2.7
12–13	2.3	2.1	1.5	2.0	1.4	1.9
13–14	1.4	1.7	1.5	1.3	2.1	1.6
14–15	0.9	1.6	1.1	1.1	1.3	1.0
10–15	*11.5*	*10.0*	*9.8*	*10.1*	*9.9*	*10.3*
Over 15	6.2	6.2	4.2	4.1	7.6	4.1
	(b) RALEIGH					
0–1		60.0	58.5	59.2	60.4	58.5
1–2		15.9	16.4	16.0	15.6	16.6
2–3		7.7	7.6	7.7	7.0	7.9
3–4		3.6	4.1	3.7	3.7	3.6
4–5		2.8	3.6	3.7	2.9	3.6
0–5		*90.0*	*90.2*	*90.3*	*89.6*	*90.2*
5–6		2.9	2.7	2.5	3.0	2.6
6–7		2.2	2.1	2.1	1.9	2.2
7–8		1.6	1.6	1.8	1.7	1.7
8–9		0.5	1.2	0.9	1.0	0.9
9–10		0.8	0.4	0.4	0.7	0.6
5–10		*8.0*	*8.0*	*7.7*	*8.3*	*8.0*
Over 10		2.0	1.8	2.0	2.1	1.8

The analysis of Pittsburgh data indicated that application of the BPR technique resulted in overestimates of the high-volume links in a greater degree than the other techniques, although this technique did match the number of over-40,000-volume links. The Free assignment also overestimated the number of high-volume links, particularly in the 15,000-20,000-volume category. Finally, the Schneider, Smock and TRC techniques resulted in similar estimates of volume; all three tended to estimate more than the observed number of links in the 15,000-20,000-volume category and to underestimate the number of links with estimated volumes of over 20,000 assigned ADT.

An analysis of the matching of assigned volumes to ground count volumes was made by calculating the root mean square error (RMS error) of the 100 highest ground count volumes for the Pittsburgh data.

TABLE 25

NUMBER OF LINKS WITH ZERO ASSIGNED VOLUME, BY TECHNIQUE

STUDY AREA	NO. OF LINKS FREE	SCHNEIDER	SMOCK 4	BPR 4	TRC 4
Pittsburgh	243	25	0	420	6
Raleigh	8	1	2	10	2

TABLE 26

HIGH-VOLUME LINK DISTRIBUTION, BY ASSIGNMENT TECHNIQUE, FOR PITTSBURGH AND RALEIGH STUDY AREAS

VOLUME RANGE (1,000's)	LINKS IN RANGE GROUND COUNTS	FREE	SCHNEIDER	SMOCK 4	BPR 4	TRC 4
			(a) PITTSBURGH			
15–16	19	39	32	30	52	36
16–17	29	28	28	19	33	21
17–18	14	33	21	19	32	21
18–19	15	31	16	18	16	10
19–20	11	22	8	8	24	9
15–20	*88*	*153*	*105*	*94*	*157*	*97*
20–21	19	24	10	9	22	10
21–22	10	7	12	6	13	4
22–23	3	7	2	6	20	9
23–24	8	9	5	7	10	6
24–25	10	4	3	3	10	3
20–25	*50*	*51*	*32*	*31*	*75*	*32*
25–30	11	18	15	14	27	14
30–35	15	8	5	7	15	2
35–40	5	0	1	2	1	5
Over 40	6	0	0	2	6	0
			(b) RALEIGH			
10–12		30	28	35	35	31
12–14		9	6	6	10	6
14–16		5	6	5	6	5
16–18		10	8	7	7	6
18–20		5	4	4	6	4
Over 20		1	2	2	2	2

A sampling of volumes assigned to the highest 100 ground count links for Pittsburgh is given in Table 27, indicating the differences in magnitude over this range of volumes.

Five estimates of the RMS error were made, one for each assignment technique, as follows:

$$\text{RMS error} = \left[\frac{\Sigma(G-A)^2}{n}\right]^{\frac{1}{2}} \qquad (12)$$

TABLE 27

SELECTED HIGH-VOLUME GROUND COUNT LINKS IN PITTSBURGH

	ASSIGNED VOLUME (1,000's)					
RANK	GROUND COUNT	FREE	SCHNEIDER	SMOCK 4	BPR 4	TRC 4
1	50	33	37	42	45	40
11	35	19	25	25	24	25
21	32	24	27	27	28	27
31	27	16	18	21	21	20
41	24	18	21	21	20	21
51	24	16	23	26	31	25
61	22	33	27	28	23	27
71	21	14	21	23	31	22
81	20	11	17	17	23	16
91	20	8	14	16	17	13

in which

G = ground count volume;
A = assigned volume by technique; and
n = number of links.

The results were as follows:

TECHNIQUE	RMS ERROR
Free	14170
Schneider	8436
Smock 4	7119
BPR 4	7284
TRC 4	7605

The highest ground count volume was 49,976, the 100th ground count volume was 18,971. For these high-volume links only, it would be expected that 67 percent of the differences between ground count and assigned volume would be less than the RMS error and 95 percent of the differences would be less than twice the RMS error.

The Free assignment, although reproducing about the correct frequency of links in this range, resulted in the greatest error. The fourth iterations of Smock and BPR give nearly identical results, both better than the fourth iteration of the TRC and Schneider assignments.

CHI-SQUARE COMPARISON

The previous tests have been concerned with an examination of the distribution of the number of links by volume category to detect bias in estimating high-volume or low-volume links. In the following test the differences between all of the links are evaluated by summing the squared difference between the estimated ground count and the assigned link volumes divided by the assigned link volume, as follows:

$$\chi^2 = \sum_{i=1}^{n} (G_i - A_i)^2 / A_i \qquad (13)$$

in which

G = ground count volume estimate;
A = assigned volume estimate; and
n = number of links in system.

Table 28 demonstrates the resulting value for each type of assignment versus the ground count estimate for the Pittsburgh network. The lowest value indicates the closest approach to the ground counts. All of the values are significantly different from the ground count estimates, indicating that the difference in assignment is more than can be expected by chance alone. But of the five techniques the fourth iteration by the Smock technique and the TRC technique give the best results. The Free assignment is extremely poor, while the Schneider technique yields a better result than the BPR technique.

COMPUTER TIME REQUIREMENTS

Because none of the techniques was clearly better than the others, the computer times for the different techniques were compared. Table 29 gives the computed machine time range on the IBM 7094 computer for applying each restraint technique. The program utilized for this work was not the most optimum one, due to the inclusion of several items for the benefit of the research work and should not be considered as typical time for a pure operational run. Table 29 is offered for its relative value only. The two networks, although having about the same number of zones, were somewhat different due to the fact that the Pittsburgh network had an estimate of capacity on every link whereas the Raleigh network was run with only 8 percent of the links restrained.

TABLE 28

CHI-SQUARE VALUES, ASSIGNMENT TECHNIQUE VS GROUND COUNT ($X10^6$), PITTSBURGH NETWORK

ASSIGNMENT TECHNIQUE	CHI-SQUARE VALUE
Free	66.8
Schneider	11.7
Smock 4	3.5
BPR 4	16.0
TRC 4	6.6

TABLE 29

IBM 7094 COMPUTER TIME BY TECHNIQUE FOR TWO STUDY AREAS

TYPE OF ASSIGNMENT	COMP. TIME (MIN)	
	PITTSBURGH	RALEIGH
Free	18.75	6.34
Schneider	35.48	9.45
Smock 1-4	74.01	28.51
BPR 1-4	75.21	28.95
TRC 1-4	130.48	108.43

SUMMARY OF COMPARISONS

When the two networks under consideration in this section were compared by total vehicle-miles and vehicle-hours of travel as calculated after each assignment technique, a close fit resulted from all of the techniques to each other. However, none of the assignments duplicated the ground count estimates in Pittsburgh. It was felt that the trip table produced more error than could be noted between techniques.

Vehicle-miles were categorized by link speed for each iteration by technique; a wide dispersion was noted in results between the Smock and the BPR restraint functions. The effect of each technique was again measured by comparing volumes crossing established screen lines in both study areas. The total crossings ranged from 2 percent above the ground counts to a low of 10 percent below for the Pittsburgh area. The Raleigh screenline volumes were consistently 7 to 8 percent below the ground count estimates. This was another proof that the tables may not have been complete.

To study the effects of each technique employed, the frequency of links in various volume ranges was examined. This analysis revealed that the Free and BPR techniques produced approximately 10 percent more links in the 0- to 1,000-veh range than did the ground count estimate, Schneider, Smock, and TRC techniques when applied to the Pittsburgh network. The frequencies from the Raleigh data were essentially alike. Links with zero assigned volume were enumerated and the BPR technique had reported more than any other for both networks.

Links with the higher volumes were further analyzed to determine bias of any technique in over-assigning links. The BPR technique appeared to produce more links in the higher-volume ranges than did the others tested. A RMS error analysis of the higher 100 links from the Pittsburgh network indicated that the Smock technique produced the closest fit with the ground counts.

A link-by-link comparison between the ground count and the loaded volume was made for each technique tested on the Pittsburgh network. This analysis indicated that although none of the methods reproduced the ground counts, the Smock technique results were significantly closer.

The analysis of time requirements for each method tested indicated a significant saving in computer time for the Schneider technique. This fact, coupled with the obvious advantages of a one-pass method in man-hours required per assignment, would produce a distinct economic advantage for this method.

The Free assignment was the least desirable of the techniques tested, whereas none of the other techniques showed a marked degree of advantage insofar as the reported volumes deviated from each other. Thus, although the Smock technique indicated a somewhat closer match with the ground count estimates, the Schneider technique should be considered for operational use, and in fact was used in the following portions of this study.

CHAPTER FIVE

LINK ASSIGNMENTS RELATED TO CHANGES IN O-D PATTERNS

What changes occur when all the trips to and from one zone are changed and all other trips are held constant? The purpose was to measure how wide-ranging the influence of an underestimate or overestimate of trip ends at a particular zone might be. A condition of this sort might occur if a large shopping center were to be built in what had been assumed to be a low-density residential area.

In the following test, a network was loaded by using the Schneider model for network assignment. A single zone was then selected and the total numbers of origins and destinations from that point were increased by a constant factor and the individual entries in the trip matrix, each with an origin or destination to the subject point, were increased by the same constant factor. A simple example is shown in the following, in which all trips to and from zone C have been doubled.

Initial Matrix

	A	B	C	D
A	—	100	23	98
B	100	—	44	18
C	23	44	—	45
D	98	18	45	—

Trips to/from C Doubled

	A	B	C	D
A	—	100	46	98
B	100	—	88	18
C	46	88	—	90
D	98	18	90	—

Both the forecast 1975 matrix and a modified 1975 O-D matrix were assigned to the 1975 New Haven network. The only changes made were the trips to and from zone 5 near the center of New Haven. There were 13,315 trips to and the same number from zone 5 in the forecast 1975 trips. All trips were multiplied by a factor of 2.5, so that in the revised trip ends there were 33,285 trips both to and from zone 5, a net increase of 19,970 trips in either direction, or a total of nearly 40,000 trips added to the system. All other trip interchanges were held constant.

CHANGES IN VOLUME ON NETWORK LINKS

The changes in volumes on the network links before and after modifying zone 5 are given in Table 30. There was a very small change in the mean volume when all links were considered. Contrary to expectation, there was an increase in the number of zero-volume links when more volume was loaded on the network. Histograms of the two volume distributions for all links with volume greater than 10,000 vpd are shown in Figure 7. The major difference occurred in the category of links with a volume range of 10,000 to 20,000 vpd, where the number of links changes from 270 to 305 after the changes in the O-D matrix. In the other volume ranges, the changes in the volume distribution patterns were minor.

A closer look at the changes in the peak-volume links is given in Table 31. The increases given in the last column are the differences between links of the same rank, rather than the differences for a particular link. All of the links are freeway links within 6-min (based on minimum-path

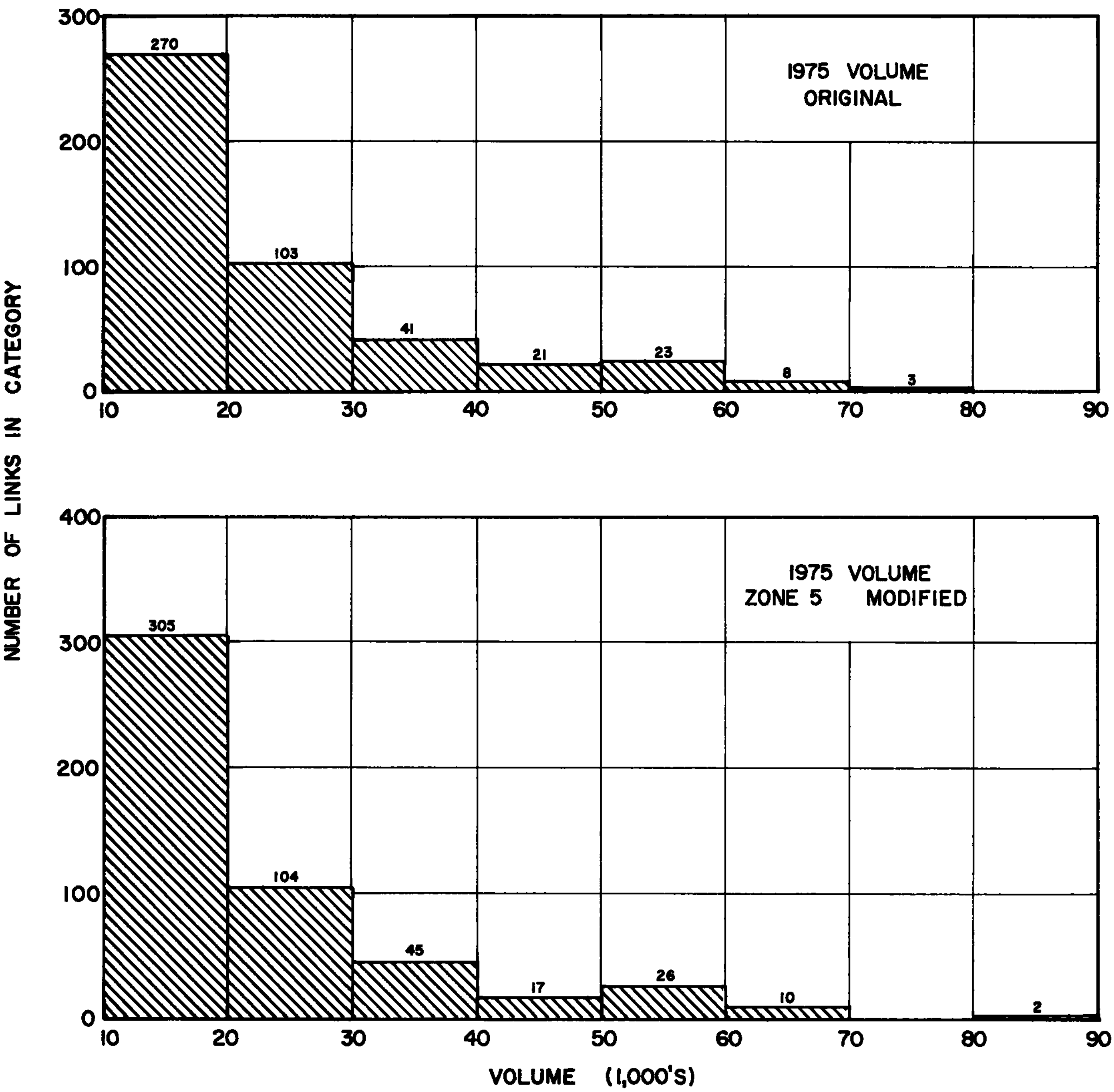

Figure 7. Number of links by volume range.

TABLE 30

NUMBER OF LINKS CATEGORIZED BY VOLUME

VOLUME RANGE (VPD)	LINKS IN CATEGORY (NO.) ORIGINAL	ZONE 5 MODIFIED
0	289	294
1–5000	2403	2348
5001–10000	640	650
10001–15000	187	210
15001–20000	83	95
20001–25000	69	63
25001–30000	34	41
30001–35000	31	27
35001–40000	10	18
40001–45000	8	6
45001–50000	13	11
50001–55000	15	15
55001–60000	8	11
60001–65000	4	4
65001–70000	4	6
70001–75000	1	0
75001–80000	2	0
80001–85000	0	2
Mean vol. per link	5248	5464

TABLE 31

VOLUME AND RANK OF TOP VOLUME LINKS

	ORIGINAL		ZONE 5 MODIFIED		INCREASE
RANK	LINK	VOL. (VPD)	LINK	VOL. (VPD)	BY SIMILAR RANKS
1	1525-1523	78,561	1525-1523	83,726	5165
2	1522-1524	75,474	1522-1524	80,461	4987
3	1519-1518	70,264	1519-1518	69,902	−362
4	1518-1515	67,820	1510-1512	67,530	−390
5	1517-1520	65,524	1518-1515	67,420	1896
6	1510-1512	65,126	1523-1521	66,893	1767
7	1523-1521	65,122	1517-1520	65,374	252
8	1512-1513	61,996	1527-1525	65,174	3171
9	1516-1517	61,786	1512-1513	64,275	2489
10	1512-1511	61,111	1512-1511	63,063	1952
11	1527-1525	60,287	1516-1517	61,647	1360
12	1520-1522	58,988	1530-1528	60,597	1609
13	1507-1505	57,888	1507-1505	59,949	2061
14	1513-1512	57,775	1513-1512	59,602	1827
15	1504-1503	57,393	1504-1503	59,399	2006

trees) travel time of zone 5. There are increases of about 5,000 vpd in the two highest-volume links and in the link which ranked eleventh with the basic assignment (8th in the alternate assignment). The other differences are less, some links (because of the operation of the capacity restraint function) having a slight decrease in volume, even with an increase in the total number of trips in the system. There does not appear to be a tendency for the change in the assignment to be related only to those links with the greatest volume.

A comparison between volumes at selected ranks for the two assignments is given in Table 32. Over the entire range of 500 top-volume links, there are more vehicles assigned after zone 5 has been increased, but the differences are almost always fewer than 1,000 vpd. When all of the links in the system are considered, the addition of 40,000 trips does not have a great influence on the assignments as related to their rank in assigned ADT. It does not appear that volume differences are particularly related to absolute volume.

A further analysis of the impact of the change in a single zone was made by listing and evaluating the differences in volumes per day assigned before and after the change. Table 33 contains a list of links, arrayed in descending order of the volume difference. There are differences of 17,017 and 16,905 to and from zone 5 on the link directly connecting zone 5 to the network. (Zone 5 is connected to the network along a second link also; the differences on this link are 2,953 and 3,065 vpd to and from zone 5.) Thereafter, there is a sharp drop-off in volume differences, ranging from 7,725 for the third greatest difference to 5,423 for the tenth greatest difference. All of the top 10 differences occur on the local street system adjacent to zone 5. This is as might be expected, but it is of interest to note the number of links with volume differences arranged as in Table 34, which shows that even though nearly 40,000 trips ADT (total both directions) are added at a single point only 20 links have volume changes in excess of 4,000 vpd. This would imply that the change in an O-D zone is not significant except for relatively few links near the point of change.

SCREENLINE COMPARISONS

Two screen lines were drawn around the central portion of the CBD, including zone 5, one just encompassing the CBD, the other at the New Haven city line. The two screen lines were further differentiated by sectors as shown in Figure 8. The results of the volumes at the two screen lines, before and after changing zone 5, are given in Table 35. At the inner screen line there is a net increase in the total volume

TABLE 32

ASSIGNED VOLUME COMPARISON, *N*th RANKED LINK

	ORIGINAL		ZONE 5 MODIFIED		
RANK	LINK	VOL. (VPD)	LINK	VOL. (VPD.)	DIFF. (VPD)
50	1511-1509	42,522	2249-2248	44,729	2207
100	1878-1871	29,170	2429-1629	30,022	852
150	2259-2260	23,347	1509-1543	23,792	445
200	1049-1028	19,986	2074-2065	21,034	1048
250	1757-1727	17,019	2414-2413	17,637	618
300	1726-1727	14,108	2024-2025	14,999	891
350	1427-1501	12,757	1936-1872	13,756	999
400	1462-1463	11,346	1016-1017	11,975	929
450	1220-1416	10,398	1547-1029	11,178	780
500	2246-2302	9,510	2618-2617	10,193	683

in either direction of 19,100 vehicles (nearly all of the zones lie beyond this screen line), but at the outer cordon line, along the New Haven city limits, the change in volume has been reduced to 10,700 vehicles in either direction. I-91 to the north is the only section where there is a change that exceeds 5,000 vpd. The impact on the network, exclusive of the expressway system, is minimal.

ASSIGNMENT DIFFERENCES RELATED TO DISTANCE FROM POINT OF CHANGE

A further test of the changes in assignment as related to a single point was made by comparing the volume changes over all links at increasing travel time from zone 5, the point of change. A minimum-path tree was constructed from

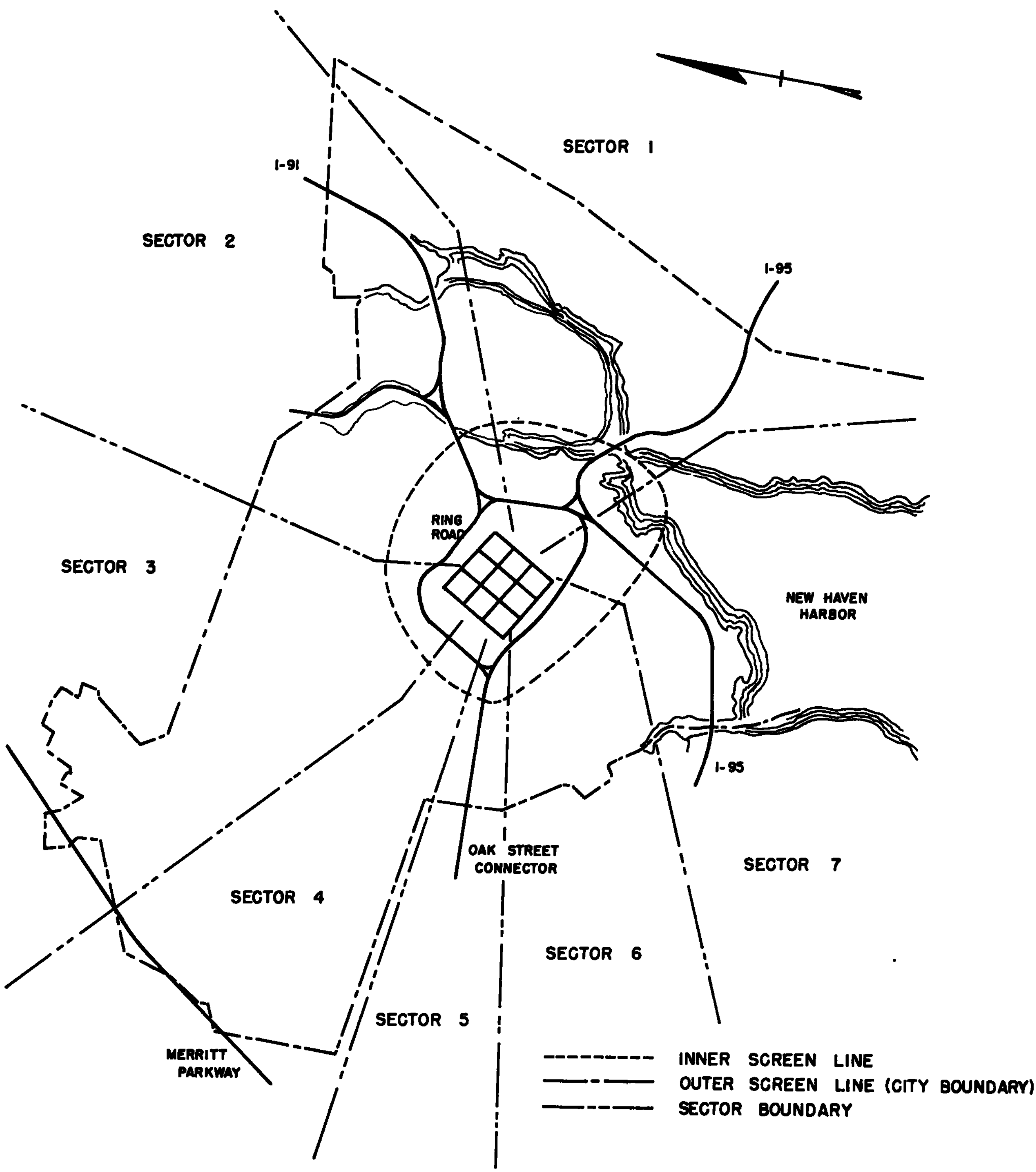

Figure 8. Screen lines and sectors, New Haven.

TABLE 33

RANK OF VOLUME DIFFERENCES (ZONE 5 MODIFIED)

RANK	VOL. DIFF. (VPD)	LINK
1	17017	1006-5
2	16905	5-1006
3	7725	1005-1006
4	7193	1006-1005
5	7114	1006-1007
6	7059	1007-1008
7	6696	1007-1006
8	5679	1009-1010
9	5663	1008-1009
10	5423	1010-1550
25	3766	1009-1008
50	2568	1021-1467
75	2070	1467-1003
100	1691	1169-1463
150	1191	1501-1500
200	930	1628-1514
250	798	7-1401
300	663	1065-1064
350	575	2085-2031
400	494	1124-1123
450	423	2236-2237
500	371	1466-1043

zone 5 and all nodes were arrayed in ascending order of travel time (this is a by-product of the tree-building technique within the computer). The tree-building program was modified to get minimum paths to as well as from zone 5 by building trees in the reverse direction on normally one-way links, thus eliminating any roundabout paths to links coded as one-way facilities.

TABLE 34

DISTRIBUTION OF VOLUME DIFFERENCES (ZONE 5 MODIFIED)

RANGE OF DIFFERENCES (VPD)	NUMBER OF LINKS
Over 15000	2
7001-8000	4
6001-7000	1
5001-6000	6
4001-5000	7
3001-4000	19
2001-3000	40
1501-2000	26
1001-1500	85
501-1000	209

The results in terms of the total and mean volume changes are given in Table 36, along with a calculation of the root-mean-square error. The root-mean-square error for each 2-min group was found by squaring the difference in volume assigned to each link before and after modifying zone 5, accumulating the squared differences, and finally dividing the sum of the squared differences by the number of links

TABLE 35

1975 NEW HAVEN O-D SCREENLINE VOLUMES

SECTOR	TRAFFIC VOLUME (VPD)			
	ORIGINAL		ZONE 5 MODIFIED	
	IN	OUT	IN	OUT
(a) INNER SCREENLINE				
1 I-95-Grand Ave.	66,600	71,700	69,200	74,400
2 I-95, State St.-Prospect St.	91,400	86,500	97,300	92,400
3 Winchester Ave.-Elm St.	14,900	14,300	16,100	15,200
4 Edgewood Ave.-George St.	7,100	3,200	7,400	3,900
5 Oak St. connector & frontage rds.	28,300	32,300	30,000	34,100
6 Congress Ave.-Union Ave.	30,400	28,400	35,800	33,300
7 I-95 & frontage rds.	56,000	58,300	57,800	60,300
Total	294,700	294,700	313,600	313,600
(b) OUTER SCREENLINE				
1 Airport, I-95-Foxon Blvd.	71,300	70,200	73,600	72,400
2 I-91, State St.-Prospect St.	83,900	85,900	87,800	90,100
3 Winchester Ave.-Merritt Pkwy.	47,300	47,400	47,800	47,800
4 Whalley Ave.-Forest Rd.	41,100	39,800	41,800	40,100
5 Derby Ave.-Oak St. connector	21,800	21,900	23,100	22,900
6 Congress Ave.-Washington Ave.	14,000	13,100	14,100	13,800
7 I-95 & Kimberly Ave.	54,500	55,600	56,300	57,400
Total	333,900	333,900	344,500	344,500

TABLE 36

CHANGES IN ASSIGNED VOLUME VS TIME FROM POINT OF CHANGE (ZONE 5 MODIFIED)

TIME (MIN)	NO. OF LINKS	TRAFFIC VOLUME (VPD) TOTAL, ALL LINKS BEFORE	AFTER	MEAN, PER LINK BEFORE	AFTER	ROOT-MEAN-SQUARE ERROR	PERCENT ERROR
0–2	61	220,550	361,356	3,616	5,924	3717.8	102.83
2–4	197	1,296,554	1,434,080	6,581	7,280	1247.2	18.95
4–6	456	3,555,130	3,706,281	7,796	8,128	786.7	10.09
6–8	618	2,976,043	3,083,181	4,816	4,989	448.7	9.32
8–10	440	2,160,638	2,231,130	4,911	5,071	387.9	7.90
10–12	433	1,954,998	2,015,447	4,515	4,655	299.1	6.62
12–14	450	2,335,125	2,383,156	5,189	5,296	211.1	4.07
14–16	343	1,794,857	1,829,027	5,233	5,332	179.4	3.43
16–18	281	1,518,186	1,540,315	5,403	5,482	130.6	2.42
18–20	227	1,003,976	1,018,341	4,423	4,486	121.6	2.75
20–22	159	711,313	720,746	4,474	4,533	105.9	2.37
22–24	62	188,671	190,245	3,043	3,068	49.7	1.63
24–26	24	55,719	56,308	2,322	2,346	48.8	2.10
26–28	15	49,216	49,742	3,281	3,316	60.8	1.85
28–30	17	68,857	69,597	4,050	4,094	61.2	1.51
> 30	14	47,290	47,502	3,378	3,393	33.1	0.98

in that group and taking the square root of the result. The percent error represents the root-mean-square error as a percentage of the mean volume assigned per link before zone 5 was changed.

Considering all links in the system, it is evident that the influence on volume per link is a maximum within a few minutes travel time of the changed node, decreasing rapidly at greater distances from the point of change. In the first 2-min ring the mean volume per link increased by 2,308 trips per link, in the second 2-min ring the mean volume increased by 699 trips per link, but in the third 2-min link the average volume change was only 332 trips per link, decreasing to a mean change of 15 vehicles per link at points 30 min or more from zone 5.

The percent root-mean-square error is plotted in Figure 9 along with two curves which are fitted to the data by least-squares techniques as follows:

$$\% \text{ error} = 93.65/t^{1.23} \qquad R^2 = 0.97 \qquad (14a)$$

and

$$\% \text{ error} = -3.97 + 102.30/t \qquad R^2 = 0.97 \qquad (14b)$$

in which t is the time in minutes from zone 5.

The decrease in the error term at increasing distance from the point of change is again evident at distances greater than 5 min from zone 5.

This result is not unexpected. The total difference of 20,000 trips in either direction enters into the error for links directly leading to zone 5 and this error is spread over relatively few links. At increasing distance from zone 5 there are increasing numbers of destinations and origins, at each of which some of the change in trips are "deposited," so that at the most distant node only the trips between zone 5 and that node are influencing the trips on the system. Also, as successive 2-min distances are included in the analysis there are more links over which the error is averaged. If the links and nodes of the network were spaced uniformly throughout the study area, the number of links would increase with distance from zone 5 in proportion to the greater area encompassed at the increased distance. In practice there are fewer nodes and links at the outer limits of the network, so that the number of links decreases after 14 min from zone 5.

The relationship between the accumulative volume change and distance from the point of change is given in Table 37. The percent error is the root-mean-square error as a percentage of the mean volume, as given in Table 36. The column of relative weight was calculated as follows for the 0 to 2-min time interval.

One hundred percent of the cumulative change in zone 5 is present at zone 5; 97.91 percent is still carried beyond the 2-min limit. It is assumed that the average cumulative change in volume within the 0 to 2-min circle is (100.00 + 97.91)/2 or 98.95 percent. This change is averaged over 61 links and finally the average is multiplied by an arbitrary constant to make the relative weight equal to 100 percent. Similar calculations were made for the other time intervals, multiplying by the constant found for the first ring. It will be seen that the RMS error at increasing distance from the point of change is nearly proportional to a function of the trip length distribution from zone 5 and the number of links that are located at different time distances from the point of change.

The previous discussion has related to errors over all links at increasing time intervals from the point of change, not all of which links are influenced by the volume changes from zone 5. Figure 10 is a plot of the volume changes on the central city portion of the network, with the width of the plotted line in proportion to the assigned volume differ-

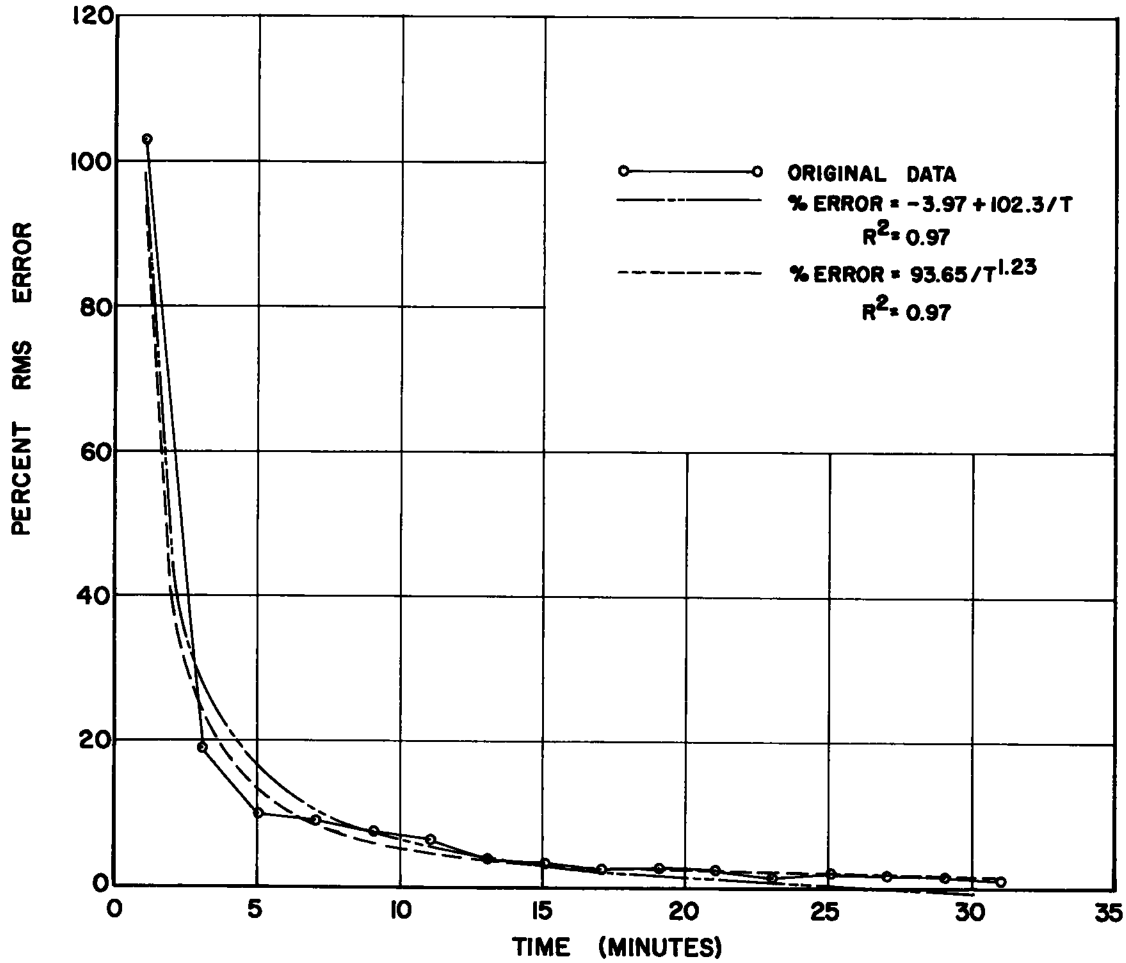

Figure 9. Percent RMS error by distance from zone 5.

ence (only differences greater than 400 were plotted).

The maximum volume differences occur on the arterial street network immediately north and south of zone 5. Except for a segment to the west of zone 5, almost all of the remaining maximum volume differences occur along the expressway network, so that the only surface streets affected are those connecting zone 5 to the expressway network. The maximum difference on the expressway network is along I-91 to the northeast, 5 min from zone 5, an increase of 5,400 trips on a southbound link and 5,000 trips on the northbound link. This difference reduces to 1,400 trips where I-91 intersects the New Haven town line, 7 min from zone 5.

To the east the maximum differences are assigned along I-95 (the Connecticut Turnpike), a difference of about 2,400 ADT volume in either direction 5 min from zone 5, reducing to 1,500 ADT difference at the New Haven town line, 7 min from zone 5. Volume differences to the west and southwest along I-95 range from a maximum of 2,000 ADT in either direction at a point 4 min from zone 5 to 1,100 ADT at the New Haven town line, 6 min from zone 5. Lesser volume differences occur to the north and to the west along connector expressways.

It is evident that the specific changes in zone 5 influence the arterial street system only adjacent to the zone itself and that the major differences occur along the expressway links, again with decreasing differences as the travel time from zone 5 is increased.

CHANGES IN SUBURBAN ZONE

An experiment similar to the test of changing the volumes at zone 5, was done for a second zone in the New Haven network, this one at a shopping area in one of the suburbs of New Haven, zone 182. The node was selected because it was a high-volume node, was not near the center of the network, and the coded network included fewer links per unit area in the vicinity of the site of the change in O-D pattern.

The forecast 1999 volume was used instead of the forecast 1975 volume to assign to the 1975 network. The purpose was to introduce greater volumes into the network so that capacity restraints would have more effect in diverting trips to different portions of the network. All trips to and from zone 182 were doubled, so that there were 25,478 added destinations and 25,478 added origins related to zone 182.

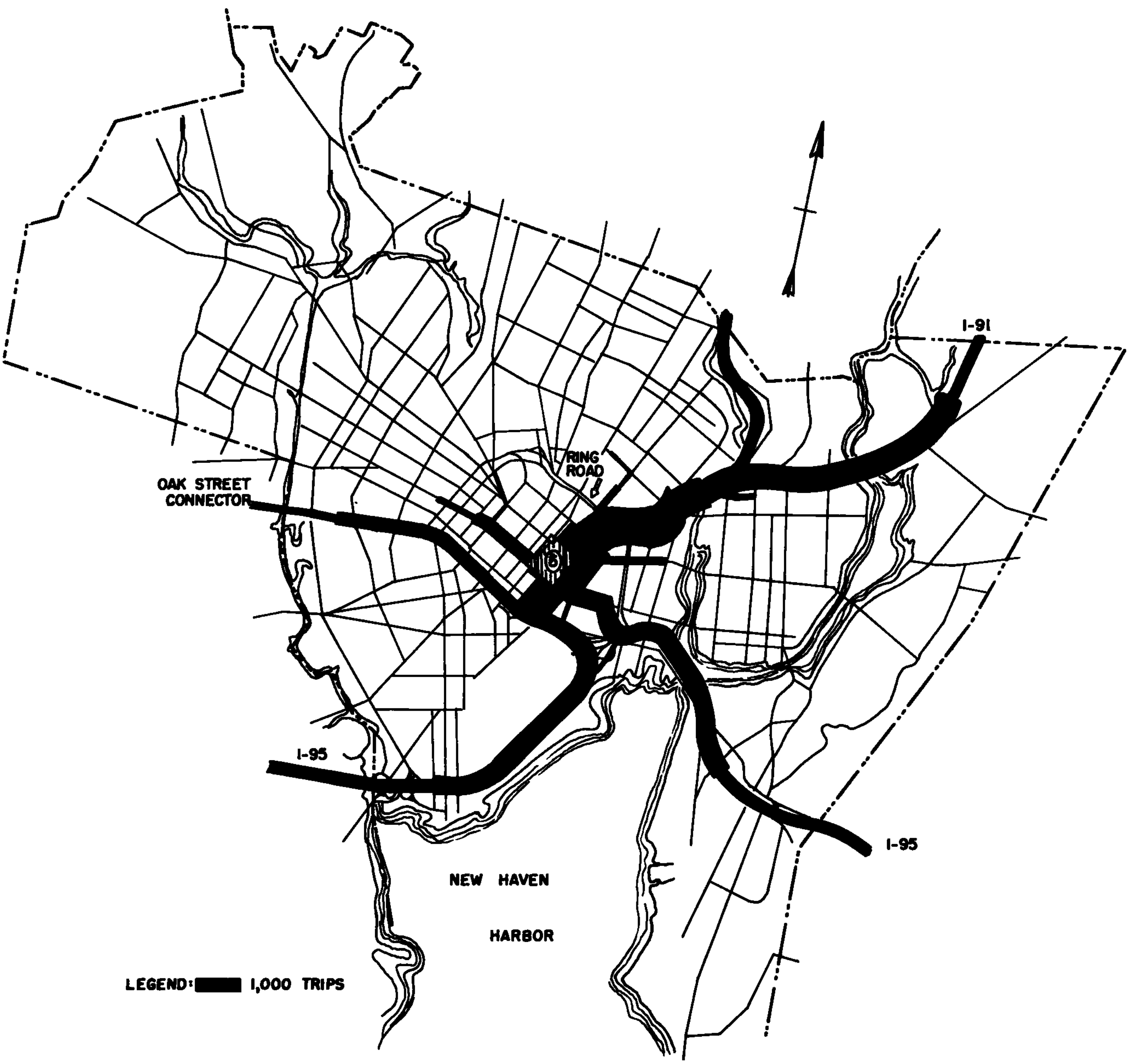

Figure 10. Volume pattern on assignment network resulting from additional loading (20,000 trips) from zone 5.

The Schneider technique was again used in making the assignments.

CHANGES IN VOLUME ON NETWORK LINKS

The changes in volumes on the network links before and after modifying zone 182 are given in Table 38, the volume and rank of the top volume links in Table 39, and comparison of the *n*th ranked links in Table 40. As for zone 5, there is a slight increase in the average assigned ADT for all links. Histograms of the two volume distributions for all links with volumes greater than 10,000 assigned ADT are shown in Figure 11. The major change occurs at links in the 50,000- to 60,000-ADT category, where there are an added 10 links with assigned volumes in this range.

In Table 39 it will be observed that all of the peak-volume links are assigned a greater volume after zone 182 has been doubled. Further, all of the links are on the expressway network (again it will be noted that the network used is the 1975 network, so that volumes on the expressway are greater than were observed when changes were made at zone 5); the increases refer to differences between similar ranks rather than between corresponding links. The link ranks are also influenced by the added volume at zone 182; for example, the third-ranked link before the change becomes the sixth-ranked link after the change.

A similar pattern is observed in Table 40, where the same

TABLE 37

RELATIVE CHANGE IN LINK VOLUME PER LINK AT SUCCESSIVE TIME RINGS FROM ZONE 5

TIME (MIN)	PERCENT TRIPS WITH O-D IN TIME RING	CUMULATIVE % TRIPS BEYOND TIME RING	LINKS PER RING	RELATIVE WEIGHT	PERCENT ERROR
0	—	100.00	—	—	—
0–2	2.09	97.91	61	100.0	102.83
2–4	7.82	90.09	197	29.4	18.95
4–6	10.04	80.05	456	11.5	10.09
6–8	13.11	66.94	618	7.3	9.32
8–10	10.17	56.77	440	8.7	7.90
10–12	12.06	44.71	433	7.2	6.62
12–14	10.75	33.96	450	5.4	4.07
14–16	12.50	21.46	343	5.0	3.43
16–18	7.77	13.69	281	3.9	2.42
18–20	2.36	11.33	227	3.4	2.75
20–22	8.05	3.28	159	2.8	2.37
22–24	1.57	1.71	62	2.5	1.63
> 24	1.71	0	70	0.7	1.62

pattern of increased volume is associated with the top 500 links, but the difference (increase due to change at zone 182) tends to be less for the lower ranked zones.

Table 41 lists the differences in assigned ADT volume for selected rankings by difference. The entire difference of 25,478 ADT volume in either direction is noted on six links of the local arterial system immediately adjacent to the zone of change. This reflects the network in the vicinity of this zone. There are no alternate routes immediately adjacent to the changed zone and the impact of the difference is noted for all of the links in the immediate vicinity. From the sixth to the tenth rank there is a sharp fall-off in volume differences and by the 100th rank the difference is down to nearly 2,000 assigned ADT, indicating that for a change of this magnitude about 100 links would need careful scutiny if in reality the assumed loading and actual loading at zone 182 would vary as much as 25,000 trips in either direction.

Table 42 indicates the number of links classified by volume differences. With the addition of about 50,000 trips ADT (total both directions) at a single point, 13 links have increases of over 10,000 assigned ADT and an added 33 links have changes of over 4,000 assigned ADT. The addition of more trips (50,000 at zone 182 vs 40,000 at zone 5) in the area of fewer alternate routes (zone 182 is suburban, zone 5 is in the CBD) would indicate that the effect is noted over more links, when comparing changes at zone 182 and zone 5.

ASSIGNMENT DIFFERENCE RELATED TO DISTANCE FROM POINT OF CHANGE

An analysis similar to that for zone 5 was made for zone 182, relating the magnitude of change to distance from the point of change. The results in terms of the total and mean ADT volume changes are given in Table 43, along with a calculation of the root-mean-square error (RMS). All calculations are as for zone 5.

The impact of the change is noted over a greater range of distance from the point of change when Table 43 is compared to Table 36. The number of links within successive time zones from zones 5 and 182 is compared in Table 44, along with a comparison of differences in mean assigned ADT for the two test zones.

As compared to zone 5, there are fewer links near zone

TABLE 38

NUMBER OF LINKS CATEGORIZED BY VOLUME (ZONE 182 MODIFIED)

VOLUME RANGE (VPD)	LINKS IN CATEGORY (NO.) ORIGINAL	ZONE 182 MODIFIED
0	281	281
1–5000	2089	2053
5001–10000	711	723
10001–15000	312	320
15001–20000	123	126
20001–25000	72	80
25001–30000	53	41
30001–35000	44	48
35001–40000	24	24
40001–45000	25	21
45001–50000	12	15
50001–55000	7	19
55001–60000	12	10
60001–65000	11	9
65001–70000	8	11
70001–75000	8	8
75001–80000	4	2
80001–85000	3	5
85000–90000	0	3
over 90000	2	2
Mean vol. per link	6924	7190

TABLE 39

VOLUME AND RANK OF TOP VOLUME LINKS (ZONE 182 MODIFIED)

	ORIGINAL		ZONE 182 MODIFIED		
RANK	LINK	VOLUME (VPD)	LINK	VOLUME (VPD)	INCREASE BY SIMILAR RANKS
1	1525-1523	95,332	1525-1523	96,469	1337
2	1522-1524	91,971	1522-1524	94,328	2357
3	1519-1518	83,962	1510-1512	88,948	4986
4	1510-1512	83,824	1512-1511	86,267	2443
5	1518-1515	81,136	1512-1513	85,036	3900
6	1512-1513	79,864	1519-1518	84,770	4906
7	1512-1511	79,256	1513-1512	81,989	2733
8	1523-1521	79,186	1518-1515	81,946	2760
9	1517-1520	78,293	1517-1520	80,726	2433
10	1527-1525	74,993	1523-1521	80,138	5145
11	1513-1512	74,978	1516-1517	76,569	1591
12	1516-1517	74,061	1727-1525	75,757	1696
13	1520-1522	71,999	1520-1522	74,211	2212
14	1529-1530	71,772	1529-1530	73,781	2009
15	1507-1505	71,757	1507-1505	72,928	1171

TABLE 40

ASSIGNED VOLUME COMPARISON, *N*th RANKED LINK (ZONE 182 MODIFIED)

	ORIGINAL		ZONE 182 MODIFIED		
RANK	LINK	VOLUME (VPD)	LINK	VOLUME (VPD)	DIFF.
50	1531-1530	54,342	1524-1526	56,485	2143
100	2429-1629	38,777	2257-2258	41,735	2958
150	2069-2068	31,385	2107-2068	32,180	795
200	2255-2254	26,221	1753-1752	26,806	585
250	151-2070	22,313	1712-1750	23,351	1038
300	2405-2414	19,182	1524-1015	19,910	728
350	2426-2422	17,808	163-2301	18,286	478
400	2528-2507	15,745	1427-1501	16,469	724
450	1567-1485	13,851	1416-1540	14,498	647
500	2215-2230	12,922	2306-2317	13,474	552

182. Consequently, the differences in the assigned ADT are distributed over fewer links, and because of the greater distance between O-D zones the influence of the change is noted at greater time distances from the point of change.

A similar effect is noted for the RMS error, plotted in Figure 12, along with two least-squares curves:

$$\% \text{ error} = 370.12/t^{1.46} \qquad R^2 = 0.89 \qquad (15a)$$

and

$$\% \text{ error} = 103.51 * 0.86\, t \qquad R^2 = 0.93 \qquad (15b)$$

in which t is the time in minutes from zone 182.

A percent RMS error of greater than 10 is present as far as 15 min from the point of change, indicating that large changes near the edge of a network have a more pronounced effect over a greater distance from the change than a similar change near the center of the network.

SUMMARY

This investigation demonstrated that a radical change in trips attracted to or from a zone in the core area of the study network has much less influence on the link volumes through the study area than a similar change in trips associated with an outlying zone. This is due to the construction of the coded network, where one usually finds more zones and links per unit area in the central core than near the outer cordon line of the study. Although the New Haven network was chosen for the examples and the probability of zone 5 being underestimated by 50 percent is slight, the precepts found in the analysis should apply to any study area.

The area of influence for any zone has been demonstrated to be relatively small. This suggests that a traffic assignment might be updated by other than a complete rerun if the trips associated with one zone were found to be somewhat different from the original estimates at a later date.

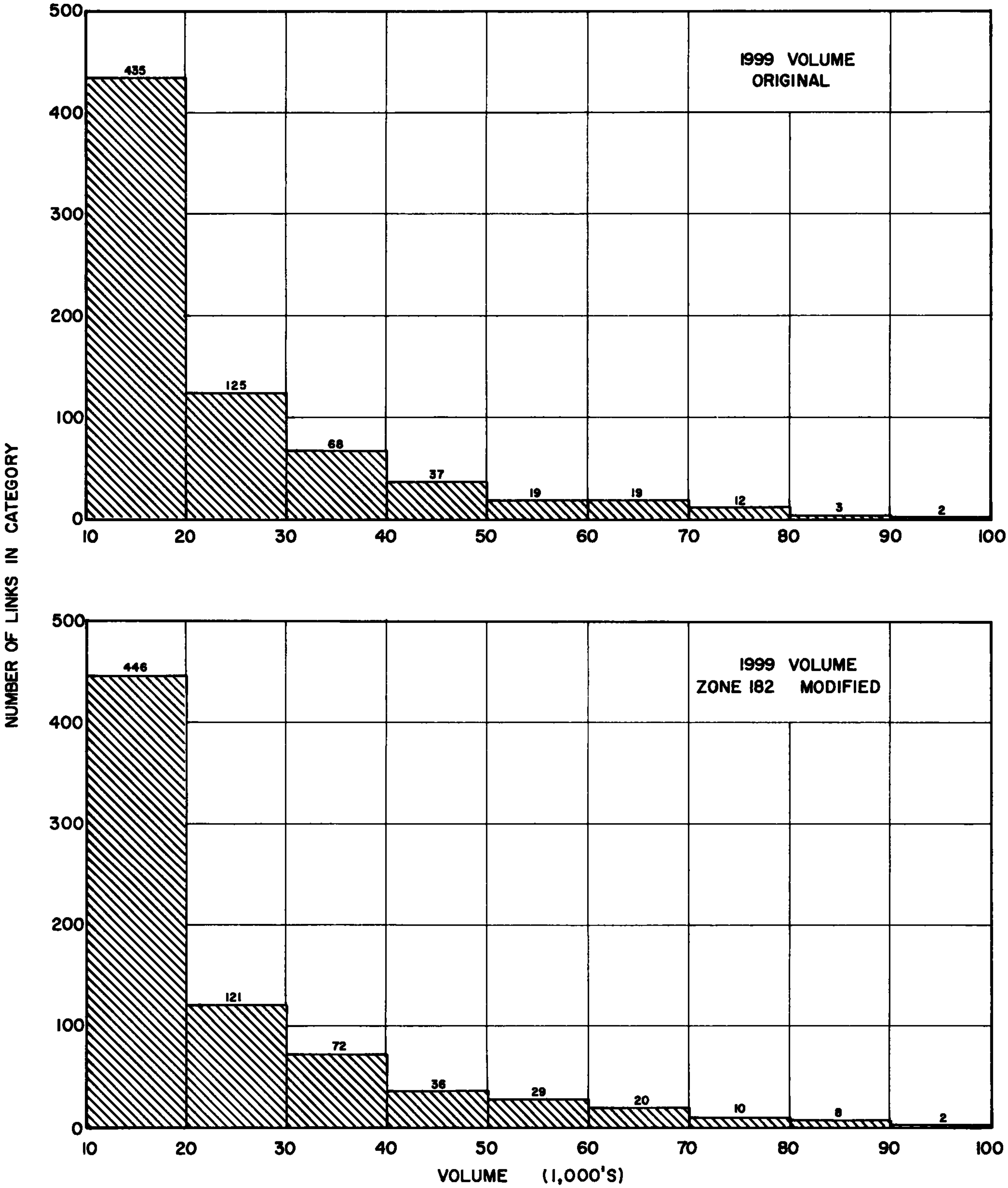

Figure 11. Number of links by volume range.

TABLE 41

RANK OF VOLUME DIFFERENCES (ZONE 182 MODIFIED)

RANK	VOLUME DIFFERENCE (VPD)	LINK
1	25,478	182-2511
2	25,478	2511- 182
3	25,478	2507-2508
4	25,478	2508-2507
5	25,478	2508-2511
6	25,478	2511-2508
7	18,179	2507-2528
8	15,854	2528-2527
9	13,998	2528-2507
10	12,357	2527-2543
25	6,710	2542-2543
50	3,421	2673-2674
75	2,393	2618-2615
100	2,082	2409-2410
150	1,566	2249-2250
200	1,131	187-2617
250	836	2523-2520
300	700	2265-2250
350	585	1608-2178
400	505	1750-1751
450	421	1066-1546
500	360	1206-1316

TABLE 42

DISTRIBUTION OF VOLUME DIFFERENCES (ZONE 182 MODIFIED)

RANGE OF DIFFERENCES (VPD)	NUMBER OF LINKS
Over 25000	6
15001-20000	2
10001-15000	5
9001-10000	1
8001- 9000	5
7001- 8000	7
6001- 7000	3
5001- 6000	11
4001- 5000	6
3001- 4000	18
2001- 3000	56
1501- 2000	37
1001- 1500	63
501- 1000	183

TABLE 43

CHANGES IN ASSIGNED VOLUME VS TIME FROM POINT OF CHANGE (ZONE 182 MODIFIED)

TIME (MIN)	NO. OF LINKS	TRAFFIC VOLUME (VPD): TOTAL, ALL LINKS		TRAFFIC VOLUME (VPD): MEAN, PER LINK		ROOT-MEAN-SQUARE ERROR	PER-CENT ERROR
		BEFORE	AFTER	BEFORE	AFTER		
0-2	6	101,908	203,820	16,985	33,970	20802.7	122.48
2-4	6	67,984	137,719	11,331	22,953	14119.9	124.62
4-6	42	375,414	496,069	8,938	11,811	5161.0	57.74
6-8	55	568,230	668,190	10,331	12,149	3072.6	29.74
8-10	60	440,101	512,935	7,335	8,549	2005.3	27.34
10-12	81	848,467	921,381	10,475	11,375	2044.3	19.52
12-14	116	1,470,769	1,572,948	12,679	13,560	1635.1	12.90
14-16	253	3,622,941	3,722,824	14,320	14,715	736.5	5.14
16-18	562	3,828,384	3,897,182	6,812	6,934	288.8	4.24
18-20	692	3,071,370	3,124,267	4,438	4,515	253.8	5.72
20-22	440	2,398,958	2,428,380	5,452	5,519	196.3	3.60
22-24	438	2,604,253	2,634,420	5,946	6,015	215.2	3.62
24-26	335	1,989,017	2,014,672	5,937	6,014	216.8	3.65
26-28	302	2,146,978	2,170,181	7,109	7,186	170.2	2.39
28-30	158	1,284,070	1,292,085	8,127	8,178	126.0	1.55
30-32	124	763,387	768,099	6,156	6,194	100.1	1.63
32-34	69	412,897	414,392	5,984	6,006	46.2	0.77
34-36	24	102,949	103,469	4,290	4,311	39.7	0.93
36-38	18	89,312	89,638	4,962	4,980	37.2	0.75
38-40	2	472	427	236	236	0.0	0.00
40-42	0	0	0	0	0	0.0	0.00
42-44	12	82,437	82,621	6,870	6,885	36.1	0.53
44-45	5	24,065	24,186	4,813	4,837	54.1	1.12

TABLE 44

NUMBER OF LINKS IN SUCCESSIVE TIME ZONES FROM POINT OF CHANGE (ZONE 5 VS ZONE 182)

TIME (MIN)	NUMBER OF LINKS		INCREASE IN MEAN ASSIGNED ADT (VPD)	
	ZONE 5	ZONE 182	ZONE 5	ZONE 182
0-2	61	6	2308	16985
2-4	197	6	699	11622
4-6	456	42	332	2873
6-8	618	55	173	1214
8-10	440	60	160	900
10-12	433	81	140	881
12-14	450	116	107	395
14-16	343	253	99	122
16-18	281	562	79	77
18-20	227	692	63	69

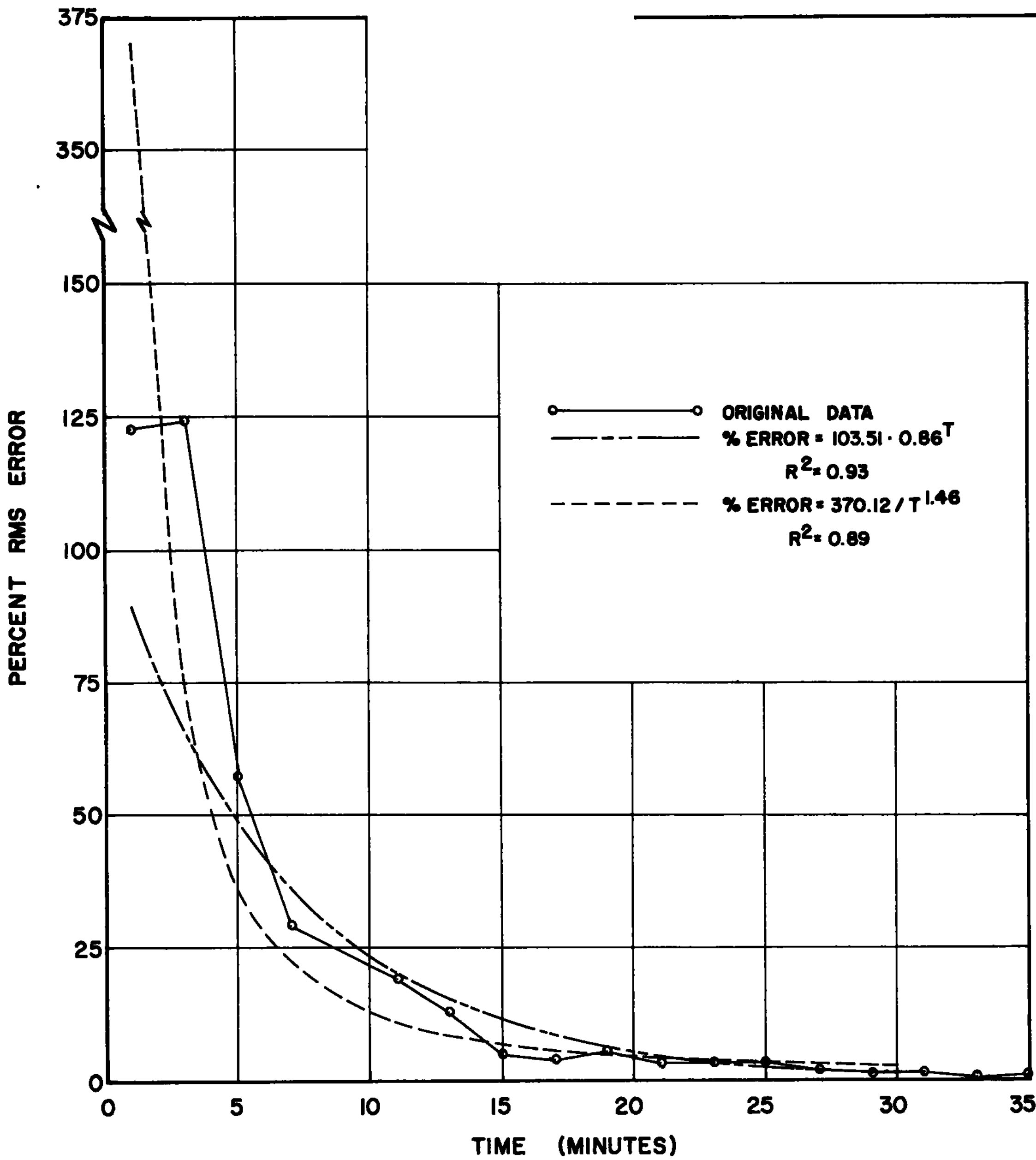

Figure 12. Percent RMS error by distance from zone 182.

CHAPTER SIX

INFLUENCE OF NETWORK CHANGES ON ASSIGNED VOLUMES

What are the consequences of modifying a portion of a proposed highway network? Are the influences felt only near the point of change or will many links be affected? In order to evaluate these and other questions a test was made by deleting a portion of the expressway network while holding the origin-destination matrix constant. The test was conducted on the 1975 New Haven network using the 1975 forecast O-D table. The network change was accomplished by effectively deleting the Oak Street connector, a 6- to 8-lane freeway parallel to the south side of the New Haven CBD. On the east the connector is joined to the intersection of I-95 (Connecticut Turnpike) and I-91. To the west of the CBD the connector is a 6-lane freeway (Fig. 10).

To minimize changes in network coding (and coding errors associated with the network changes) the connector was retained, but the assumed speed along each of 29 links was changed to 1 mph so minimum-path trees deleted the connector as a possible route. The resulting assignment was then compared to the assignments made on the unchanged 1975 network.

CHANGES IN VOLUMES ON NETWORK LINKS

The changes in volumes on the network links before and after deleting the Oak Street connector are given in Table 45. The slight increase in mean volume per link is a reflection of the volume shift from the connector to other portions of the network. There is an increase in the number of links with no volume, reflecting the zero-volume links along the connector. Again, the great majority of all links have fewer than 5,000 trips assigned. The distribution of all links with volume greater than 10,000 assigned ADT are shown in Figure 13, and is similar to the volume distribution with the connector retained.

TABLE 45

NUMBER OF LINKS CATEGORIZED BY VOLUME (OAK ST. CONNECTOR DELETED)

VOLUME RANGE (VPD)	NO. OF LINKS IN CATEGORY: ORIGINAL NETWORK	MODIFIED NETWORK
0	289	343
1-5000	2403	2309
5001-10000	640	673
10001-15000	187	179
15001-20000	83	103
20001-25000	69	66
25001-30000	34	34
30001-35000	31	33
35001-40000	10	11
40001-45000	8	10
45001-50000	13	10
50001-55000	15	7
55001-60000	8	11
60001-65000	4	7
65001-70000	4	3
70001-75000	1	2
75001-80000	2	0
Mean vol. per link	5248	5272

The 15 greatest volume links with and without the connector are ranked in Table 46 along with the difference in volume for similar ranks (although not necessarily the same links). The seven top links, in the vicinity of the intersection of the connector, I-91, and I-95, all have lesser volume assigned when the Oak Street connector was removed. For the next eight greatest volume links there is a slight increase in volume.

Selected similar ranked links are compared in Table 47. The differences between similar ranks are mixed, indicating that the volume differences are not related to the absolute volume on the network.

Table 48 lists the top 13 assigned ADT differences in descending order along with other selected rank differences. All of the top 13 differences, which now have zero volume, are on the Oak Street connector. From the 25th to the 500th ranked positions the differences range from 15,707 down to 1,428 assigned ADT. (The 500th difference for the zone 5 test was 371 vehicles; for the zone 182 test, 360 vehicles.) A change in the network appears to have a greater effect over more links than does a change in the O-D pattern. This is further evident in Table 49, comparing the changes in the 1975 assignment caused by deleting the Oak Street connector to changes in the 1975 assignment caused by increasing the trips at zone 5. Over all ranges of differences there are more changes brought about by the network variation than by changing a single zone.

SCREENLINE COMPARISONS

The same two screen lines shown in Figure 8 were checked before and after deleting the Oak Street connector. The results of the comparison are shown in Table 50. Without the Oak Street connector (most of which is inside of the inner screen line) there is a decrease in volume of nearly 16,000 vpd at the inner screen line and an increase of 10,000 vpd at the outer screen line. It is evident that many trips which had been assigned to pass through the inner cordon now pass around the area after the Oak Street connector has been removed. Again, in examining the sectors, the principal differences are found at the points where the expressway system crosses the screen line. Only along the

TABLE 46

VOLUME AND RANK OF TOP VOLUME LINKS
(OAK STREET CONNECTOR DELETED)

	1975 VOLUME		1975 VOL. WITHOUT OAK ST.		
RANK	LINK	VOLUME (VPD)	LINK	VOLUME (VPD)	INCREASE BY SIMILAR RANKS
1	1525-1523	78,561	1525-1523	74,380	4181
2	1522-1524	75,474	1522-1524	71,332	4142
3	1519-1518	70,264	1507-1505	66,696	3568
4	1518-1515	67,820	1504-1503	66,288	1532
5	1517-1520	65,524	1505-1504	65,400	124
6	1510-1512	65,126	1503-1512	63,936	1190
7	1523-1521	65,122	1519-1518	63,698	1424
8	1512-1513	61,996	1503-1504	62,331	−335
9	1516-1517	61,786	1509-1507	61,984	−198
10	1512-1511	61,111	1502-1501	61,281	−170
11	1527-1525	60,287	1512-1513	60,968	−681
12	1520-1522	58,988	1518-1515	60,755	−1767
13	1507-1505	57,888	1503-1502	59,234	−1346
14	1513-1512	57,775	1512-1511	59,137	−1362
15	1504-1503	57,393	1517-1520	58,868	−1475

Oak Street connector and adjacent roadways are the volume differences greater than 5,000 vpd.

ASSIGNMENT DIFFERENCES RELATED TO DISTANCE FROM POINT OF CHANGE

A point in the middle of the deleted Oak Street connector (on a ramp leading to the arterial system) was arbitrarily selected for comparing changes in successive *t*-min intervals from the site of the network change. The number of links, total volumes, and mean volumes before and after deleting the Oak Street connector, and the RMS error, were calculated by the same methods used to evaluate the changes in zones 5 and 182. The results are given in Table 51.

There is a great decrease in the mean assigned ADT

TABLE 47

ASSIGNED VOLUME COMPARISON, *N*th-RANKED LINK
(OAK STREET CONNECTOR DELETED)

	1975 VOLUME		1975 VOL. WITHOUT OAK ST.		
RANK	LINK	VOLUME (VPD)	LINK	VOLUME (VPD)	DIFF. (VPD)
50	1511-1509	42,522	1524-1526	40,402	2120
100	1878-1871	29,170	2429-1629	28,477	693
150	2259-2260	23,347	2254-2253	23,209	138
200	1049-1028	19,986	2252-2253	19,729	523
250	1757-1727	17,019	1846-1849	16,753	266
300	1726-1727	14,108	1564-1563	14,862	−754
350	1427-1501	12,757	2617-2616	12,889	−132
400	1462-1463	11,346	2507-2508	11,308	38
450	1220-1416	10,398	2369-2370	10,291	107
500	2264-2302	9,510	1179-1364	9,552	−42

TABLE 48
RANK OF VOLUME DIFFERENCES
(OAK ST. CONNECTOR DELETED)

RANK	VOLUME DIFFERENCE (VPD)	LINK
1	54,640	1542-1540
2	52,997	1540-1541
3	52,270	1543-1542
4	50,211	1541-1544
5	34,350	1539-1538
6	34,350	1568-1539
7	34,279	1538-1539
8	34,279	1539-1568
9	30,425	1568-1540
10	30,257	1567-1538
11	30,244	1540-1568
12	29,869	1538-1567
13	25,645	1569-1536
25	15,707	1509-1507
50	11,208	1550-1522
75	8,517	1007-1008
100	6,994	1415-1014
150	5,721	1101-1102
200	4,070	1930-1931
250	2,840	1624-2248
300	2,419	1164-1602
350	2,046	1423-1424
400	1,766	1407-1463
450	1,588	1418-1212
500	1,428	8-1402

TABLE 49

DISTRIBUTION OF VOLUME DIFFERENCES
(OAK STREET CONNECTOR DELETED VS MODIFIED ZONE 5)

RANGE OF DIFFERENCES (VPD)	NUMBER OF LINKS	
	CONNECTOR	ZONE 5
Over-50000	4	0
25001-50000	9	0
20001-25000	5	0
15001-20000	9	2
10001-15000	24	0
9001-10000	10	0
8001- 9000	24	0
7001- 8000	14	4
6001- 7000	34	1
5001- 6000	30	6
4001- 5000	42	7
3001- 4000	33	19
2001- 3000	118	40
1501- 2000	119	26
1001- 1500	—[a]	85
501- 1000	—[a]	209

[a] No data obtained in this range.

TABLE 50

SCREENLINE VOLUMES (OAK STREET CONNECTOR DELETED)

SECTOR	TRAFFIC VOLUME (VPD)			
	ORIGINAL		OAK ST., CONNECTOR DELETED	
	IN	OUT	IN	OUT
(*a*) INNER SCREENLINE				
1 I-95-Grand Ave.	66,600	71,700	65,100	70,900
2 I-95, State St.-Prospect St.	91,400	86,600	87,600	83,300
3 Winchester Ave.-Elm St.	14,900	14,300	17,100	16,700
4 Edgewood Ave.-George St.	7,100	3,200	10,400	4,200
5 Oak St. connector & frontage rds.	28,300	32,300	9,500	12,300
6 Congress Ave.-Union Ave.	30,400	28,400	25,600	23,200
7 I-95 & frontage rds.	56,000	58,300	63,100	67,800
Total	294,700	294,700	278,400	278,400
(*b*) OUTER SCREENLINE				
1 Airport, I-95-Foxon Blvd.	71,300	70,200	71,100	70,100
2 I-91, State St.-Prospect St.	83,900	85,900	82,700	85,800
3 Winchester Ave.-Merritt Pkwy.	47,300	47,400	53,500	52,400
4 Whalley Ave.-Forest Rd.	41,100	39,800	44,000	42,800
5 Derby Ave.-Oak St. connector	21,800	21,900	11,900	11,000
6 Congress Ave.-Washington Ave.	14,000	13,100	21,900	19,700
7 I-95 & Kimberly Ave.	54,500	55,600	58,800	62,100
Total	333,900	333,900	343,900	343,900

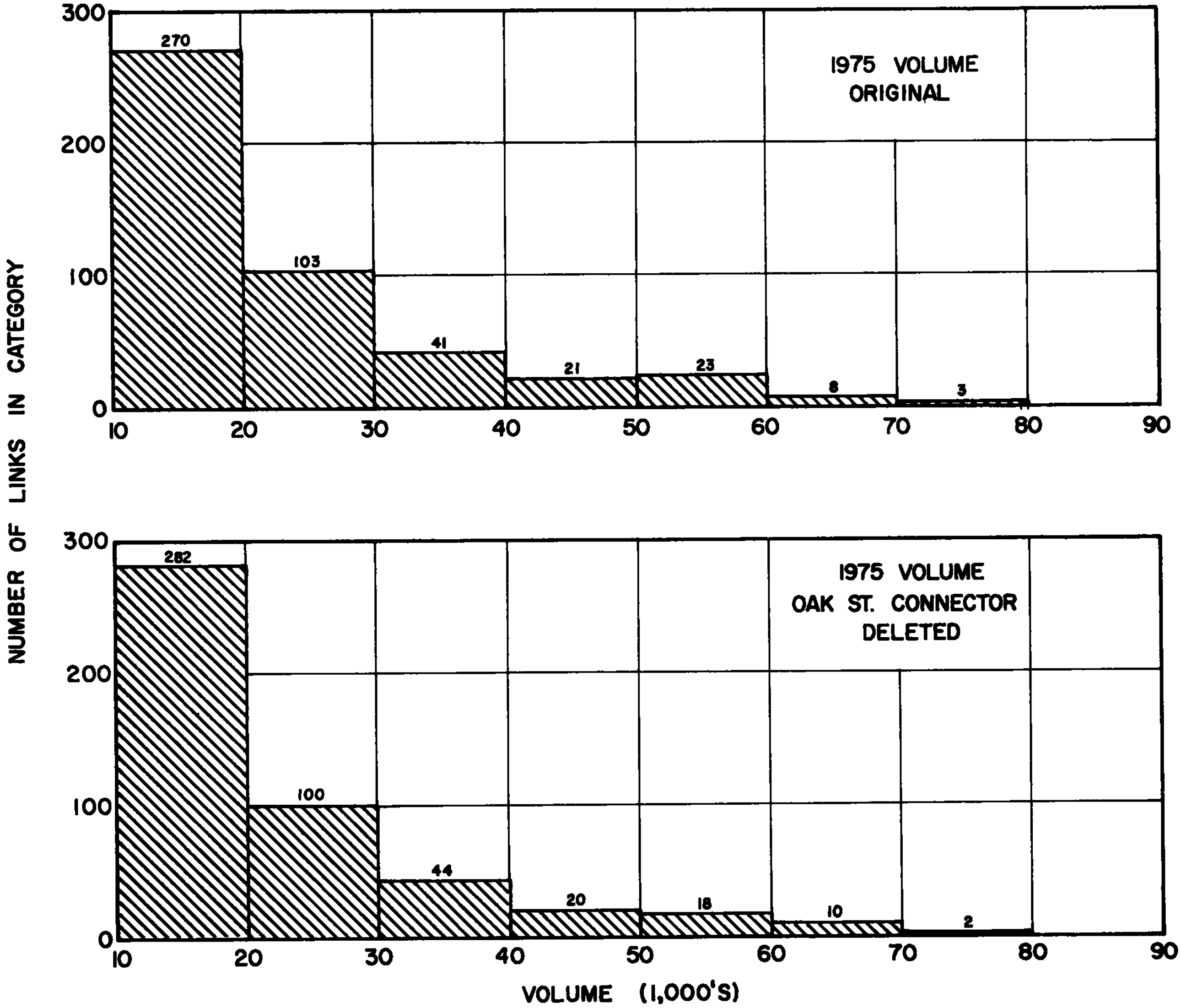

Figure 13. Number of links by volume range.

within 2 min of the point of change, from 11,783 down to 6,450 trips per link. This reflects the volumes lost on the Oak Street connector itself. Beyond 2 min from the connector the mean volumes over all links change only slightly, the plus and minus volume differences tending to cancel each other.

A comparison of the RMS error related to the Oak Street connector and the RMS error related to the changes in zone 5 is given in Table 52. Up to 16 min from the point of change there are greater errors introduced by modifying the network than by changing the O-D table at a single zone.

The RMS error, expressed as a percentage of the mean volume per link before deleting the Oak Street connector is plotted in Figure 14, with two best fitting regression equations as follows:

$$\% \text{ error} = 1.57 + 115.8/t \qquad R^2 = 0.95 \qquad (16a)$$

and

TABLE 51

CHANGES IN ASSIGNED VOLUME VS TIME FROM POINT OF CHANGE (OAK STREET CONNECTOR DELETED)

TIME (MIN)	NO. OF LINKS	TRAFFIC VOLUME (VPD) TOTAL, ALL LINKS BEFORE	AFTER	MEAN, PER LINK BEFORE	AFTER	ROOT-MEAN-SQUARE ERROR	PER-CENT ERROR
0-2	150	1,767,427	967,521	11,783	6,450	13060.1	110.84
2-4	453	3,176,705	3,378,121	7,013	7,457	3565.3	50.84
4-6	713	3,397,027	3,856,158	4,764	5,408	1984.5	41.65
6-8	487	2,166,050	2,344,927	4,448	4,815	1202.4	27.03
8-10	486	1,954,217	1,996,200	4,021	4,107	585.8	14.57
10-12	446	2,291,297	2,303,793	5,137	5,165	402.5	7.83
12-14	313	1,854,029	1,885,247	5,923	6,023	499.0	8.43
14-16	283	1,320,939	1,345,812	4,668	4,756	426.2	9.13
16-18	178	866,128	868,429	4,866	4,879	159.8	3.28
18-20	155	626,444	629,060	4,042	4,058	165.7	4.10
20-22	64	253,322	254,204	3,958	3,972	106.0	2.68
22-24	23	42,861	42,735	1,864	1,858	64.0	3.44
24-26	23	100,729	100,730	4,380	4,380	17.6	0.40
26-28	15	38,786	39,224	2,586	2,615	152.0	5.88
> 28	8	25,848	26,372	3,231	3,297	131.1	4.06

TABLE 52

ROOT-MEAN-SQUARE ERROR (ZONE 5 MODIFIED VS OAK STREET CONNECTOR DELETED)

TIME (MIN)	RMS VALUE ZONE 5 MODIFIED	OAK ST. CONNECTOR DELETED
0-2	3718	13060
2-4	1247	3565
4-6	787	1984
6-8	449	1202
8-10	388	586
10-12	299	403
12-14	211	499
14-16	179	426
16-18	131	160
18-20	122	166
20-22	106	106
22-24	50	64
24-26	49	18
26-28	61	152

$$\% \text{ error} = 200.6/t^{1.31} \qquad R^2 = 0.77 \qquad (16b)$$

in which t is the time in minutes from point of change.

Again, the error as related to time distance from point of change is evident.

SUMMARY

In general, similar comparison of changes in assignment brought about by changing zone 5 and the Oak Street connector indicate that changes in the network have more far-reaching influence than a change in volume at a single zone. The two changes were within only a few city blocks of each other, but the RMS error, based on the influence of differences in all of the links, had more effect for a greater distance when the Oak Street connector was deleted as compared to zone 5.

It is probable that a serious change in trip ends at a given zone could be corrected by "hand calculating" the distribution of added trips to and from that zone and modifying the machine assignment accordingly. On the other hand, there does not appear to be any rational way in which to evaluate a network change other than the expensive process of repeating the entire assignment.

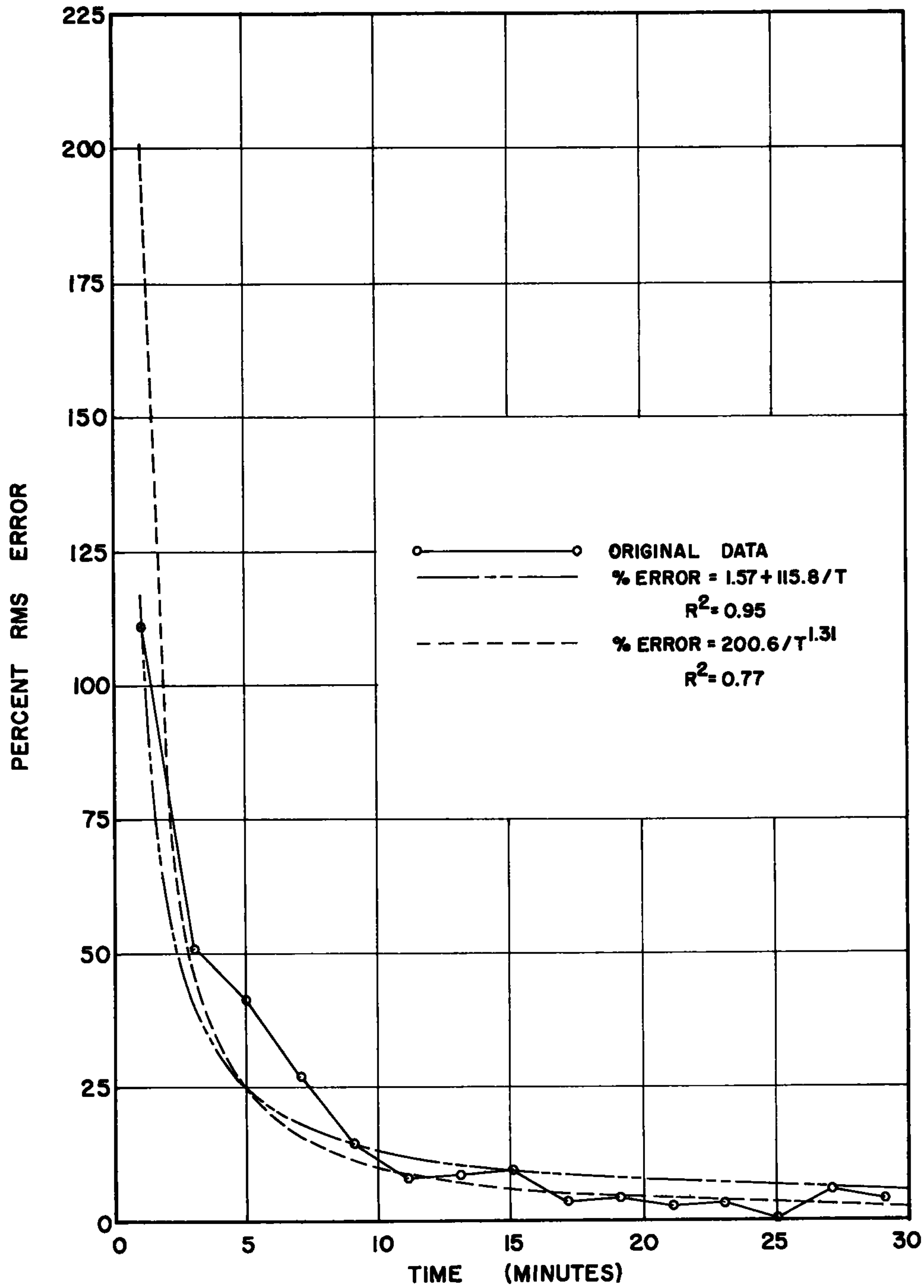

Figure 14. Percent RMS error by distance from Oak Street connector

CHAPTER SEVEN

THE PITTSBURGH STUDIES

In contrast to the Connecticut studies, which were primarily of a rural travel nature, the Pittsburgh studies that followed were of an urban character. State highway departments have had to give increasing attention to the urban problems, so that today perhaps one-half of the highway planning effort is expended on urban highway needs. Techniques are necessarily somewhat different from those traditionally applied to rural route or major facility traffic studies, because of the closer interactions between one route and another in urban situations and because of greater interactions of more densely developed land uses and the transport systems. The awareness of these interactions is not as new as the technology that permits them to be evaluated and incorporated in the highway planning process.

The Pittsburgh region was selected for study for a variety of reasons. In line with the objectives of evaluating forecasts for a major facility, the Pittsburgh region presented opportunities worthy of investigation. During World War II, and shortly thereafter, several forecasts had been made of 1960 traffic volumes on a proposed freeway. Construction had followed the preliminary design patterns upon which the forecasts had been based, and, by 1960, the necessary assumptions of other changes in the network were found to be reasonably valid. In another part of the Pittsburgh region, a 1949 forecast, based on cordon line interviews, could be compared with appropriate actual data for the forecast year. Finally, the possibility existed of measuring diversion effects due to the opening of a new facility and comparing these with traffic assignment results. The recent data on which studies would be based were obtainable from the Pittsburgh Area Transportation Study (PATS), which in 1958 and 1962 had conducted major travel surveys in the region as part of the preparation of a long-range transportation system plan.

STUDY RESOURCES

In 1958, the Pittsburgh Area Transportation Study was organized to develop the 1980 needs for transportation facilities in the Pittsburgh Metropolitan Area. The work performed by the Study has been adequately described in the two study reports (*20*). The following phases of the study bear particularly on the work of this project. Within the 420-sq mi area shown in Figure 15 lived 1,500,000 people in 1958, roughly 92 percent of the population of Allegheny County. A survey of the travel characteristics of these people was made in 1958, based on a 4 percent sample of households, a 10 percent sample of truck and taxi registrations, and a 20 percent sample of external trips at 63 stations on the indicated cordon line. The average weekday travel for the area was constructed from these surveys based on trips between 280 zones, 226 of which were inside the cordon line. Zone sizes range from ¼ sq mi or less in the CBD to a maximum of about 4 sq mi, averaging a little under 2 sq mi. A companion survey of land uses was related to the 226 internal traffic zones. Lastly, an inventory was made of the transportation facilities, highway and transit, in sufficient detail to obtain capacity estimates. Volume and classification counts were made on all segments to obtain a thorough coverage of traffic flows on the average weekday.

Of equal value to the project was the availability of the computer programs for making the necessary traffic assignments. The procedures that were followed conformed to the program descriptions in the CATS *Operations Manual, Traffic Assignment System* (*21*).

The following exploratory studies were made using data from the Pittsburgh area:

1. Comparison of traffic estimates on a bypass in the vicinity of Etna-Sharpsburg.
2. A check of the screenline volumes at and near the Fort Pitt Bridge.
3. A measure of the effect of a new facility (Fort Pitt Bridge and Tunnel) on the network loading.
4. A comparison of assigned volumes on the Penn-Lincoln Parkway (hereafter referred to as PLP).

ETNA-SHARPSBURG BYPASS

In addition to the two study reports by PATS (*20*) a search of historical work on traffic in the Pittsburgh area revealed a 1949 study (*22*), in which the results of roadside interviews were reported along with estimates of traffic use 20 years ahead on the proposed facility. The relocation concerned what is now State Route 28, a controlled-access highway with four interchanges, bypassing the Allegheny River communities of Etna, Sharpsburg, and Aspinwall. This study had used some 31,000 interviews, representing almost two-thirds of the daily volume, factored them to average April weekday for 1949, assigned trips by the Day and Zimmermann formula * based on time and distance, and tabulated the potential users 20 years hence to each segment of the facility.

The bypass was in fact constructed almost exactly as detailed in the 1949 report with the first interchange opened to traffic in mid-1958 and the remainder in the early 1960's. An analysis of volume counts entering the study area showed that the total traffic was 87,283 vpd in 1949 and 105,848 vpd as reported by the ground counts in 1958. This growth represents a 2.2 percent increase per year. The 1949 report used a 1.55 growth factor for the 20-year estimates. This corresponds, probably by coincidence, to a 2.2

* Exact formulation not available.

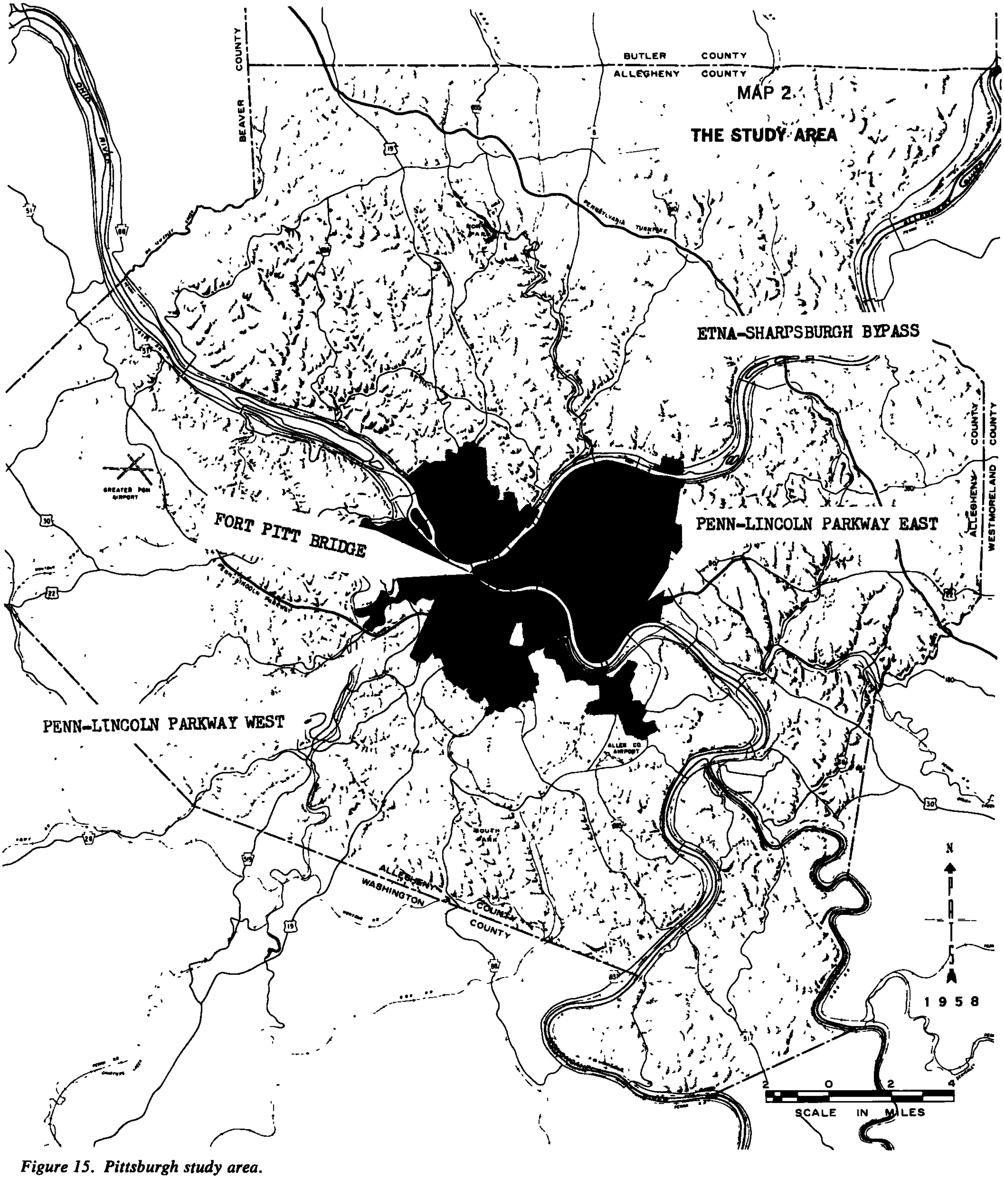

Figure 15. Pittsburgh study area.

percent growth per year compounded. For purposes of evaluation, selected link assignments were made using the PATS home interview trip table for two locations corresponding to two of the 1949 interview stations in an attempt to duplicate the trip distribution found in the 1949 study. The selected links assignment yields zone-to-zone trip information using any single pre-selected links in the network. In this case, the two links selected were the sites of the 1949 roadside interview stations. The 1949 data were expanded to 1958 values and further adjusted for vehicle equivalents to match the 1958 information. A further adjustment of zone grouping was necessary in order to compare the two study results. Table 53 gives the results of these calculations between stations 1 and 3 and all the other zones, reported as vehicle equivalents.

TABLE 53

COMPARISON OF ADJUSTED 1949 VOLUMES AND 1958 COMPUTER ASSIGNMENTS FOR TWO PITTSBURGH INTERVIEW STATIONS

	TRAFFIC VOLUME (VPD)	
1949 ZONE	1949 ADJ. TO 1958	1958 COMPUTER ASSIGNMENT
(*a*) 1949 STATION 1 (PATS LINK 1302-1544)		
20, 30	5,268	2,384
2	13,338	7,616
3	2,762	560
5, 40, 50	4,313	2,440
7	1,006	488
8, 9, 60, 70, 80, 90	1,689	4,312
10	4,196	6,192
Total	32,572	23,992
(*b*) 1949 STATION 3 (PATS LINK 0055-1542)		
1	2,762	6,048
20, 30	2,574	1,720
2	7,849	8,040
5, 40, 50	2,809	648
7	21	32
8, 9, 60, 70, 80, 90	392	1,728
10	513	488
Total	16,920	18,704

This was merely a test to ascertain if the assignment technique utilized in the CATS-PATS program package could duplicate another type of study. As may be seen from Table 53, this is not the case because the distribution of traffic reported by the selected link assignment is far different on station 1 and rather close for station 3. The value of this analysis is to illustrate some of the problems encountered in attempting to update older studies for comparisons with more recent work. In the case of the Etna-Sharpsburg study, the 1949 zones were quite detailed, whereas the PATS zones in this area were of much greater magnitude. The 1949 study utilized roadside interview information amounting to almost a 66 percent sample, whereas the PATS data were based on a 3.6 percent sample of dwelling units.

Another test of the assignment technique was to incorporate the proper coding of the completed bypass into the PATS network and then compare the segment volumes as assigned from the 1958 data with the adjusted volumes from the 1949 study. Figure 16 details the results of this work.

It should be noted here that although there appears to be a wide divergence between the two estimates, either would require the same basic design standards. This analysis also indicates that the urban area network assignment technique, although reproducing proper traffic loading across the whole area (*20*), probably does not represent actual loading in a micro-analysis of a small section.

FORT PITT BRIDGE AND TUNNEL

In 1960 the Pittsburgh Bureau of Traffic Planning conducted a study (*23*) of the effect the Fort Pitt Bridge and Tunnel (final section opened to traffic spring 1960) had created on the distribution of traffic crossing the Ohio-Monongahela Rivers. This report utilized ground counts from the 1958 PATS data as the before situation, and reported 1960 counts for each of the river crossings. A test of the ability of the assignment technique to match this diversion was made by assigning the 1958 trip table to the 1958 network not including the new bridge-tunnel. Then the network was modified to reflect the inclusion of this

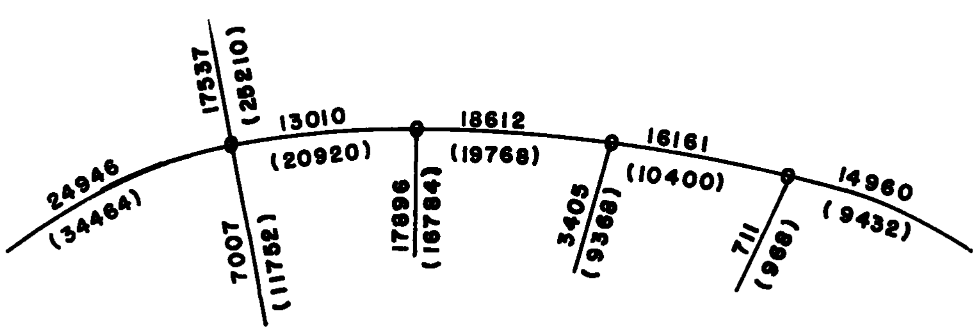

Figure 16. Comparison of 1949 adjusted volumes for 1958 and ( ) 1958 assignment volumes. Units are average weekday vehicle equivalents.

facility as well as deleting the older Point Bridge, which was closed to traffic soon after the Fort Pitt Bridge opened. The results of these two assignments were checked against the ground counts to compare how well the model duplicated the introduction of a major facility. These comparisons are given in Table 54. It may be seen that the assignment departs rather markedly on certain facilities such as the Liberty Street Bridge, but it did approximate the changes in total screenline crossings. No attempt was made to recalibrate the network as received from PATS. This would have improved the individual figures, but the contractor preferred to use the data without any attempt to introduce bias.

Based on the previously mentioned assignments, an investigation was conducted to ascertain the extent of the influence that the new facility had on the urban area. To accomplish this, concentric circles centered at the bridge were drawn on the network maps at radial distances of 1, 2, 3, 4, 5, 10, and 15 miles. The link volumes for each link that intersected a circle were accumulated and the root mean square (RMS) of the volume differences with and without the Fort Pitt Bridge-Tunnel was calculated. Figure 17, a plot of the percent that the RMS is of the average link volume at each radius, shows that the impact of this facility was greatest within 1 mile of the bridge but diminished rapidly at a point 3 to 4 miles away. Beyond this point the new facility had little or no effect on the network assignments.

TABLE 54

COMPARISONS OF 1958 AND 1960 GROUND COUNTS AND 1958 O-D COMPUTER ASSIGNMENTS WITH AND WITHOUT FORT PITT BRIDGE

LOCATION	GROUND COUNT (ADT) 1958	1958 O-D COMPUTER ASSIGNMENT [a] WITHOUT FT. PITT	WITH FT. PITT
West End Br.	31,300	47,096	34,568
Point Br.	33,300	26,952	—
Ft. Pitt Br.	—	—	92,024
Smithfield Br.	11,700	22,736	11,424
Liberty St. Br.	52,000	21,896	15,136
10th St. Br.	21,400	22,592	13,664
Total	149,700	141,272	166,816

[a] Vehicle equivalents.

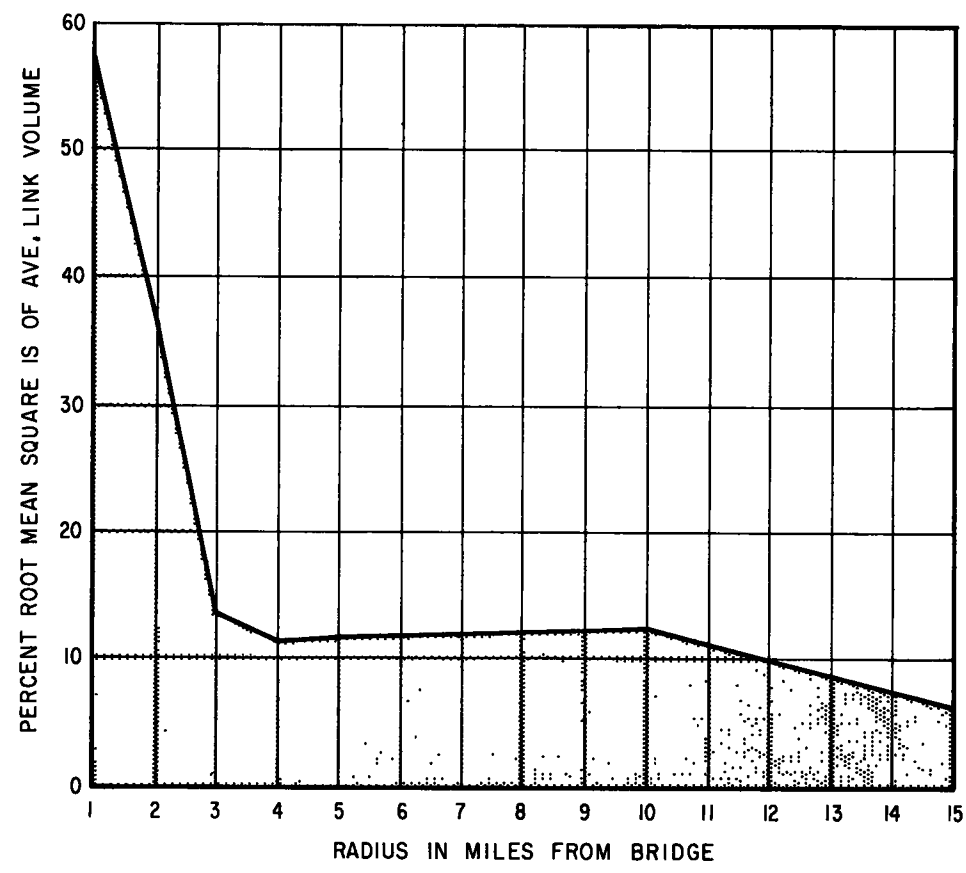

Figure 17. Concentric ring analysis of effect of Fort Pitt Bridge and Tunnel in Pittsburgh, Pa.

PENN-LINCOLN PARKWAY

The report on the Penn-Lincoln Parkway (PLP) (*24*) was published in 1955, when many sections were opened to traffic. A major tunnel, river crossing, and a downtown segment were not complete at that stage. However, the report presented traffic estimates for 1960, based on the entire length of the Parkway being open. The original traffic estimate had been made in the 1940's by consultants for the Department of Highways (*25*), by the Department itself (*26*), and by the Pittsburgh Bureau of Traffic Planning (*27*). Two studies were based in part on 1937 O-D studies of traffic approaching the CBD and on growth rates experienced in the 1930's. The third study, made in 1947, was based in part on a 1945 CBD cordon O-D survey, plus a series of traffic volume counts made since World War II. It took into account the anticipated development of a major airport at the western Parkway terminus, and the prospects of greater residential development, resulting from increased accessibility, in addition to growth in vehicle registrations and use. Furthermore, assumptions were made regarding other major highway improvements that could affect the Parkway volumes. By and large, the assumptions were reasonably valid when the forecast year of 1960 was reached. The 1945 report forecasted traffic volumes for a date 10 years after the traffic volumes had regained their 1941 magnitudes. Inasmuch as most areas found that 1948 reflected the total recovery of the war-time slumps in auto traffic, 1958 was assumed to be the date for this forecast on the PLP East. The 1947 study (*28*) forecasted travel on the PLP West for the year 1960. This traffic volume forecast used an estimate of 1965 population, an estimate of 1960 airport activity, and the existing traffic as of 1945 was multiplied by a factor of 2.0 to estimate the 1960 year.

A comparison of the 1960 volume as forecasted in 1947 with 1958 ground counts and computer assignments is given in Table 55. The assignment utilizing the 1958 network was in close agreement with the 1958 ground counts. The 1947 estimate assumed some 14,000 vpd to and from the regional airport west of Carnegie; however, the selected link information for the same location found only 4,296 assigned to or from the airport. The difference in generation of traffic by this one facility accounts for the major discrepancies in the two assignments. The earlier assignment also assumed a much greater growth in a residential development in the areas adjacent to the parkway west of Greentree interchange than was actually experienced. Much of this difference was due to the lack of any improvement in crossing the Monongahela until mid-1950 when Fort Pitt Tunnel was opened to traffic.

Table 55 also shows the influence capacity restraint exerts on the network loading. Without any restraint, trips utilize the shortest time and thus tend to reduce the volumes using the parkway.

A similar comparison was made for the PLP East. Estimates of 1958 traffic made in 1943 were compared with computer assignments of the 1958 network and with the 1958 ground counts (Table 56).

The earlier estimate of traffic volumes was in close agreement with the computer-assigned volumes on the segment nearest the central city (west of Squirrel Hill). The discrepancy between the two assignments increases as the distance from downtown increases. The migration of housing toward the easterly side of the city was not anticipated in 1943; development of this facility soon after World War II encouraged travel that was undreamed of in 1943, but is reflected in the computer assignments.

Both the 1943 estimate and the computer assignments were substantially less than the 1958 ground counts. Further analysis is required to determine the cause or causes of these discrepancies. The sampling technique, network descriptions, or assignment techniques are all possible sources of error which will be explored during future phases of this project.

FINDINGS

The Pittsburgh work clearly demonstrated some of the problems encountered when older estimates of traffic were compared to recent studies. Zone matching seldom produced a

TABLE 55

COMPARISON OF 1960 VOLUME AS FORECASTED IN 1947 WITH 1958 GROUND COUNT AND 1958 AND 1960 COMPUTER ASSIGNMENTS

	TWO-WAY VOLUME (VEH. EQUIV.)				
			COMPUTER ASSIGNMENT		
LOCATION	1947 EST. OF 1960	1958 GROUND COUNT	1958 NETWORK	1960 NETWORK	WITHOUT CAP. RES.[a]
Airport (Coraopolis Rd.)	38,222	18,896	11,952	14,968	14,784
W. of Carnegie	59,976	31,143	25,736	32,480	26,664
W. of Greentree	55,138	34,711	31,232	41,584	26,800
W. Saw Mill Run	57,112	39,409	33,912	60,816	41,452

[a] Without capacity restraint.

clear-cut situation; trip tables based on different techniques of sampling and unforeseen urban development all contributed to serious errors which could not be explained away. The failure of the computer assignments to reproduce specific link volumes indicated a need for further exploration of assignment techniques. Across the study area, vehicle-miles or minutes of travel were closely reproduced by the assignment technique; but individual link volumes did not match ground counts to the point where older estimates of traffic could reasonably be compared with the results of the computer assignments.

TABLE 56

COMPARISON OF 1958 VOLUME AS FORECASTED IN 1943 WITH 1958 GROUND COUNT AND RESTRAINED AND UNRESTRAINED COMPUTER ASSIGNMENTS

	TRAFFIC VOLUME (VEH. EQUIV.)			
			COMPUTER ASSIGNMENT	
LOCATION	1943 EST. OF 1958	1958 GROUND COUNT	RE-STRAINED	UNRE-STRAINED
W. of Squirrel Hill	66,690	87,073	67,530	57,832
W. of Ardmore Blvd.	42,390	70,888	54,768	49,208
W. of Wm. Penn Hwy.	12,150	45,928	33,512	27,432

CHAPTER EIGHT

CHANGES IN TRAVEL RELATED TO CONSTRUCTION OF A MAJOR FACILITY

Several measures have been used in the past to evaluate the effect of the addition of a major traffic facility upon a given network. These measures include the total vehicle-miles on the network and the total vehicle-hours for the network with the proposed facility as compared with the existing network without the proposed facility. Chapter Seven measured the effect of the new Fort Pitt Bridge in Pittsburgh by accumulating the root-mean-square of the volume differences along links intercepted by concentric circles centered at the bridge site. Similar tests are discussed in Chapter Six, where the Oak Street connector was deleted from the New Haven network. In both the Pittsburgh and New Haven analyses the variable studied was the link loadings at different points in the network. These latter two analyses were not concerned with overall evaluation of the network.

A review of a dissertation on network geometry by Kansky (*29*) suggested a different approach to this problem. It was reasoned that if a more direct route was provided for trips crossing a physical barrier the attractiveness of such a trip would be reflected in changes in the O-D trip table. The proposed measure has been called the "degree of circuity" of the network. The purpose is to measure the relative location of a network's individual nodes and to measure the overall property of a network.

To evaluate this measure it was necessary to have access to O-D information made before and after the construction of a new highway facility. Data from the Norfolk, Va., area satisfied this requirement. The Norfolk data consisted of two separate O-D studies, the first in 1950 (*30*), the second in 1962 (*31*). In 1952 a bridge-tunnel was opened between Norfolk and Portsmouth, replacing a ferry service across the Elizabeth River. The O-D data for these two years (1950 and 1962) were used in evaluating the "degree of circuity" changes introduced by the 1952 facility.

DEGREE OF CIRCUITY

The degree of circuity for a single O-D node, j, is defined as:

$$\text{Degree of circuity (node j)} = \frac{\sum_{i=1}^{n} (E_{ij} - A_{ij})^2}{n} \qquad (17)$$

in which

E = distance between O-D nodes along quickest path;
A = airline distance between nodes;
i = all of the O-D nodes as destinations from origin node j;
j = all of the O-D nodes as origins; and
n = number of O-D nodes in the network.

The degree of circuity for the entire network is defined as:

$$\text{Degree of circuity (network)} = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} (E_{ij} - A_{ij})^2}{n^2} \qquad (18)$$

The application of Eq. 18 compares the difference between an existing (or proposed) transportation system and an imaginary transportation system that connects zones by the shortest possible path. By using this formula, the degree of circuity for the entire network, the circuity for selected nodes with the remainder of the network, or the degree of circuity between selected nodes can be obtained.

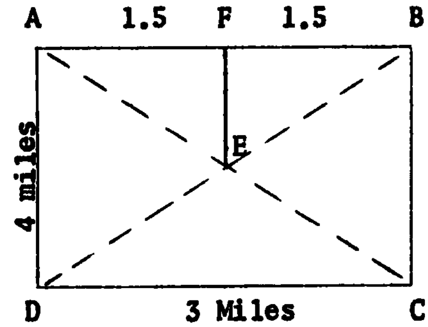

Figure 18. Network example to illustrate degree of circuity.

Figure 18 is an example to illustrate the degree of circuity. Node A is linked to nodes F and D; Node B is linked to nodes F and C, etc. Zone centroids in this simplified network are nodes A, B, C, D, and E. The basic degree of circuity would be calculated as follows:

Network Distance

	A	B	C	D	E
A	–	3	7	4	3.5
B	3	–	4	7	3.5
C	7	4	–	3	7.5
D	4	7	3	–	7.5
E	3.5	3.5	7.5	7.5	–

Airline Distance

	A	B	C	D	E
A	–	3	5	4	2.5
B	3	–	4	5	2.5
C	5	4	–	3	2.5
D	4	5	3	–	2.5
E	2.5	2.5	2.5	2.5	–

Difference, in Miles ^{2}

	A	B	C	D	E
A	–	0	4	0	1
B	0	–	0	4	1
C	4	0	–	0	25
D	0	4	0	–	25
E	1	1	25	25	–
Σ	5	5	29	29	52

Degree of circuity:

Node A = Node B = 5/5 = 1.0
Node C = Node D = 29/5 = 5.8
Node E = 52/5 = 10.4

Network = (5+5+29+29+52)/(5×5) = 4.80

The smaller the degree of circuity, the less the amount of adverse travel; the greater the degree of circuity, the less the network meets demands of direct connections between O-D nodes.

A modification of the basic degree of circuity formula was also investigated in order to compute a network degree of circuity which would take the relative importance of the various O-D nodes into consideration. The formula was adjusted to weight the circuity of each O-D node by the number of trips associated with each O-D node. The modified formula is

Degree of circuity (weighted network) =

$$\frac{\sum_{j=1}^{n} R_j \cdot \sum_{i=1}^{n} (E_{ij} - A_{ij})^2}{n^2} \qquad (19)$$

in which R_j is the ratio between trip ends at O-D node to mean trip ends in the system.

In the example, assume the following trip ends and ratios:

Node	*Trips Ends* [a]	*Ratio* [b]
A	60	1.50
B	50	1.25
C	40	1.00
D	40	1.00
E	10	0.25

The degree of circuity (weighted network) becomes

(1.50×5+1.25×5+1.00×29+1.00×29+0.25×52)/(5×5) = 3.39

In this example the node with the most adverse degree of circuity also has the least activity. The better degree of circuity is associated with the most active nodes, so that the weighted degree of circuity, reflecting travel interchange, is reduced from 4.80 to 3.39.

The network degree of circuity with and without the new Elizabeth River crossing in Norfolk was calculated as follows:

Network	*Deg. of Circuity*
1950	22.34
1962	19.07

This comparison is based on all nodes having equal weight and indicates the decrease in the total degree of circuity for the network created by the new Elizabeth River crossing.

Inasmuch as the number of trips generated at each O-D node in the network varies, a degree of circuity for the entire network was also calculated by weighting for trip ends. The resulting circuity is as follows:

Network	*1950 Trips*	*1962 Trips*
1950	16.58	19.24
1962	13.28	15.85

As indicated, when weighted for trip ends, the degree of circuity is decreased by the new facility. The increase in the number of trips between O-D nodes more distant (and with

[a] Mean = 40. [b] Trip ends j/mean trip ends.

a greater degree of circuity) resulted in an increase in the degree of circuity based on 1962 trips as compared with 1950 trips.

CHANGES IN CIRCUITY BETWEEN SELECTED NODES

A third comparison was made to evaluate the change in trips and the change in circuity between selected zones on opposite sides of the river. It was expected that the new facility would increase the number of trips between specific zones on opposite sides of the river because of the ease of crossing with the new facility as compared with the ferry crossing during the 1950 study. Accordingly, 34 pairs of zones on opposite sides of the Elizabeth River were selected which had an increase in the traffic volumes in 1962 above that predicted by expanding the 1950 trip table to the year 1962 using a Fratar (*32*) model and the actual trip ends as indicators of growth.

The Fratar model was used because it reflects the changes in trip ends for all O-D nodes during the 1950-1962 period but assumes that the impedances to travel will remain the same in the interim. The result of expanding the 1950 data to the year 1962 is a forecast of the expected volume between zones if the indicated growth had taken place but the network had remained the same.

The results of the calculations, including zone pairs, 1962 measured trips, 1962 Fratar forecast trips, trip ratio, and circuity ratio, are given in Table 57. The trip ratio is the ratio of measured 1962 trips to forecast 1962 trips. The circuity ratio is the ratio of 1950 circuity to 1962 circuity.

The evaluation of these interchange trips revealed that in most cases the degree of circuity between the individual zones decreased as a result of the new facility. However, the circuity of several of the selected zone-to-zone interchanges increased. This was due to the fact that the route selection was based on the minimum-time path and the new facility provided a quicker though longer travel distance between the two zones; hence, the degree of circuity in 1962 between the two zones exceeded the degree of circuity in the 1950 network.

A plot of the trip ratio against the circuity ratio is shown in Figure 19. The regression equation is

$$\text{Trip ratio} = 0.86 + 0.85 \times \text{Circuity ratio} \qquad (20)$$

This plot indicates that a decrease in circuity (as the result of a new facility) results in an increase in the number of trips between those two zones. However, only about 25 percent of the variation in trip ratio is explained by the association with circuity ratio ($R = 0.52$).

Although the results are in the expected direction, a stronger relationship was expected. It would be anticipated that a degree of circuity, expressed in time units rather than distance units, would provide a better relationship, but this factor was not tested. However, the network degree of circuity, both weighted and unweighted, did prove to be sensitive to a change in the network and have some value in evaluating the overall effect of network changes.

TABLE 57

CHANGE IN TRAVEL RELATED TO CHANGE IN CIRCUITY; RALEIGH, N.C., NETWORK

ZONE		1962 TRIPS			
FROM	TO	MEASURED	FRATAR FORECAST	TRIP RATIO [a]	CIRCUITY RATIO [b]
140	5	24	10.8	2.2	0.46
141	11	17	8.6	2.0	0.53
141	61	61	10.8	5.6	0.62
164	2	27	13.8	2.0	4.8
164	5	31	14.8	2.1	8.7
164	25	7	4.9	1.4	1.5
165	1	206	107.1	1.9	3.2
165	2	31	21.6	1.4	3.7
165	24	28	25.2	1.1	6.4
165	5	69	7.1	9.7	5.7
173	1	333	122.6	2.7	0.20
173	11	76	8.7	8.7	3.5
173	2	54	29.4	1.8	5.5
173	13	29	3.6	8.1	4.2
173	5	136	15.9	8.6	13.0
173	7	19	18.4	1.0	5.8
173	17	45	21.6	2.1	4.0
173	19	45	25.6	1.8	2.2
174	1	107	64.2	1.7	4.4
174	5	37	2.8	13.0	11.0
177	13	12	9.7	1.2	0.60
163	1	233	55.4	4.2	3.3
163	11	46	29.5	1.6	2.6
163	4	11	6.2	1.8	2.3
163	5	83	3.0	28.0	9.0
163	16	14	5.8	2.4	2.6
163	36	15	9.1	1.6	1.8
163	9	16	15.5	1.1	2.0
168	5	39	15.2	2.6	0.40
30	179	10	5.6	1.8	2.2
32	162	4	1.1	3.6	0.64
36	169	26	17.6	1.5	6.0
37	162	1	0.8	1.3	1.0
50	162	5	1.5	3.3	1.0

[a] Measured 1962 trips/forecast 1962 trips.
[b] 1950 circuity/1962 circuity.

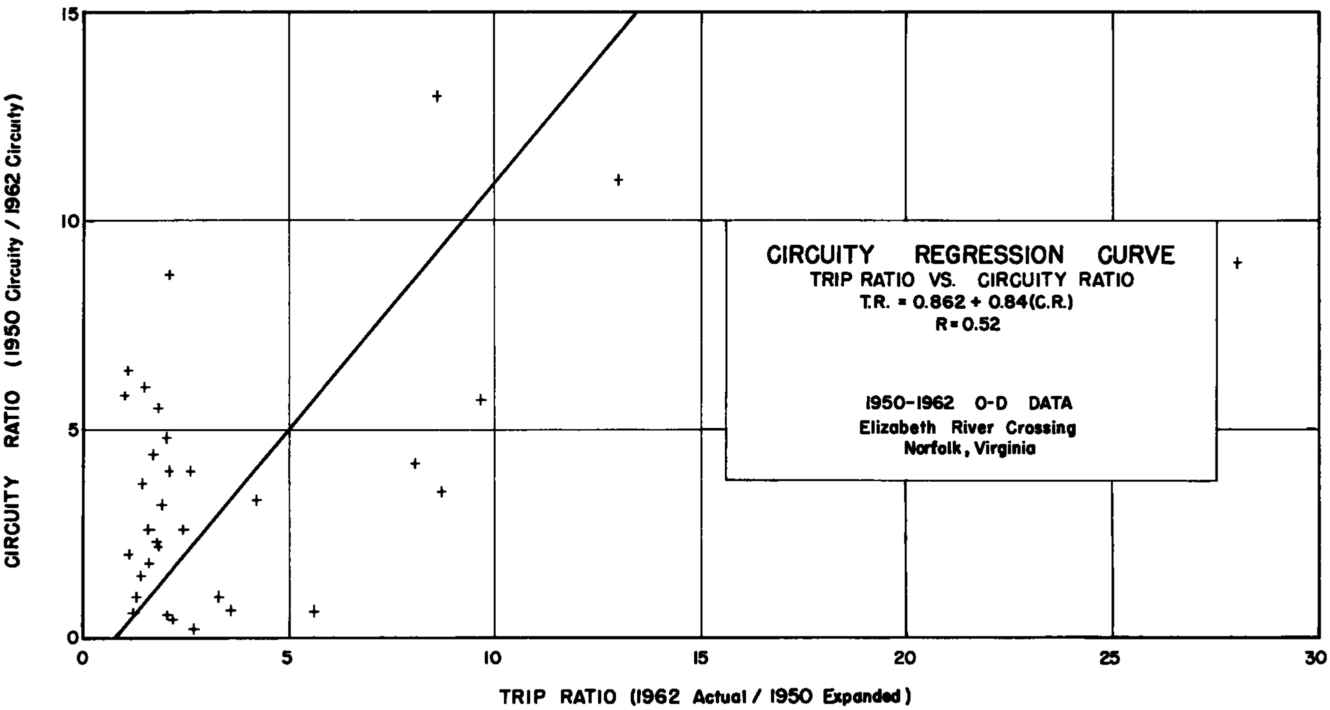

Figure 19. Circuity regression curve.

CHAPTER NINE

APPRAISAL AND APPLICATION

The estimation of the future number of trips on a highway network can be thought of as involving two basic steps; first, a forecast of expected travel, and second, the assignment of that travel to the network. This analysis has been primarily concerned with the assignment phase of the estimating process. It is necessary to have an understanding of assignment before the impact of travel forecasting can be evaluated.

Before comparing assignment results to observed volumes on a network, the limit on the minimum errors that might be expected by any assignment process has been evaluated. The whole is the sum of the parts and the accuracy of the whole is related to the accuracy of the parts. No assignment can be more accurate than the O-D information used as input. If all other elements of the volume assignment technique are correct, the assignment error will be the same as the sampling error for the O-D survey. Implicit to this relationship of errors is the fact that the amount of error as a percentage of assigned volume will decrease with an increase in the assigned volume. Future O-D patterns are subject to more error than are present in an O-D survey, but even under these circumstances there is a decrease in relative error as assigned volumes increase.

Which of the various assignment techniques give the best results when compared to observed volumes? The Free technique is the simplest, selecting one single minimum path between an O-D pair and assigning all traffic between the pair to that single path. The process is the least expensive, but also the least accurate, because there is no relationship between the assigned volume and the capacity of the network.

The Smock and TRC methods, carried to four iterations, average the volumes assigned at different repetitions of the assignment process. The travel time is adjusted at the end of each pass so that the minimum paths change from assignment to assignment and both low- and high-volume links are adequately represented. Of the five methods tested, the Smock method gave the best results over all ranges of volume and the TRC was the next best.

The BPR technique, requiring a minimum of four iterations, uses only the volumes assigned on the final iteration as output. The previous iterations are used to adjust the travel time as related to the volume/capacity ratio. The method does not load the minor links of the system as much as some of the other techniques, but does reproduce the volume on the links at the higher end of the volume scale.

The Schneider method revises the travel time as each of the home nodes is successively used as the origin node, and although no averaging is done the links over the entire range of the volume scale are adequately represented. It should be repeated that the Schneider method integrates trip distribution and assignment into one process, but in this test a fixed O-D table was used. Next to the Free method this technique uses the least computer time and the results are about the same as those obtained with the Smock and TRC methods. When weighting adequacy of results with computation costs, it would appear that the Schneider method is the most desirable one to use.

When only some of the links have capacity limits assigned, as for the Raleigh network, the variation in results by the different methods are minimized and all techniques other than Free give about the same results when compared to each other.

The impact of a change in an O-D pattern at a single point in space was treated in a very elementary manner in this study. It is unreasonable to expect that all other points will remain constant while the subject point changes. In spite of this lack of realism there are some fundamental points that emerge. If there are many nearby O-D points the change at any one point will be "absorbed" at the nearby destinations and not influence much of the network. If there are few adjacent O-D points (i.e., large areas represented by the loading node), the network influences will be observed at a greater distance. In either instance the results suggest that the impact upon assignment of changes at a single O-D zone can be evaluated by adjusting the volumes along minimum paths adjacent to the point of change. This might be done without requiring the use of a computer to repeat the entire process. Links more than 5 min from the point of change appear to be little affected.

The impact of the changes brought about by revising the network are not as easily estimated. From the results of this study it would appear that it is not possible to evaluate network changes except by repeating the entire assignment process. Even in this instance, though, there is evidence that a change at a given point has little effect at another link beyond 10 min distance.

There are two questions which arise from the use of the circuity ratio in evaluating the changes in O-D patterns that result from a network change. The first of these relates to the use of time in place of distance. What is the ideal time between zones? Is it the airline distance divided by 60 mph? or 20 mph? Should the speed be variable—15 mph near the center of the network, 50 mph at the extremes? When questions on the use of an ideal speed (travel time) are resolved the degree of circuity measure can be further evaluated.

The second question relates to changes in travel patterns measured at two separate points in time, one before and one after a network change. Both surveys reflect the network in existence at the time of the O-D study. How do we estimate "what might have been" if a network change had not been made? If the studies are some years apart there is a growth and change process that takes place because of population changes, land-use changes, and network changes. How does one isolate the influence of the network change only? This has been done by using the 1950 to 1962 trip-end growth factors and expanding the 1950 pattern to 1962 by the Fratar technique, which assumes no changes in the network between 1950 and 1962. Here it has been assumed that the changes in volumes between forecast and observed values for pairs of zones are due solely to network changes. This is an oversimplification of the process. Better tools might well provide different results.

CHAPTER TEN

SUGGESTED RESEARCH AND RECOMMENDATION

After almost three years of this investigation concerning traffic assignment, the authors feel that Campbell's remarks to the effect that "traffic assignment is considered to be more of an art than a science" (*33*) are still true. The advent of digital computers of sufficient size to perform intricate manipulations with large arrays of data has freed the transportation analyst of many months of drudgery. However, the results or answers from a traffic assignment program still require judgment in interpretation and application. The study report herein has attempted to explain the effect of some of the known errors inherent in this type of work.

The analysis of expected errors, as reported in the present study, is only a first step in evaluating the sum of all of the errors. The errors considered are those that are introduced by using a sample O-D table, which is concerned with assigning present traffic to a network.

The sources of errors in estimating future traffic volumes are many. Forecasts are predicated upon estimates of future population and economic activity within the study area. The distribution of these two factors within the area will also influence future traffic distribution. It is also necessary to estimate the future trip production per residential unit and the trip attraction for economic units (i.e., industrial areas, major recreation areas, shopping centers, etc.) A third assumption must be made relative to the trip length distributions: will this distribution remain the same in terms of miles or time of travel? All of these factors combine to introduce errors into the O-D matrix that is assigned to the network. How much do the different errors, individually and in aggregate, contribute to the total errors in the assignment process? This report has considered changes in O-D at only one point at a time. The next step is to randomize errors of this type and extend the process to the entire study region.

Too little is still known about the urban traveler. An assignment model that could place trips on the network according to the time of day and remove them or sequence them along their various routings to their destination would be of immeasurable help to all disciples of transportation planning. A dynamic model of this type would provide means of studying the peak movement of traffic whenever it might occur. The all-or-none routing for each trip, dependent on the travel time present on the network at the moment of that trip's departure from its place of origin, should permit a transportation analysis to simulate reality with far greater accuracy than is presently possible. This model could be an efficient way of determining the effect of staggered working hours, optimum transit schedules, and signal timing sequences, as well as the usual applications associated with traffic assignment. The required information is generally available to calibrate such a model. It is the authors' belief that a high priority should be assigned to such an effort.

The network degree of circuity proved to be sensitive to the changes introduced into a network when a new facility is added, but was not as sensitive to evaluating the trips between pairs of zones. Further research, using time rather than distance as a parameter, is needed.

This study did not investigate modal splits. Basic research is needed to ascertain the motivations and restraints associated with the transit rider in urban communities. A recent report on the Niagara Frontier Transportation Study (*34*) suggested that capacity may not be a determinant when predicting the person-trips utilizing transit systems, because most transit operations have far more seat-miles per day available than person-miles using the system. The accurate assignment of person-trips on an urban highway network is dependent on the transit use, so that neither one may be neglected in a complete analysis of urban travel.

Finally, there is still a shortage of adequate before and after information that can be utilized in comparing forecasts with actual use. The data which should be available from the Continuing Urban Study groups will provide more information for making evaluations of this type. Area descriptions, O-D values and network descriptions will be compatible with each other from year to year, so that errors in adjusting data to a common base will be eliminated.

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APPENDIX A

GLOSSARY OF SELECTED DEFINITIONS

The following definitions are provided for terms commonly used in this report. Although they have been compiled and are in agreement for the most part with definitions given for the same terms in either *Principles and Techniques of Predicting Future Demand for Urban Area Transportation* (*35*) or the BPR *Traffic Assignment Manual* (*10*), there have been some occasional minor changes, with additional definitions provided where this was felt advisable.

AASHO: American Association of State Highway Officials.

ADT: Average daily traffic.

All-or-nothing assignment: The process in which the total number of trips between two zones are assigned entirely to the path or route with the minimum travel resistance.

Arterial: A general term denoting a highway primarily for through traffic, usually on a continuous route. In traffic assignment, a link connecting two arterial nodes is classified as arterial.

Capacity restraint: A process in which the travel resistance of a link is increased according to a relation between the practical capacity of the link and the volumes assigned to the link.

Central business district (CBD): The intensively developed core of an urban community that is the principal center of commerce, service, and cultural activities, and as a result usually the location of the greatest trip density.

Centroid: An assumed point in a zone that represents the origin or destination of all trips to or from the zone. Generally, it is the center of trip ends rather than a geometrical center of zonal area.

Destination: The zone in which a trip terminates.

Distribution: The process by which the movement of trips between zones is estimated. The distribution may be measured or be estimated by a growth factor process, or by a synthetic model.

Diversion assignment: The process of assigning the total number of trips between two zones to at least two paths or routes, according to the relative travel resistance of the paths or routes.

Double crossing: The situation occurring when a trip crosses the same cordon or screenline twice between its origin and destination; for example, trips originating and ending on the west bank of a river use a route via the east bank as part of the minimum path.

Fratar distribution: A method of distributing trip ends based on the growth factor of the origin and destination and on the given trip interchanges.

Freeway: An expressway with full control of access. In traffic assignment, a link connecting two freeway nodes.

Gravity model: A mathematical model of trip distribution based on the premise that trips produced in any given area will distribute themselves in accordance with the accessibility of other areas and the opportunities they offer.

Growth factor: A ratio of future trip ends divided by present trip ends.

Interzonal travel time: The total travel time between zones, consisting of the terminal times at each end of the trip plus the driving time.

Interzonal trip: A trip traveling between two different zones.

Intrazonal trip: A trip with both its origin and destination in the same zone.

Level of service: The term used to indicate the quality of service provided by a facility under a given set of operating conditions.

Link: In traffic assignment, a section of the highway network defined by a node at each end.

Link load: The assigned volume on a link.

Major street or highway: An arterial highway with intersections at grade and direct access to abutting property, and on which geometric design and traffic control measures are used to expedite the safe movement of through traffic.

Minimum path: That route of travel between two points which has the least accumulation of time, distance, or other parameter to traverse.

Modal split: The term applied to the division of person-trips between public and private transportation. The process of separating person-trips by the mode of travel.

Model: A mathematical formula that expresses the actions and interactions of the elements of a system in such a manner that the system may be evaluated under any given set of conditions.

Network description: The binary record which describes the highway system within the computer in terms of distance and time and includes turn indications and turn prohibitors.

Node: The point of intersection between two links in the highway network.

O-D survey: A study to determine the origin and destination of trips on a facility or in an area.

Origin: The zone in which a trip begins.

Output: Information transferred from the internal storage of a computer to output devices or external storage.

Point of choice: A point at which two alternate routes between a given origin and destination diverge or converge. Between these points a travel time or distance ratio may be computed.

Program: A precise sequence of machine-coded instructions for a digital computer to use to solve a problem.

Ramp: A turning roadway at an interchange for travel between intersection legs. In traffic assignment, a link between a freeway node and an arterial node.

Regional growth model: A land-use model used to estimate and distribute growth in population, employment, etc.

Route: That combination of street and freeway sections connecting an origin and destination. In traffic assignment, a continuous group of links connecting two centroids that normally requires the minimum time to traverse.

Screenline: An imaginary line, usually along physical barriers such as rivers or railroad tracks, splitting the study area into two parts. Traffic classification counts, and possibly interviews, are conducted along this line, and the crossings are compared to those calculated from the interview data as a check of the survey accuracy.

Selected link assignment: An option of computer assignment program that provides detailed trip data regarding use of one predesignated link as well as the typical assignment outputs.

Square trip table: A table of zone-to-zone trips showing trips by direction between each pair of zones.

Standard error of estimate: The difference between the actual and estimated values of the dependent variable, as found by the least-squares analysis, within which one would expect to find 67 percent of the cases.

Station: A location at the external cordon line where driver interviews are conducted.

Study area: That portion of the urban area included within the scope of a transportation study.

Trace (tree): That sequence of nodes which defines the links comprising the minimum path between two centroids. (See minimum path)

Traffic assignment: The process of determining route or routes of travel and allocating the zone-to-zone trips to these routes.

Travel: The act of moving from origin to destination, combining a trip as an event with the property of length or distance.

Travel time: The time required to travel between two points, including the terminal time at both ends of the trip.

Travel time ratio (diversion assignment): Travel time between points of choice by a freeway route divided by the travel time between the same points by a nonfreeway route.

Tree: A record showing the shortest routes and time of travel from a given zone to all nodes in the highway network.

Trip: The act of traveling between an origin and a destination without respect to length or distance.

Trip end: Either a trip origin or a trip destination.

Trip length frequency distribution: The array which relates the trips or the percentage of trips made at various trip time or distance intervals.

Urban area: The area which includes both the central (core) city and surrounding suburbs where urban area activities predominate.

Vehicle equivalent: A measure of auto traffic which has been weighted to include commercial vehicles.

Zone: A portion of the study area, delineated as such for particular land-use and traffic analysis purposes. There may be two types of zones used in the traffic assignment process:

1. *Survey zone:* A subdivision of the study area which is used during the data collection phase of the study.
2. *Traffic assignment zone:* A subdivision of the study area represented by a centroid.

APPENDIX B

PUBLISHED TRANSPORTATION STUDIES REVIEWED

Report Title	*Agency*	*Year*
A Street Arterial Plan for Phoenix, Arizona, 1950	Arizona State Highway Dept.	1950
Tucson Metropolitan Traffic Survey	Arizona State Highway Dept.	1949
A Street Arterial Plan for Tucson, Arizona	Arizona State Highway Dept.	1951
Tucson Area Transportation Study, Vol. I	City of Tucson, Ariz.	1960
Highway and Transportation Plan for Greater Little Rock, Arkansas	Arkansas State Highway Comm.	1948
Project Report on a State Highway in Alameda County between Jackson Street in Hayward and Castro Valley Junction	California Div. of Highways	1950
Traffic Report Pertaining to Proposed Bayshore Freeway	California Div. of Highways	1944
Transportation Plan for San Francisco	San Francisco City Planning Comm.	1948
Major Highway Plan	San Mateo County Planning Comm.	1951
Traffic and Parking in Santa Cruz	Santa Cruz City Planning Dept.	1954
Ukiah Traffic Survey	California Division of Highways	1951-52
US 1, Bridgeport Area	Connecticut State Highway Dept.	1951
Proposed Improvement in Danielson	Connecticut State Highway Dept.	1947
Proposed Improvement, Glastonbury to East Hartford	Connecticut State Highway Dept.	1946
Planning Study, Route 9, Granby to Hartford	Connecticut State Highway Dept.	1951
Route US 1 Improvement, Guilford to Westbrook	Connecticut State Highway Dept.	1950
New London Turnpike, Routes 2 and 85, Glastonbury to New London	Connecticut State Highway Dept.	1948
Coordinated Transportation for Hartford, Connecticut	Hartford Dept. of Engineering	1947
Hartford Area Traffic Study Report	Connecticut State Highway Dept.	1961
New Haven Short Approach Master Plan	City Plan Comm., New Haven, Conn.	1953
Proposed Reconstruction, US 1, New Haven Harborfront	Connecticut State Highway Dept.	1947
US 1, Norwalk	Connecticut State Highway Dept.	1950
Traffic Improvement Plan, Waterbury, Connecticut	City of Waterbury	1954
Denver Metropolitan Area Origin and Destination Study	Colorado State Highway Dept.	1946
Wilmington Metropolitan Area Transportation Study	Delaware State Highway Dept.	1950
Interstate Highway Plan for Jacksonville, Florida	Florida State Road Dept.	1945-46
A Traffic Survey Report and Limited Access Highway Plan of the Tampa Metropolitan Area	Florida State Road Dept.	1946-47
Highway and Transportation Plan, Atlanta, Georgia	Georgia State Highway Dept.	1946
Street and Highway Plan for Augusta, Georgia	Georgia State Highway Dept.	1948
Street and Highway Plan for Columbus, Georgia	Georgia State Highway Dept.	1947
Preliminary Report on a Highway Improvement Plan for Savannah, Georgia	Georgia State Highway Dept.	1945
Street and Highway Plan for the Decatur Area	Illinois Dept. of P.W. & Blds.	1952
Traffic Survey, East St. Louis Metropolitan Area	Illinois Dept. of P.W. & Blds.	1948
Highway and Transportation Plan, Evanston, Illinois	Evanston Plan Comm.	1948
Street and Highway Plan for the Rockford Area	Illinois Dept. of P.W. & Blds.	1952
Street and Highway Plan for the Springfield Area	Illinois Dept. of P.W. & Blds.	1953
Highway Plan for the Illinois Portion of the St. Louis Metropolitan Area	Illinois Dept. of P.W. & Blds.	1951
Highway Plan for the Tri-City Area, Evansville, Illinois	Illinois Dept. of P.W. & Blds.	1952
Traffic Survey Report	Indiana State Highway Dept.	1952
Indianapolis, Indiana, Engineering Report	Indiana State Highway Dept.	1954
Richmond, Indiana, Traffic Survey Report	Indiana State Highway Dept.	1954
Traffic Problems in Topeka, Kansas	Burgwin & Martin, Topeka, Kans.	1955
Highway Plan for Baton Rouge, La.	Louisiana State Highway Dept.	1947
Lake Charles Traffic Survey	Louisiana State Highway Dept.	1947

Report Title	*Agency*	*Year*
An Urban Highway and Major Street Plan for Minden, La.	Louisiana State Highway Dept.	1955
Major Streets—The Master Plan for New Orleans	New Orleans Planning & Zoning Comm.	1951
Highway Plan for Shreveport, La.	H. W. Lochner & Co., Chicago, Ill.	1947
Master Highway Plan for the Boston Metropolitan Area	Joint Board for the Metropolitan Master Highway Plan	1948
Master Highway Plan for the Springfield Metropolitan Area	Charles A. Maguire & Associates, Boston	1953
Origin and Destination Traffic Survey of Duluth, Minnesota and Superior, Wisconsin	Wisconsin State Highway Comm. and Minnesota Dept. of Highways	1949
Albany Waterfront Aerial Highway	Parsons, Brinckerhoff, Hogan and MacDonald	1946
Urban Area Report, Albany-Renssalaer	N.Y. Dept. of Public Works	1950
Urban Area Report, Batavia	N.Y. Dept. of Public Works	1948
Urban Area Report, Binghamton	N.Y. Dept. of Public Works	1947
Urban Area Report, Buffalo	N.Y. Dept. of Public Works	1946
Urban Area Report, Canandaigua	N.Y. Dept. of Public Works	1948
Urban Area Report, Corning	N.Y. Dept. of Public Works	1947
Urban Area Report, Dunkirk	N.Y. Dept. of Public Works	1947
Urban Area Report, Elmira	N.Y. Dept. of Public Works	1951
Urban Area Report, Fulton	N.Y. Dept. of Public Works	1951
Urban Area Report, Geneva	N.Y. Dept. of Public Works	1948
Urban Area Report, Glens Falls	N.Y. Dept. of Public Works	1952
Urban Area Report, Gloversville-Johnstown	N.Y. Dept. of Public Works	1949
Urban Area Report, Hornell	N.Y. Dept. of Public Works	1948
Urban Area Report, Jamestown	N.Y. Dept. of Public Works	1950
Urban Area Report, Kingston	N.Y. Dept. of Public Works	1954
Urban Area Report, Lackawanna	N.Y. Dept. of Public Works	1949
Urban Area Report, Lockport	N.Y. Dept. of Public Works	1949-50
Urban Area Report, Mechanicsville	N.Y. Dept. of Public Works	1949
Urban Area Report, New Rochelle	N.Y. Dept. of Public Works	1949
Urban Area Report, Norwich	N.Y. Dept. of Public Works	1953
Urban Area Report, Olean	N.Y. Dept. of Public Works	1951
Urban Area Report, Oneida	N.Y. Dept. of Public Works	1952
Urban Area Report, Oneonta	N.Y. Dept. of Public Works	1951
Urban Area Report, Oswego	N.Y. Dept. of Public Works	1951
Urban Area Report, Plattsburgh	N.Y. Dept. of Public Works	1951
Urban Area Report, Poughkeepsie	N.Y. Dept. of Public Works	1947
Urban Area Report, Rochester	N.Y. Dept. of Public Works	1947
Urban Area Report, Rome	N.Y. Dept. of Public Works	1947
Urban Area Report, Salamanca	N.Y. Dept. of Public Works	1951
Urban Area Report, Saratoga Springs	N.Y. Dept. of Public Works	1952
Urban Area Report, Schenectady	N.Y. Dept. of Public Works	1950
Urban Area Report, Syracuse	N.Y. Dept. of Public Works	1947
Urban Area Report, North Tonawanda and Tonawanda	N.Y. Dept. of Public Works	1949
Urban Area Report, Utica	N.Y. Dept. of Public Works	1950
Urban Area Report, Watertown	N.Y. Dept. of Public Works	1949
Urban Area Report, White Plains	N.Y. Dept. of Public Works	1951
Traffic Improvement Plan, Asheville, North Carolina	Wilbur Smith & Associates, Columbia, S.C.	1953
Report on Origin-Destination Traffic Survey at Raleigh, North Carolina	N.C. State Highway & Public Works Comm.	1953
Origin and Destination Traffic Study of Fargo, North Dakota, and Moorhead, Minnestota	North Dakota State Highway Dept. and Minnesota Dept. of Highways	1949
Lakewood, Ohio, Traffic and Trafficways Study	Ladislas Segoe & Assoc., Cincinnati	1954
Traffic Survey Report and Recommendations, Galion, Ohio	Ohio Dept. of Highways	1948
Traffic Survey Report and Recommendations, Hamilton, Ohio	Ohio Dept. of Highways	1950
Traffic Survey Report and Recommendations, Middletown, Ohio	Ohio Dept. of Highways	1948
Proposed Thoroughfare Plan for the Toledo, Ohio, Urban Area	Howard, Needles, Tammen & Bergendorff, Kansas City, Mo.	1950

Report Title	*Agency*	*Year*
Traffic Survey, Grants Pass and Vicinity	Oregon State Highway Dept.	1954
Traffic Survey, Klamath Falls	Oregon State Highway Dept.	1952
Traffic Survey, La Grande	Oregon State Highway Dept.	1952
Traffic Study, Medford	Oregon State Highway Dept.	1953
Traffic Survey, Pendleton	Oregon State Highway Dept.	1955
1946 Portland Metropolitan Area Traffic Survey	Oregon State Highway Dept.	1946
Traffic Survey, Roseburg and Vicinity	Oregon State Highway Dept.	1954
Erie Traffic Survey	Pennsylvania Dept. of Highways	1950
Traffic Survey, Report and Recommendations, Williamsport, Pa.	National Conservation Bureau, Association of Casualty and Surety Companies	1947
Expressway System for Metropolitan Providence, R.I.	Charles A. Maguire Assoc.	1947
Highway and Transportation Plan, Chattanooga, Tennessee	H. W. Lochner & Co., Chicago	1948
Highway and Transportation Plan, Nashville, Tennessee	H. W. Lochner & Co., and DeLeuw Cather & Co.	1946
Highway and Transportation Plan, Knoxville, Tennessee	H. W. Lochner & Co., and DeLeuw Cather & Co.	1948
Traffic Study, Salt Lake Metropolitan Area	Utah Road Comm.	1947
Traffic Study, Charlottesville, Va.	Virginia Dept. of Highways	1947
Report on Express Highways, Richmond-Petersburg District	R. Stuart Royer and Consoer, Townsend & Assoc.	1946
Origin and Destination Survey of Olympia, Washington	Washington Dept. of Highways	1948
Origin and Destination Survey of Spokane, Washington	Washington Dept. of Highways	1946-47
Origin and Destination Survey of Tacoma, Washington	Washington Dept. of Highways	1949
Origin and Destination Survey of Seattle Metropolitan Area	Washington Dept. of Highways	1947
Moving People and Goods	National Capital Park and Planning Comm., Washington, D.C.	1950
Traffic Survey Report, Charleston-South Charleston Area	West Virginia State Road Comm.	1950
Traffic Survey Report, Fairmont, W. Va.	West Virginia State Road Comm.	1952
Traffic Survey Report, Montgomery, W. Va.	West Virginia State Road Comm.	1949
Traffic Survey Report, Parkersburg, W. Va.	West Virginia State Road Comm.	1951
Traffic Survey Report, Welch, W. Va.	West Virginia State Road Comm.	1951
Origin-Destination Traffic Survey, Milwaukee Metropolitan Area	Wisconsin State Highway Comm.	1946
Manila Traffic Survey	Philippine Bur. of Public Works	1949

APPENDIX C

CONNECTICUT RIVER AREA STUDY

SOURCES OF DATA

One source of data for the Connecticut River area was found in a 1956 roadside interview conducted over a 4-day period. Examination of the origin and destination zone coding showed that a major modification was necessary in order to make the trip tables compatible with the coded network used by the Hartford Area Transportation Study. Within the immediate vicinity of the bridges, zoning was already coded in detail. However, zones had to be grouped at the outer limits of the study area and a complete renumbering was required. This was accomplished by a computer program written for the purpose. Points of entry were established by judgment based on the major highway system.

The 1963 O-D data comprised a portion of a State-wide study and thus had only been coded to township-sized zones. The survey stations operated for eight hours on each bridge. This coded information was again renumbered and grouped so that the two O-D studies would be compatible.

New trip tables were created for each year after removing all trips having an origin and a destination on the same side of the river. It was felt that any assignment technique would be unable to handle this type of trip properly, as the shortest distance would certainly be along one side without crossing either bridge. Recoding and grouping of the O-D information would have required untold months of labor if it had been attempted outside of a computer.

ASSIGNMENT TECHNIQUES USED

The testing of diversion techniques utilized four basic methods. These were (1) the AASHO diversion curve; (2) the California time and distance curves; (3) a ratio method designated here as the "easy" method; and (4) all-or-nothing minimum path. The formulations employed were as follows:

1. For the AASHO diversion curve

$$\text{Percent use} = \frac{1}{(1 + T^6)} \qquad \text{(C-1)}$$

in which T is the ratio of the travel time via the facility under study to the time via the best alternate. Distances were substituted for time in the same equation. Eq. C-1 is considered an approximation of the curves shown by Schmidt and Campbell (*34*, p. 137)* and in AASHO's "Policy on Arterial Highways in Urban Areas" (*1*, p. 111).

2. The California time and distance curves (*14*)

$$\text{Percent use} = 50 + \frac{50(d + 0.5t)}{[(d - 0.5t)^2 + 4.5]^{0.5}} \qquad \text{(C-2)}$$

in which d is the distance saved by the route under study compared to the best alternate, and t is the time saved by the route under study versus the time of the best alternate. Both d and t may be negative. For the purposes of this study when the percentage of use was calculated using the time differential of the best alternate, the distances associated with the same minimum alternate paths were employed to obtain d. When the minimum distance and best alternate distance paths were compared, their associated time values were used to obtain t. This was necessary because the time and distance paths frequently did not coincide for either the minimum or best alternate path.

3. The "easy" method

$$\text{Percent use} = 50 + 250\,\frac{(B - A)}{(B + A)} \qquad \text{(C-3)}$$

in which A is the travel time via the route under study and B is the travel time via the alternate route (i.e., the other bridge). The percentage of use was automatically set at 0 if $(B - A)/(B + A)$ was less than -0.2, and at 100 if it exceeded $+0.2$. The method was reported by Brown and Weaver (*14*). It was also employed using distance.

4. The all-or-nothing technique. In this case, all trips were assigned to the path, or bridge, that provided the minimum absolute time between origin and destination, and no trips were assigned to the alternate route. The same was true when distance was used as the criterion.

It might be noted that both time and distance ratios or differences were calculated from overall travel times from origin to destination. The use of this method, rather than a point-of-choice comparison, obviously does not affect an all-or-nothing assignment. Its effect is felt most strongly on the diversion of long trips between two facilities with relatively small differences in time or distance. The point-of-choice technique, for example, would cause a greater deviation from an equal distribution between almost equal alternates than would the ratio based on overall travel time or distance. It was felt, in this case, that the added work of establishing points of choice for the various interchanges that might be affected was not warranted.

The root-mean-square error was selected as a measure of the performance of each technique. That is,

$$\text{RMS error} = \left[\frac{\sum_1^n (V_a - V_s)^2}{n}\right]^{0.5} \qquad \text{(C-4)}$$

in which

V_a = volume assigned by a technique;
V_s = volume determined by the survey; and
n = number of destination zones receiving trips from the origin zone.

The RMS error is comparable, statistically, to the standard deviation of a group of values around their mean. In other words, if the error term has a value of 100 for assignment method 1, one would not be far wrong in assuming that two-thirds of the individual trip transfers estimated for this zone of origin will be within ± 100 trips of the survey volume. The error term on the summary tabulations is an estimate of the differences of total trips assigned from a zone of origin and the total observed trips from the survey.

The advantage of the RMS method is that one may use these values to estimate the performance of any one of these assignment methods by assuming that two-thirds of the time this method would only show deviation of ± one RMS. If one used the pure difference between the estimate and the survey, only the absolute value would mean much, because the plus and minus items might tend to dampen the true error. If they were equally arrayed about zero, the result would be zero, even though the actual dispersion might be great.

DATA STRATIFICATION

The various assignments made using the Connecticut River data were stratified in order to detect any inherent bias that might have been introduced. Each assignment technique was broken down on a volume, travel time, and travel distance basis. Both the number of zones and the number of trips for each group were compared to the same grouping of the survey data. Primary interest centered in whether one method particularly favored the short or long trips based on time or distance and the small- versus large-volume types. These stratifications were carried out using time and distance ratios versus volume, time, and distance groups. These double stratifications are not given herein, but are available for any researcher interested in the final breakdowns.

No one technique demonstrated a decided advantage over another in any of the stratifications. What closely matched the survey results in one year might be somewhat apart in the other year.

The following tables and graphs are results of the detail stratifications. The first group reports the breakdown by volume group; the second, trip length; and the third, travel time, for each assignment technique. For each stratification, the tables and graphs report the 1956 study first, followed by the 1963 data. Each table gives the absolute number in the top section, followed by the same information computed as a percentage below.

* Numbers in parentheses refer to entries in the bibliography, Appendix D.

RANGE	SURVEY ZONE-ZONE	SURVEY TRIPS	AASHO TIME ZONE-ZONE	AASHO TIME TRIPS	AASHO DIST ZONE-ZONE	AASHO DIST TRIPS	CALIF TIME ZONE-ZONE	CALIF TIME TRIPS	CALIF DIST ZONE-ZONE	CALIF DIST TRIPS	EASY TIME ZONE-ZONE	EASY TIME TRIPS	EASY DIST ZONE-ZONE	EASY DIST TRIPS	A/N TIME ZONE-ZONE	A/N TIME TRIPS	A/N DIST ZONE-ZONE	A/N DIST TRIPS
1- 10	246	822	272	863	275	865	232	810	229	813	269	851	266	828	224	772	204	698
10- 50	77	1804	72	1627	69	1553	80	1899	80	1917	71	1622	70	1617	89	2102	85	2025
50- 100	18	1343	15	1065	14	1035	13	1026	14	1126	15	1135	13	1011	17	1254	14	1061
100- 200	8	1052	10	1441	9	1260	9	1249	9	1343	9	1348	9	1275	10	1442	10	1442
200- 500	7	1989	6	1949	6	1848	8	2382	7	2160	5	1470	5	1386	6	1798	5	1490
500-1000	2	1031	1	554	1	517	2	1113	2	1113	2	1054	2	1022	4	2630	3	1958
1000-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000 PLUS	1	2168	1	2155	1	2163	1	2174	1	2174	1	2174	1	2174	1	2174	1	2174
TOTALS	359	10209	377	9654	375	9241	345	10653	342	10646	372	9654	366	9313	351	12172	322	10848

PERCENTAGES OF ABOVE

RANGE	SURVEY ZONE-ZONE	SURVEY TRIPS	AASHO TIME ZONE-ZONE	AASHO TIME TRIPS	AASHO DIST ZONE-ZONE	AASHO DIST TRIPS	CALIF TIME ZONE-ZONE	CALIF TIME TRIPS	CALIF DIST ZONE-ZONE	CALIF DIST TRIPS	EASY TIME ZONE-ZONE	EASY TIME TRIPS	EASY DIST ZONE-ZONE	EASY DIST TRIPS	A/N TIME ZONE-ZONE	A/N TIME TRIPS	A/N DIST ZONE-ZONE	A/N DIST TRIPS
1- 10	68.5	8.1	72.1	8.9	73.3	9.4	67.2	7.6	67.0	7.6	72.3	8.8	72.7	8.9	63.8	6.3	63.4	6.4
10- 50	21.4	17.7	19.1	16.9	18.4	16.8	23.2	17.8	23.4	18.0	19.1	16.8	19.1	17.4	25.4	17.3	26.4	18.7
50- 100	5.0	13.2	4.0	11.0	3.7	11.2	3.8	9.6	4.1	10.6	4.0	11.8	3.6	10.9	4.8	10.3	4.3	9.8
100- 200	2.2	10.3	2.7	14.9	2.4	13.6	2.6	11.7	2.6	12.6	2.4	14.0	2.5	13.7	2.8	11.8	3.1	13.3
200- 500	1.9	19.5	1.6	20.2	1.6	20.0	2.3	22.4	2.0	20.3	1.3	15.2	1.4	14.9	1.7	14.8	1.6	13.7
500-1000	0.6	10.1	0.3	5.7	0.3	5.6	0.6	10.4	0.6	10.5	0.5	10.9	0.5	11.0	1.1	21.6	0.9	18.0
1000-2000	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000 PLUS	0.3	21.2	0.3	22.3	0.3	23.4	0.3	20.4	0.3	20.4	0.3	22.5	0.3	23.3	0.3	17.9	0.3	20.0

Figure C-1. Printout of volume distribution for 1956 trips assigned to South Bridge by the various techniques.

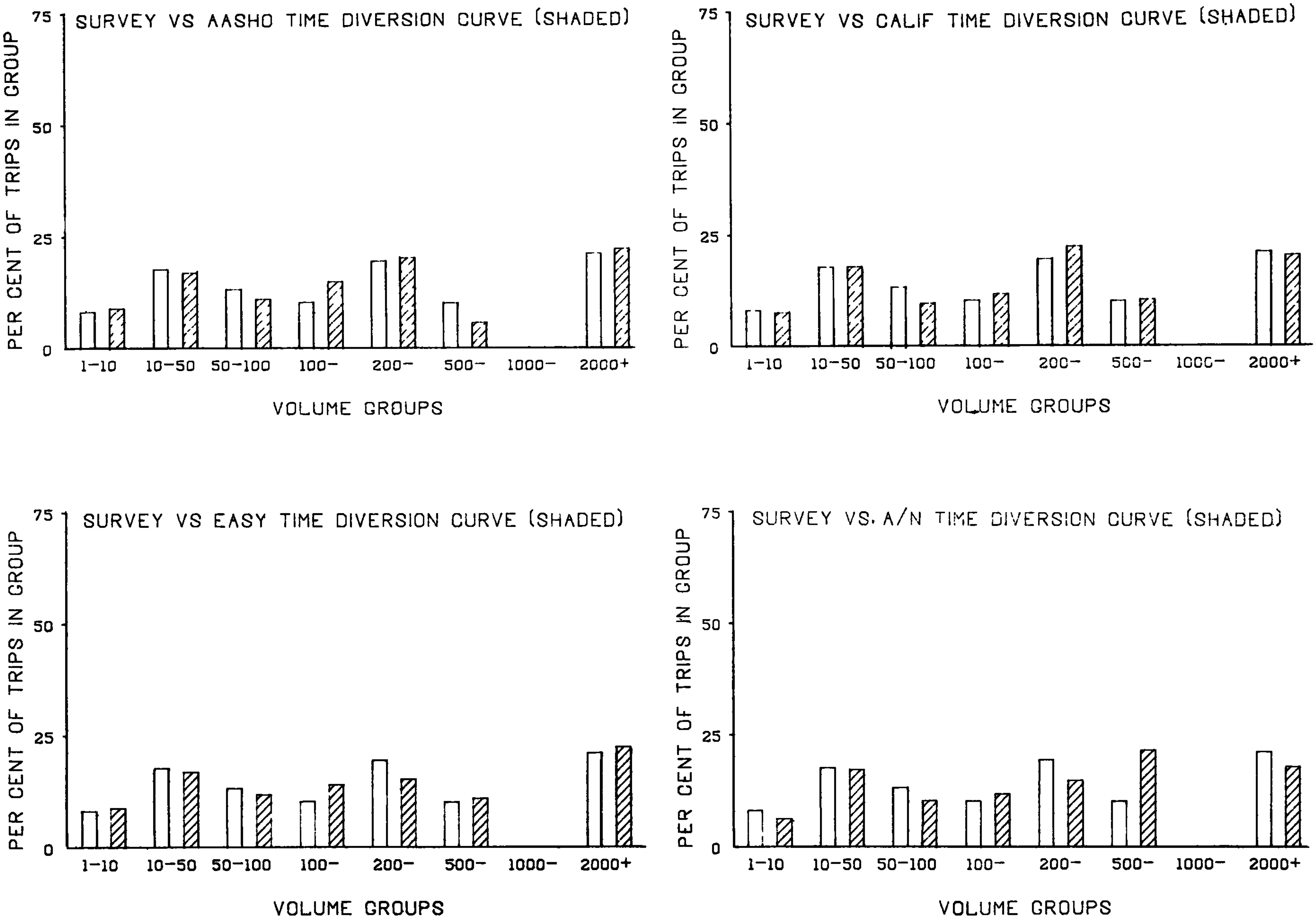

Figure C-2. Comparisons of volume distribution by time for 1956 trips assigned to South Bridge.

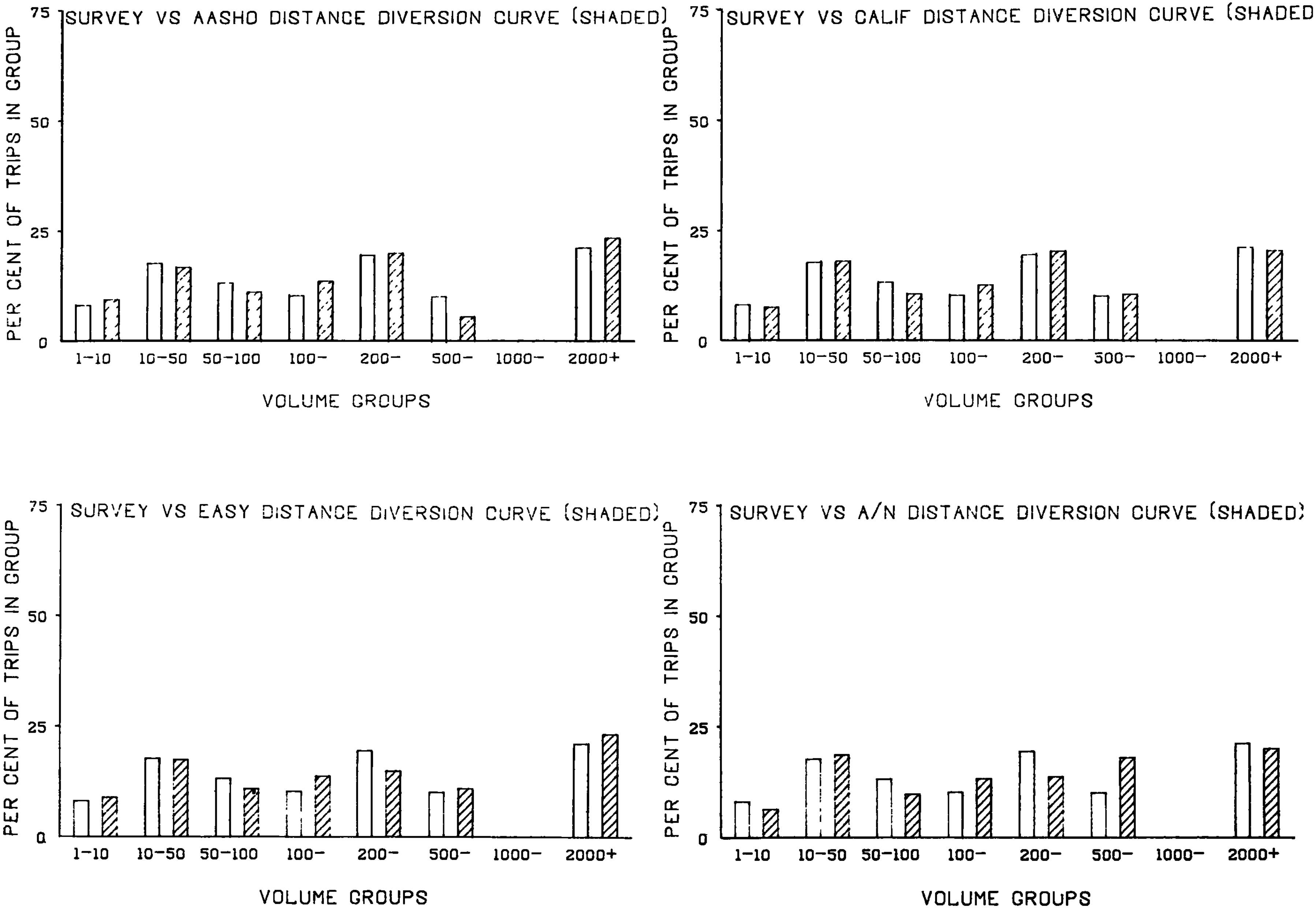

Figure C-3. Comparisons of volume distribution by distance for 1956 trips assigned to South Bridge.

RANGE	SURVEY ZONE-ZONE	SURVEY TRIPS	AASHO TIME ZONE-ZONE	AASHO TIME TRIPS	AASHO DIST ZONE-ZONE	AASHO DIST TRIPS	CALIF TIME ZONE-ZONE	CALIF TIME TRIPS	CALIF DIST ZONE-ZONE	CALIF DIST TRIPS	EASY TIME ZONE-ZONE	EASY TIME TRIPS	EASY DIST ZONE-ZONE	EASY DIST TRIPS	A/N TIME ZONE-ZONE	A/N TIME TRIPS	A/N DIST ZONE-ZONE	A/N DIST TRIPS
1- 10	66	385	136	632	149	641	83	398	83	411	138	646	143	617	61	328	26	147
10- 50	92	2266	74	1740	68	1586	64	1540	55	1374	70	1640	66	1499	61	1286	37	757
50- 100	20	1476	14	972	12	841	12	902	12	865	15	1056	14	953	17	1057	12	754
100- 200	9	1275	10	1204	9	1313	7	1016	8	1114	9	1109	9	1333	10	1485	6	843
200- 500	7	2297	8	2336	5	1651	6	1882	5	1598	9	2838	5	1675	6	2040	4	1363
500-1000	7	5023	4	3066	5	3842	4	3098	5	3414	3	2551	5	3877	3	2148	3	2148
1000-2000	3	4446	4	6207	1	1095	4	5394	4	5807	4	6195	1	1156	4	5632	3	4581
2000 PLUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3035	0	0
TOTALS	204	17168	250	16157	249	10969	180	14230	172	14583	248	16035	243	11110	163	17011	91	10593

PERCENTAGES OF ABOVE

RANGE	SURVEY ZONE-ZONE	SURVEY TRIPS	AASHO TIME ZONE-ZONE	AASHO TIME TRIPS	AASHO DIST ZONE-ZONE	AASHO DIST TRIPS	CALIF TIME ZONE-ZONE	CALIF TIME TRIPS	CALIF DIST ZONE-ZONE	CALIF DIST TRIPS	EASY TIME ZONE-ZONE	EASY TIME TRIPS	EASY DIST ZONE-ZONE	EASY DIST TRIPS	A/N TIME ZONE-ZONE	A/N TIME TRIPS	A/N DIST ZONE-ZONE	A/N DIST TRIPS
1- 10	32.4	2.2	54.4	3.9	59.8	5.8	46.1	2.8	48.3	2.8	55.6	4.0	58.8	5.6	37.4	1.9	28.6	1.4
10- 50	45.1	13.2	29.6	10.8	27.3	14.5	35.6	10.8	32.0	9.4	28.2	10.2	27.2	13.5	37.4	7.6	40.7	7.1
50- 100	9.8	8.6	5.6	6.0	4.8	7.7	6.7	6.3	7.0	5.9	6.0	6.6	5.8	8.6	10.4	6.2	13.2	7.1
100- 200	4.4	7.4	4.0	7.5	3.6	12.0	3.9	7.1	4.7	7.6	3.6	6.9	3.7	12.0	6.1	8.7	6.6	8.0
200- 500	3.4	13.4	3.2	14.5	2.0	15.1	3.3	13.2	2.9	11.0	3.6	17.7	2.1	15.1	3.7	12.0	4.4	12.9
500-1000	3.4	29.3	1.6	19.0	2.0	35.0	2.2	21.8	2.9	23.4	1.2	15.9	2.1	34.9	1.8	12.6	3.3	20.3
1000-2000	1.5	25.9	1.6	38.4	0.4	10.0	2.2	37.9	2.3	39.8	1.6	38.6	0.4	10.4	2.5	33.1	3.3	43.2
2000 PLUS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.6	17.8	0.	0.

Figure C-4. Printout of volume distribution for 1963 trips assigned to I-91 Bridge by the various techniques.

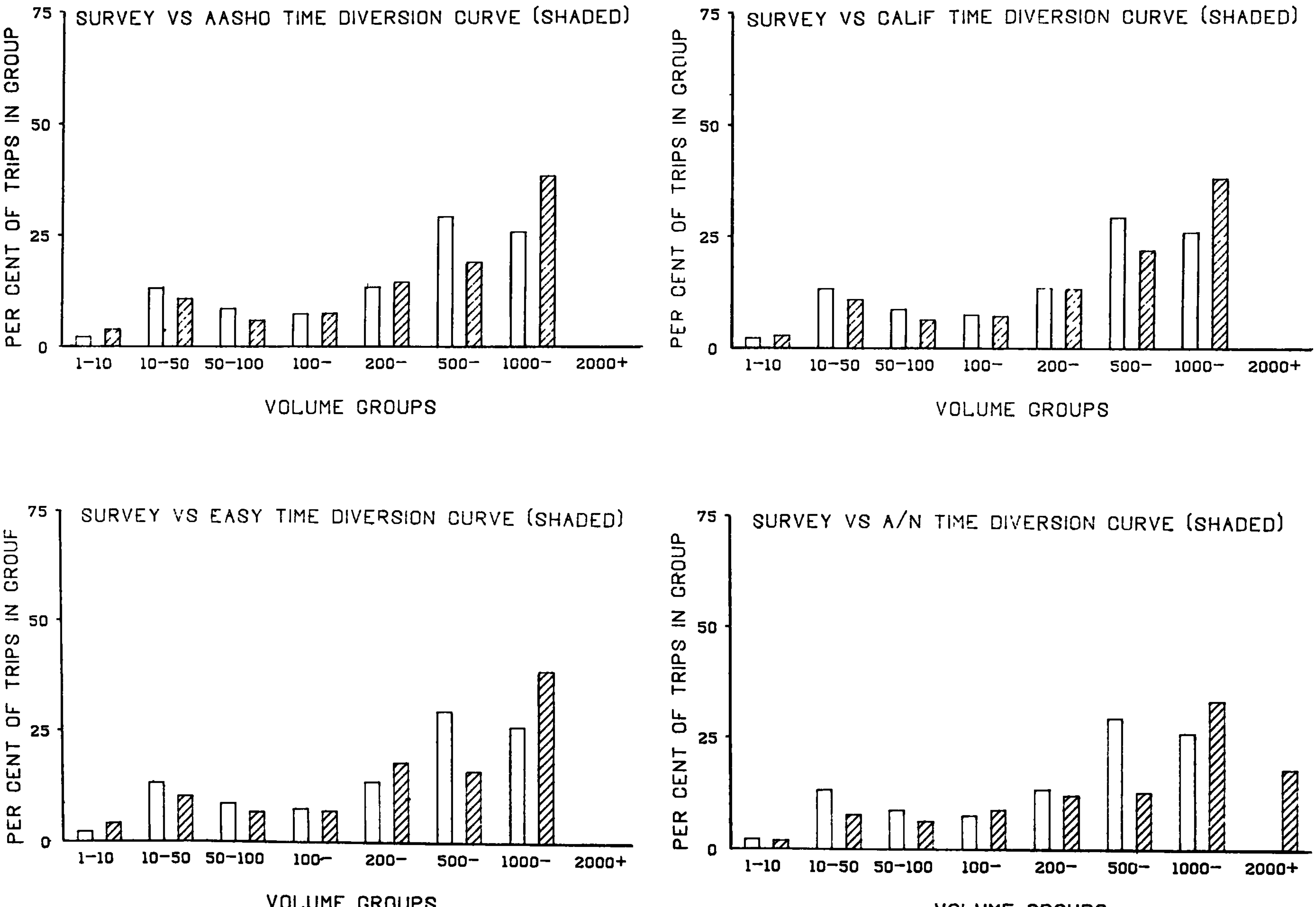

Figure C-5. Comparisons of volume distribution by time for 1963 trips assigned to I-91 Bridge.

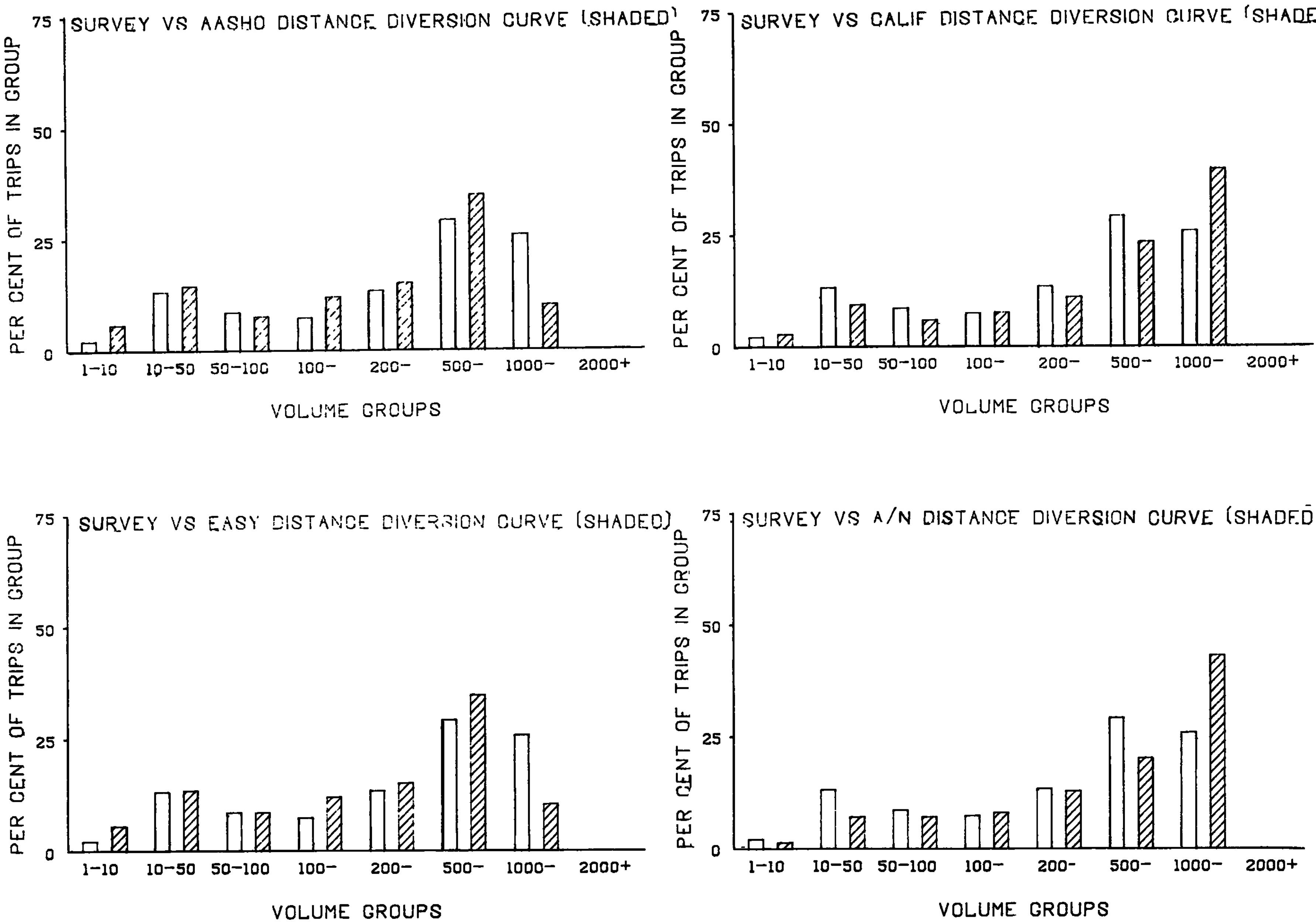

Figure C-6. Comparisons of volume distribution by distance for 1963 trips assigned to I-91 Bridge.

	SURVEY		AASHO				CALIF				EASY				A/N			
			TIME		DIST		TIME		DIST		TIME		DIST		TIME		DIST	
RANGE	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS
0- 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- 10	7	3886	7	3946	7	3798	7	4203	7	4185	7	3955	7	3817	7	4735	6	4063
10- 15	27	1475	28	1425	28	1325	26	1497	26	1497	27	1409	26	1342	26	1647	24	1588
15- 20	63	2412	65	2283	65	2180	60	2509	60	2508	63	2313	62	2230	60	2892	53	2461
20- 25	68	950	71	807	71	789	67	998	67	988	70	806	69	787	67	1068	62	1030
25- 30	52	584	56	473	56	456	51	587	51	579	55	466	54	453	51	763	49	747
30- 35	42	278	42	209	42	205	40	285	40	282	42	205	42	200	40	295	39	294
35- 40	26	173	29	153	29	147	27	197	26	196	29	147	29	144	27	207	27	207
40- 45	26	197	26	168	26	162	24	188	22	196	26	165	26	161	24	259	22	252
45- 50	14	99	17	76	17	70	14	67	14	85	17	76	17	71	14	120	11	39
50- 55	13	84	19	74	19	72	16	82	14	82	19	72	19	71	17	121	12	109
55- 60	6	22	5	14	4	12	4	14	5	17	5	14	4	12	6	25	5	18
60 PLUS	15	49	12	26	11	25	9	26	10	31	12	26	11	25	12	40	12	40
TOTALS	359	10209	377	9654	375	9241	345	10653	342	10646	372	9654	366	9313	351	12172	322	10848
AVE. TRIP LENGTH		16.15		15.36		15.37		15.72		15.82		15.32		15.34		16.13		16.27

PERCENTAGES OF ABOVE

	SURVEY		AASHO				CALIF				EASY				A/N			
			TIME		DIST		TIME		DIST		TIME		DIST		TIME		DIST	
RANGE	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS
0- 5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5- 10	1.9	38.1	1.9	40.9	1.9	41.1	2.0	39.5	2.0	39.3	1.9	41.0	1.9	41.0	2.0	38.9	1.9	37.5
10- 15	7.5	14.4	7.4	14.8	7.5	14.3	7.5	14.1	7.6	14.1	7.3	14.6	7.1	14.4	7.4	13.5	7.5	14.6
15- 20	17.5	23.6	17.2	23.6	17.3	23.6	17.4	23.6	17.5	23.6	16.9	24.0	16.9	23.9	17.1	23.8	16.5	22.7
20- 25	18.9	9.3	18.8	8.4	18.9	8.5	19.4	9.4	19.6	9.3	18.8	8.3	18.9	8.5	19.1	8.8	19.3	9.5
25- 30	14.5	5.7	14.9	4.9	14.9	4.9	14.8	5.5	14.9	5.4	14.8	4.8	14.8	4.9	14.5	6.3	15.2	6.9
30- 35	11.7	2.7	11.1	2.2	11.2	2.2	11.6	2.7	11.7	2.6	11.3	2.1	11.5	2.1	11.4	2.4	12.1	2.7
35- 40	7.2	1.7	7.7	1.6	7.7	1.6	7.8	1.8	7.6	1.8	7.8	1.5	7.9	1.5	7.7	1.7	8.4	1.9
40- 45	7.2	1.9	6.9	1.7	6.9	1.8	7.0	1.8	6.4	1.8	7.0	1.7	7.1	1.7	6.8	2.1	6.8	2.3
45- 50	3.9	1.0	4.5	0.8	4.5	0.8	4.1	0.6	4.1	0.8	4.6	0.8	4.6	0.8	4.0	1.0	3.4	0.4
50- 55	3.6	0.8	5.0	0.8	5.1	0.8	4.6	0.8	4.1	0.8	5.1	0.7	5.2	0.8	4.8	1.0	3.7	1.0
55- 60	1.7	0.2	1.3	0.1	1.1	0.1	1.2	0.1	1.5	0.2	1.3	0.1	1.1	0.1	1.7	0.2	1.6	0.2
60 PLUS	4.2	0.5	3.2	0.3	2.9	0.3	2.6	0.2	2.9	0.3	3.2	0.3	3.0	0.3	3.4	0.3	3.7	0.4

Figure C-7. Printout of trip length distribution for 1956 trips assigned to South Bridge by the various techniques.

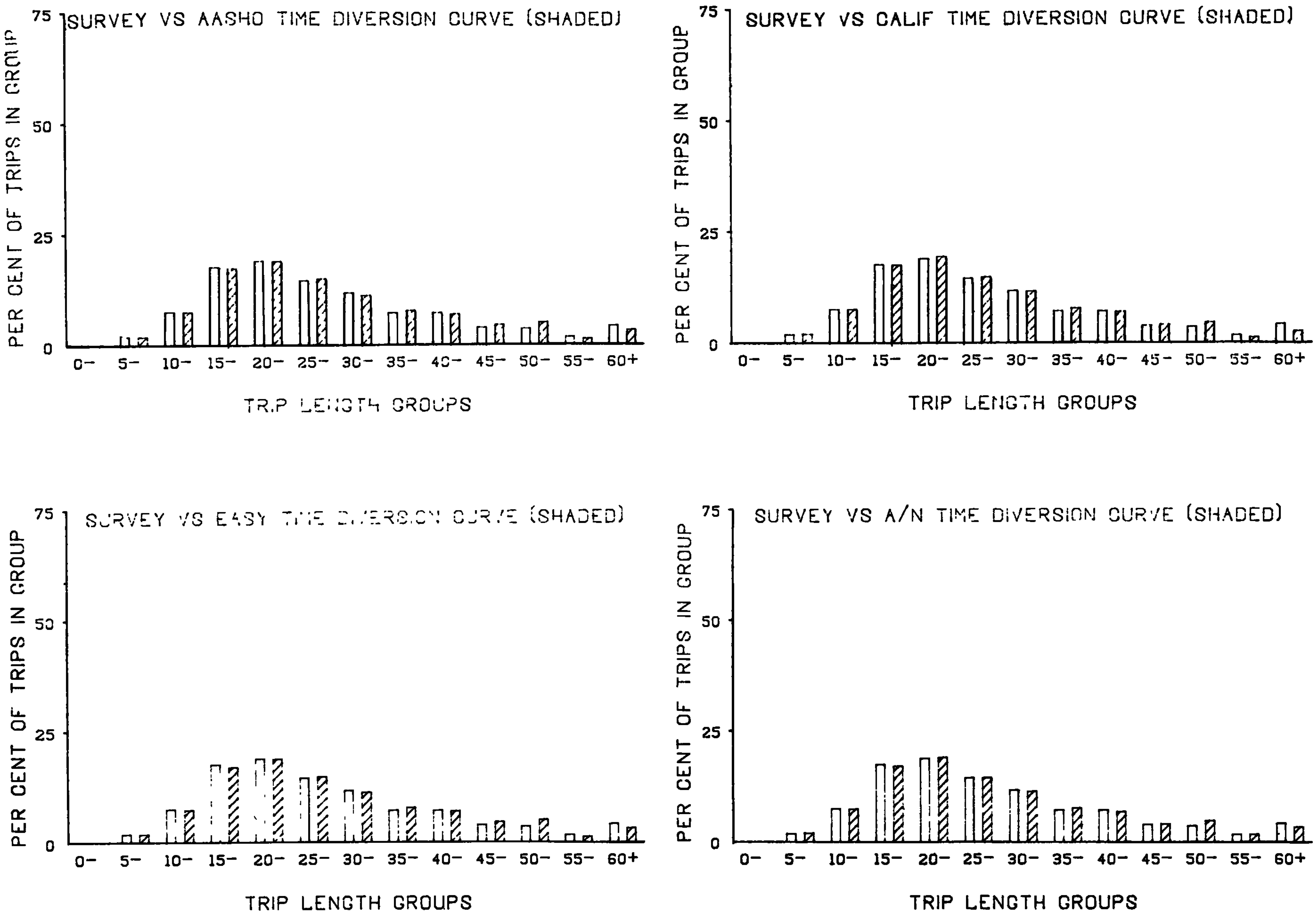

Figure C-8. Comparisons of trip length distribution by time for 1956 trips assigned to South Bridge.

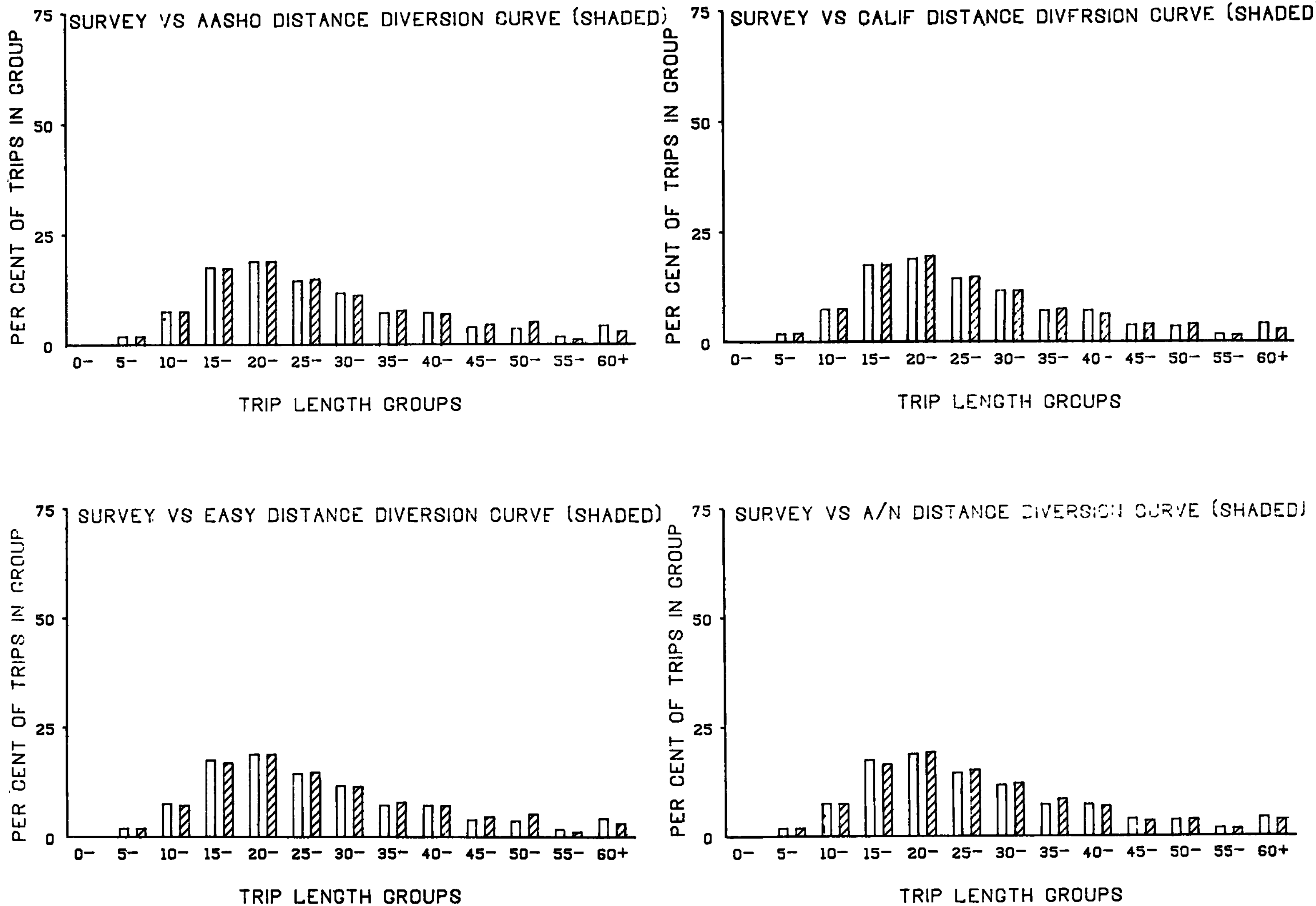

Figure C-9. Comparisons of trip length distribution by distance for 1956 trips assigned to South Bridge.

RANGE	SURVEY ZONE-ZONE	SURVEY TRIPS	AASHO TIME ZONE-ZONE	AASHO TIME TRIPS	AASHO DIST ZONE-ZONE	AASHO DIST TRIPS	CALIF TIME ZONE-ZONE	CALIF TIME TRIPS	CALIF DIST ZONE-ZONE	CALIF DIST TRIPS	EASY TIME ZONE-ZONE	EASY TIME TRIPS	EASY DIST ZONE-ZONE	EASY DIST TRIPS	A/N TIME ZONE-ZONE	A/N TIME TRIPS	A/N DIST ZONE-ZONE	A/N DIST TRIPS
0- 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- 10	2	1439	2	3331	2	1955	2	1981	2	2262	2	3275	2	2084	1	3035	0	0
10- 15	12	2545	13	2528	13	1686	10	1753	10	1859	12	2485	12	1714	6	2385	2	1057
15- 20	25	5162	29	4256	29	2935	20	3932	20	3918	28	4239	27	2925	16	4555	7	3565
20- 25	27	2603	36	2217	36	1427	24	2250	23	2318	36	2267	36	1423	22	2480	10	1990
25- 30	25	976	32	781	32	564	22	756	20	745	32	791	30	561	21	761	13	688
30- 35	22	571	30	425	30	346	19	395	18	380	30	423	29	348	17	398	10	340
35- 40	10	212	15	134	14	122	10	112	10	119	15	135	14	122	9	143	7	131
40- 45	23	715	25	518	25	410	21	681	19	621	25	505	25	410	20	736	13	547
45- 50	13	1371	16	1003	16	728	10	1247	9	1294	16	973	16	725	9	1331	4	1270
50- 55	17	472	21	300	21	244	16	310	15	292	21	294	21	244	16	340	8	249
55- 60	6	75	6	52	6	41	6	74	6	72	6	50	6	41	6	80	4	56
60 PLUS	22	1027	25	612	25	511	20	739	20	703	25	598	25	513	20	767	13	703
TOTALS	204	17168	250	16157	249	10969	180	14230	172	14583	248	16035	243	11110	163	17011	91	10593
AVE. TRIP LENGTH		25.70		21.81		23.10		24.90		24.32		21.68		22.90		23.37		28.70

PERCENTAGES OF ABOVE

RANGE	SURVEY ZONE-ZONE	SURVEY TRIPS	AASHO TIME ZONE-ZONE	AASHO TIME TRIPS	AASHO DIST ZONE-ZONE	AASHO DIST TRIPS	CALIF TIME ZONE-ZONE	CALIF TIME TRIPS	CALIF DIST ZONE-ZONE	CALIF DIST TRIPS	EASY TIME ZONE-ZONE	EASY TIME TRIPS	EASY DIST ZONE-ZONE	EASY DIST TRIPS	A/N TIME ZONE-ZONE	A/N TIME TRIPS	A/N DIST ZONE-ZONE	A/N DIST TRIPS
0- 5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5- 10	1.0	8.4	0.8	20.6	0.8	17.8	1.1	13.9	1.2	15.5	0.8	20.4	0.8	18.8	0.6	17.8	0.	0.
10- 15	5.9	14.8	5.2	15.6	5.2	15.4	5.6	12.3	5.8	12.7	4.8	15.5	4.9	15.4	3.7	14.0	2.2	10.0
15- 20	12.3	30.1	11.6	26.3	11.6	26.8	11.1	27.6	11.6	26.9	11.3	26.4	11.1	26.3	9.8	26.8	7.7	33.7
20- 25	13.2	15.2	14.4	13.7	14.5	13.0	13.3	15.8	13.4	15.9	14.5	14.1	14.8	12.8	13.5	14.6	11.0	18.8
25- 30	12.3	5.7	12.8	4.8	12.9	5.1	12.2	5.3	11.6	5.1	12.9	4.9	12.3	5.0	12.9	4.5	14.3	6.5
30- 35	10.8	3.3	12.0	2.6	12.0	3.2	10.6	2.8	10.5	2.6	12.1	2.6	11.9	3.1	10.4	2.3	11.0	3.2
35- 40	4.9	1.2	6.0	0.8	5.6	1.1	5.6	0.8	5.8	0.8	6.0	0.8	5.8	1.1	5.5	0.8	7.7	1.2
40- 45	11.3	4.2	10.0	3.2	10.0	3.7	11.7	4.8	11.0	4.3	10.1	3.1	10.3	3.7	12.3	4.3	14.3	5.2
45- 50	6.4	8.0	6.4	6.2	6.4	6.6	5.6	8.8	5.2	8.9	6.5	6.1	6.6	6.5	5.5	7.8	4.4	12.0
50- 55	8.3	2.7	8.4	1.9	8.4	2.2	8.9	2.2	8.7	2.0	8.5	1.8	8.6	2.2	9.8	2.0	8.8	2.4
55- 60	2.9	0.4	2.4	0.3	2.4	0.4	3.3	0.5	3.5	0.5	2.4	0.3	2.5	0.4	3.7	0.5	4.4	0.5
60 PLUS	10.8	6.0	10.0	3.8	10.0	4.7	11.1	5.2	11.6	4.8	10.1	3.7	10.3	4.6	12.3	4.5	14.3	6.6

Figure C-10. Printout of trip length distribution for 1963 trips assigned to I-91 Bridge by the various techniques.

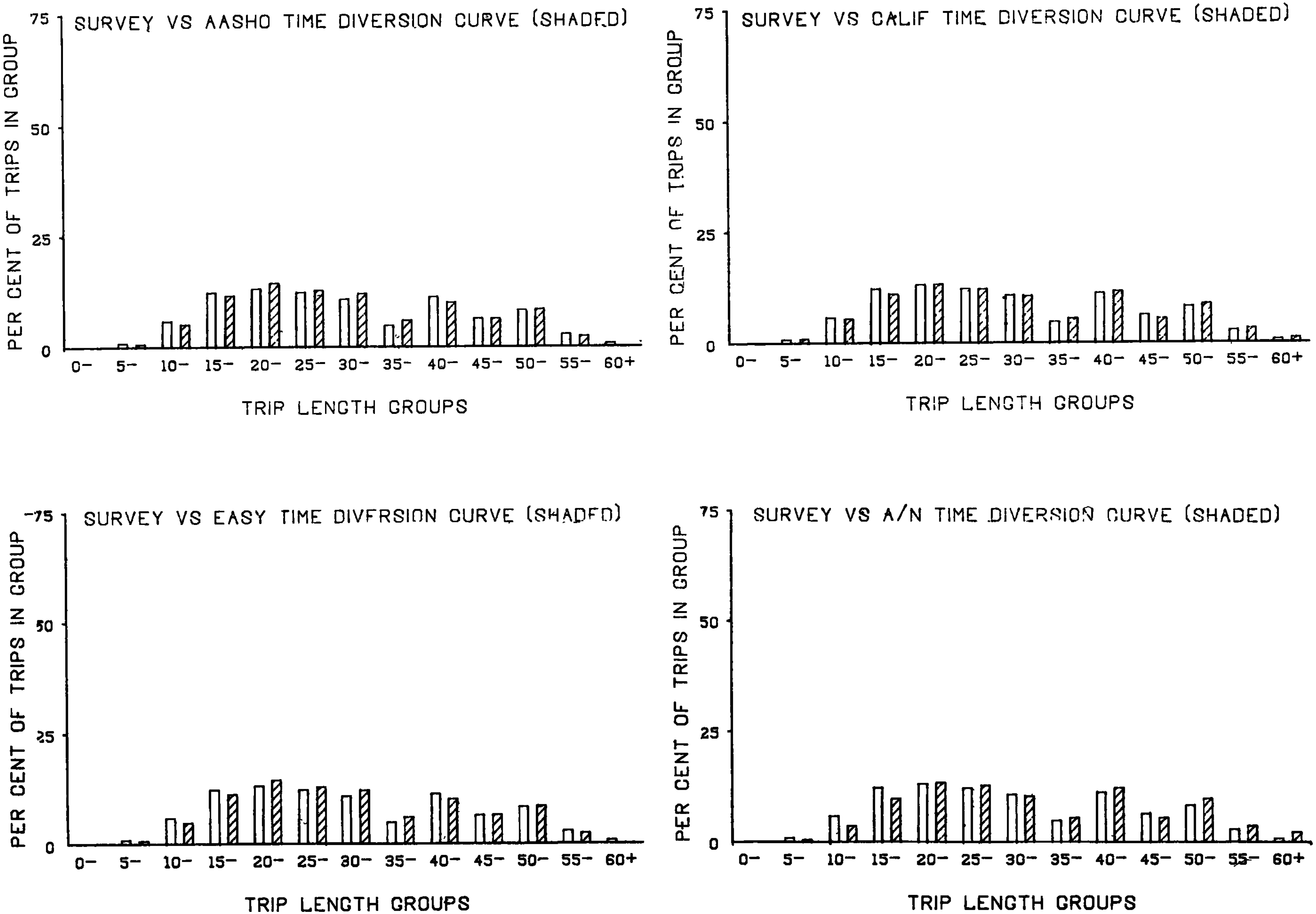

Figure C-11. Comparisons of trip length distribution by time for 1963 trips assigned to I-91 Bridge.

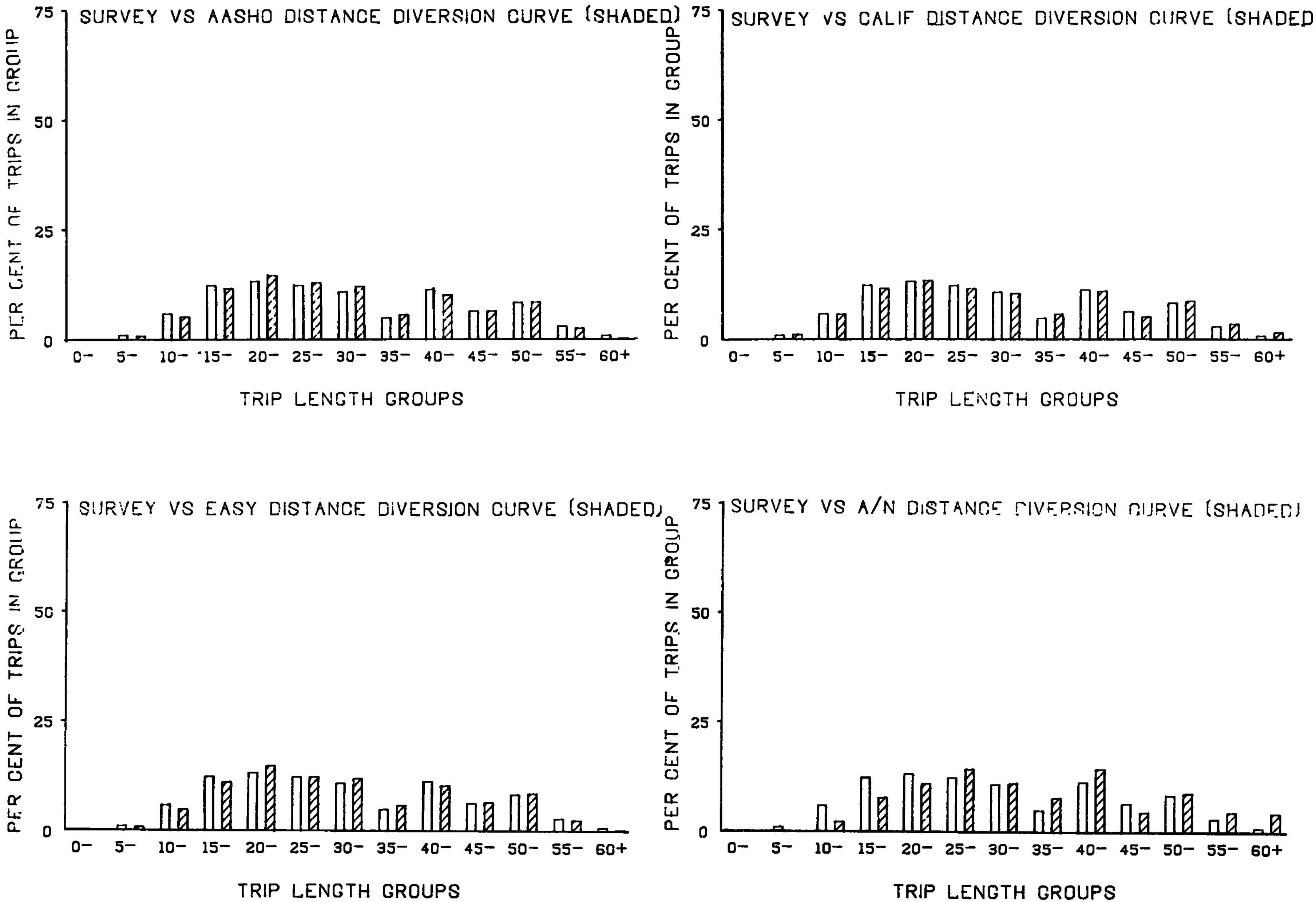

Figure C-12. Comparisons of trip length distribution by distance for 1963 trips assigned to I-91 Bridge.

RANGE	SURVEY		AASHO TIME		AASHO DIST		CALIF TIME		CALIF DIST		EASY TIME		EASY DIST		A/N TIME		A/N DIST	
	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS
0- 10	2	2688	2	2709	2	2680	2	2772	2	2772	2	2713	2	2681	2	3077	2	3077
10- 20	14	2023	14	2039	14	1841	12	2256	12	2238	13	2011	12	1856	12	2545	11	1873
20- 30	54	2393	56	2284	56	2186	53	2488	53	2487	54	2315	54	2246	53	2933	47	2469
30- 40	81	1447	86	1295	86	1245	77	1513	77	1504	84	1308	82	1250	77	1577	69	1513
40- 50	66	773	68	618	68	606	66	794	66	789	68	612	67	604	66	978	64	962
50- 60	48	403	50	315	50	303	46	392	46	396	50	307	50	298	46	451	45	450
60- 70	37	243	40	204	40	197	36	222	35	239	40	202	40	197	36	313	34	233
70- 80	28	125	32	114	32	111	30	132	28	134	32	112	32	109	30	175	25	158
80 PLUS	29	114	29	76	27	72	23	84	23	87	29	74	27	72	29	123	25	113
TOTALS	359	10209	377	9654	375	9241	345	10653	342	10646	372	9654	366	9313	351	12172	322	10848
AVE. TRAVEL TIME		22.84		21.42		21.35		22.35		22.45		21.38		21.34		23.00		22.85

PERCENTAGES OF ABOVE

RANGE	SURVEY		AASHO TIME		AASHO DIST		CALIF TIME		CALIF DIST		EASY TIME		EASY DIST		A/N TIME		A/N DIST	
	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS
0- 10	0.6	26.3	0.5	28.1	0.5	29.0	0.6	26.0	0.6	26.0	0.5	28.1	0.5	28.8	0.6	25.3	0.6	28.4
10- 20	3.9	19.8	3.7	21.1	3.7	19.9	3.5	21.2	3.5	21.0	3.5	20.8	3.3	19.9	3.4	20.9	3.4	17.3
20- 30	15.0	23.4	14.9	23.7	14.9	23.7	15.4	23.4	15.5	23.4	14.5	24.0	14.8	24.1	15.1	24.1	14.6	22.8
30- 40	22.6	14.2	22.8	13.4	22.9	13.5	22.3	14.2	22.5	14.1	22.6	13.5	22.4	13.4	21.9	13.0	21.4	13.9
40- 50	18.4	7.6	18.0	6.4	18.1	6.6	19.1	7.5	19.3	7.4	18.3	6.3	18.3	6.5	18.8	8.0	19.9	8.9
50- 60	13.4	3.9	13.3	3.3	13.3	3.3	13.3	3.7	13.5	3.7	13.4	3.2	13.7	3.2	13.1	3.7	14.0	4.1
60- 70	10.3	2.4	10.6	2.1	10.7	2.1	10.4	2.1	10.2	2.2	10.8	2.1	10.9	2.1	10.3	2.6	10.6	2.1
70- 80	7.8	1.2	8.5	1.2	8.5	1.2	8.7	1.2	8.2	1.3	8.6	1.2	8.7	1.2	8.5	1.4	7.8	1.5
80 PLUS	8.1	1.1	7.7	0.8	7.2	0.8	6.7	0.8	6.7	0.8	7.8	0.8	7.4	0.8	8.3	1.0	7.8	1.0

Figure C-13. Printout of travel time distribution for 1956 trips assigned to South Bridge by the various techniques.

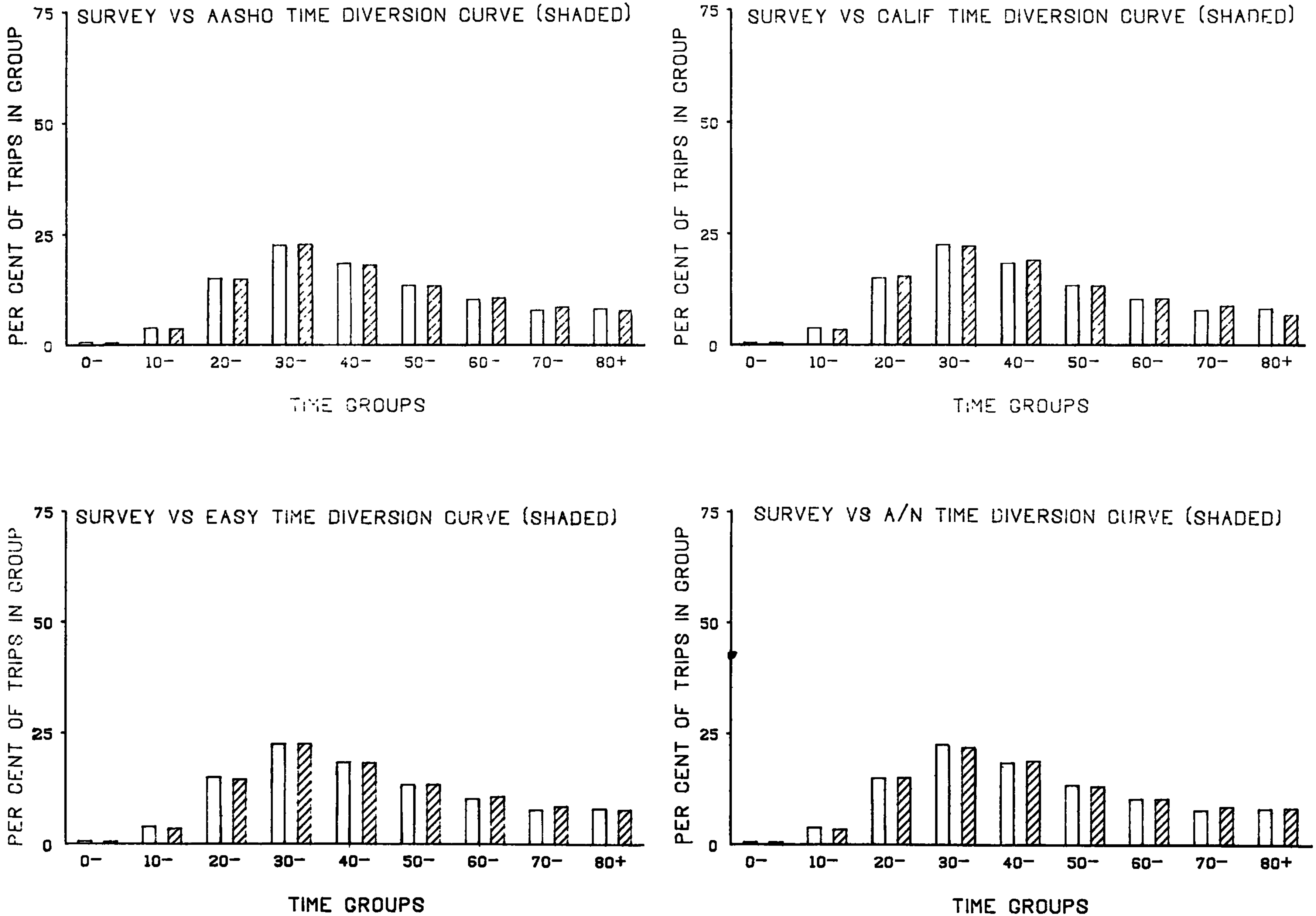

Figure C-14. Comparisons of travel time distribution by time for 1956 trips assigned to South Bridge.

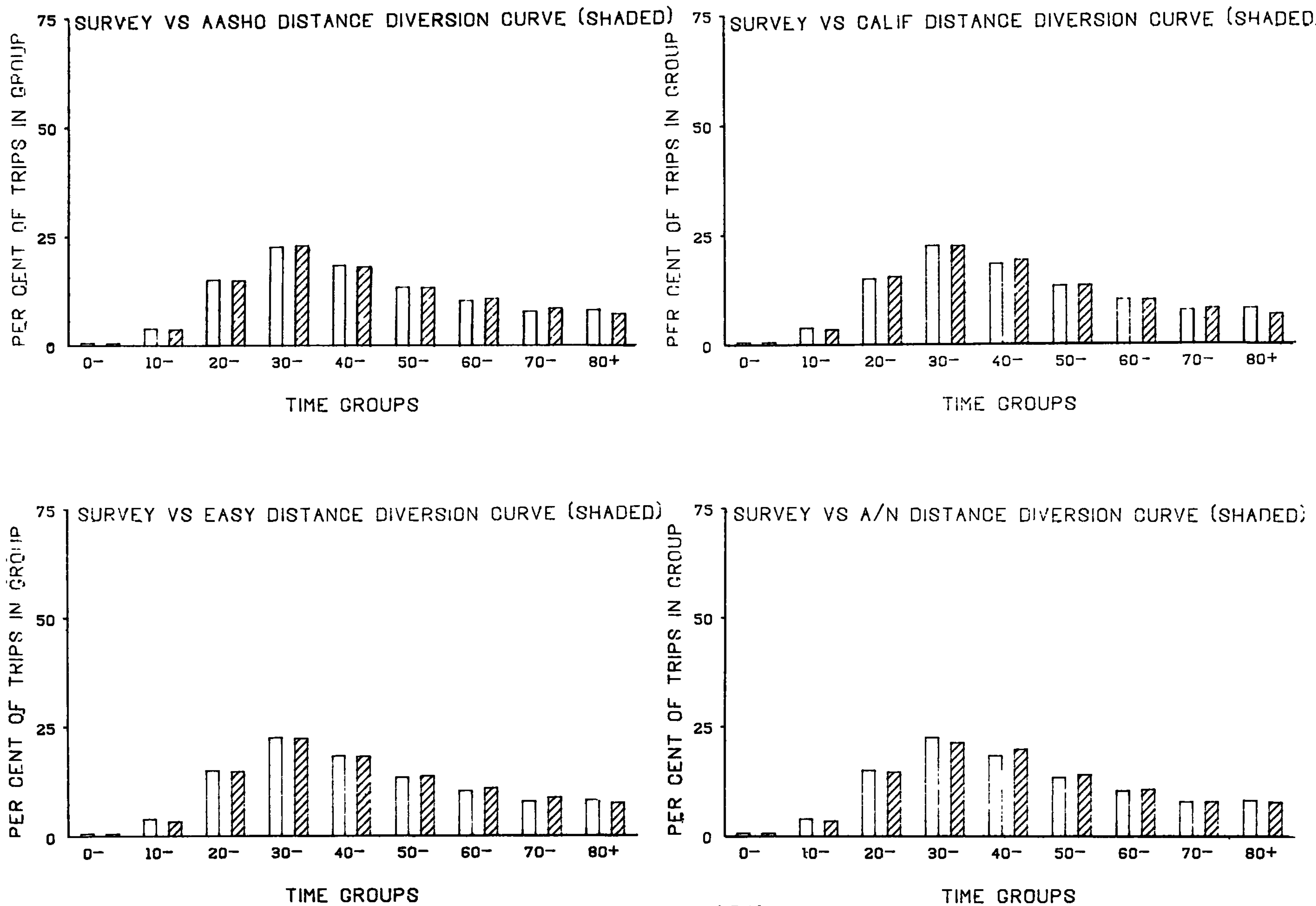

Figure C-15. Comparisons of travel time distribution by distance for 1956 trips assigned to South Bridge.

RANGE	SURVEY		AASHO				CALIF				EASY				A/N			
			TIME		DIST		TIME		DIST		TIME		DIST		TIME		DIST	
	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS
0- 10	2	1439	2	3331	2	1955	2	1981	2	2262	2	3275	2	2084	1	3035	0	0
10- 20	9	2174	9	2183	9	1400	7	1577	7	1699	8	2134	8	1414	5	2239	2	1057
20- 30	32	7476	37	6332	37	4262	28	5931	28	5990	36	6377	35	4259	22	6702	10	5258
30- 40	32	1311	41	1009	41	740	25	934	23	913	41	1013	39	738	23	1008	9	784
40- 50	26	519	35	410	35	334	22	335	21	326	35	413	34	336	20	305	13	239
50- 60	25	935	36	684	35	558	27	831	26	762	36	671	35	559	25	896	16	722
60- 70	27	1680	31	1227	31	896	24	1571	22	1623	31	1189	31	892	24	1676	15	1581
70- 80	21	403	23	261	23	211	17	283	16	270	23	255	23	212	15	313	9	229
80 PLUS	30	1231	36	720	36	613	28	787	27	738	36	708	36	616	28	837	17	723
TOTALS	204	17168	250	16157	249	10969	180	14230	172	14583	248	16035	243	11110	163	17011	91	10593
AVE. TRAVEL TIME		34.74		27.86		30.21		32.57		31.51		27.81		29.86		32.41		39.06

PERCENTAGES OF ABOVE

RANGE	SURVEY		AASHO				CALIF				EASY				A/N			
			TIME		DIST		TIME		DIST		TIME		DIST		TIME		DIST	
	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS	ZONE-ZONE	TRIPS
0- 10	1.0	8.4	0.8	20.6	0.8	17.8	1.1	13.9	1.2	15.5	0.8	20.4	0.8	18.8	0.6	17.8	0.	0.
10- 20	4.4	12.7	3.6	13.5	3.6	12.8	3.9	11.1	4.1	11.7	3.2	13.3	3.3	12.7	3.1	13.2	2.2	10.0
20- 30	15.7	43.5	14.8	39.2	14.9	38.9	15.6	41.7	16.3	41.1	14.5	39.8	14.4	38.3	13.5	39.4	11.0	49.6
30- 40	15.7	7.6	16.4	6.2	16.5	6.7	13.9	6.6	13.4	6.3	16.5	6.3	16.0	6.6	14.1	5.9	9.9	7.4
40- 50	12.7	3.0	14.0	2.5	14.1	3.0	12.2	2.4	12.2	2.2	14.1	2.6	14.0	3.0	12.3	1.8	14.3	2.3
50- 60	12.3	5.4	14.4	4.2	14.1	5.1	15.0	5.8	15.1	5.2	14.5	4.2	14.4	5.0	15.3	5.3	17.6	6.8
60- 70	13.2	9.8	12.4	7.6	12.4	8.2	13.3	11.0	12.8	11.1	12.5	7.4	12.8	8.0	14.7	9.9	16.5	14.9
70- 80	10.3	2.3	9.2	1.6	9.2	1.9	9.4	2.0	9.3	1.9	9.3	1.6	9.5	1.9	9.2	1.8	9.9	2.2
80 PLUS	14.7	7.2	14.4	4.5	14.5	5.6	15.6	5.5	15.7	5.1	14.5	4.4	14.8	5.5	17.2	4.9	18.7	6.8

Figure C-16. Printout of travel time distribution for 1963 trips assigned to I-91 Bridge by the various techniques.

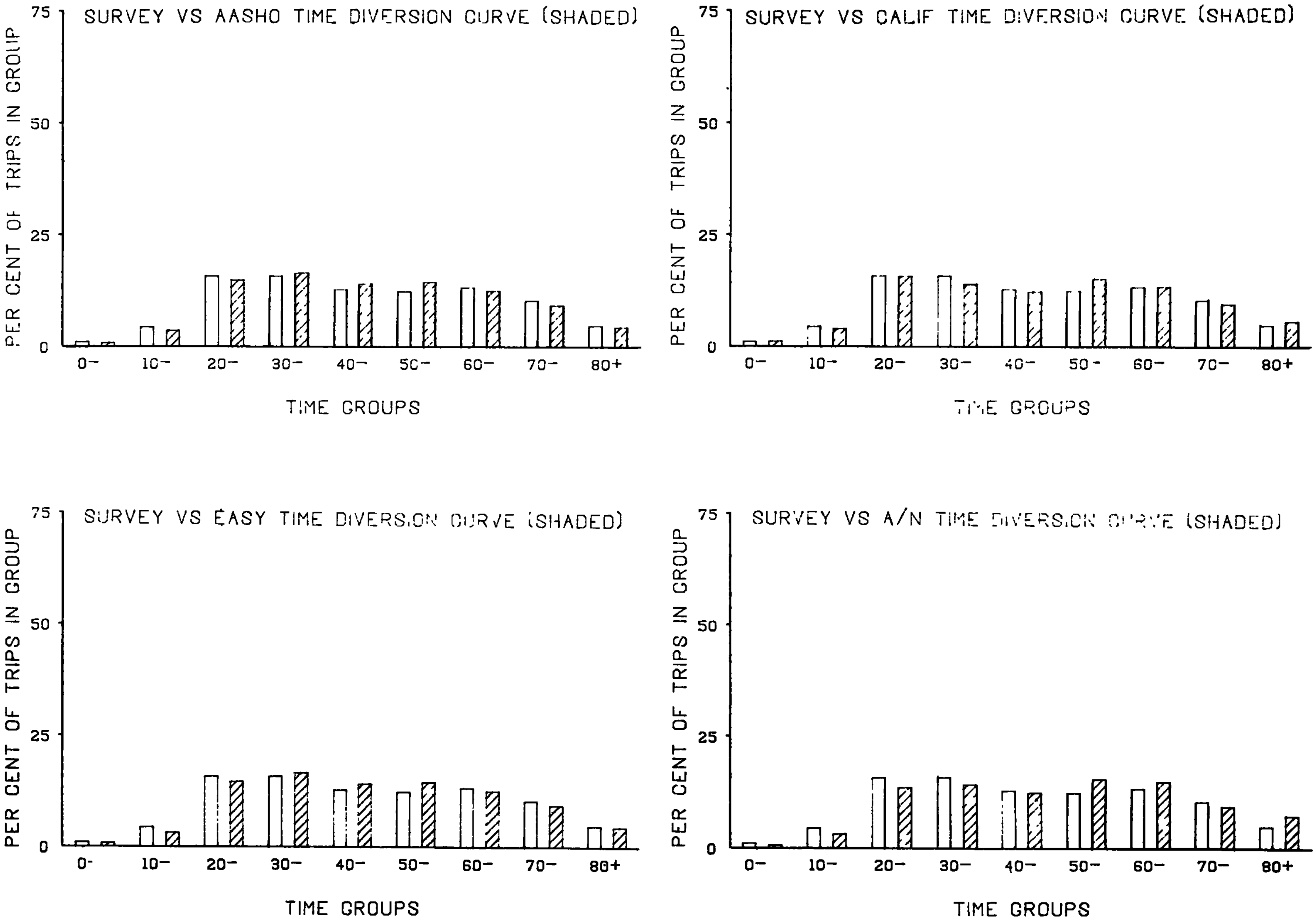

Figure C-17. Comparisons of travel time distribution by time for 1963 trips assigned to I-91 Bridge.

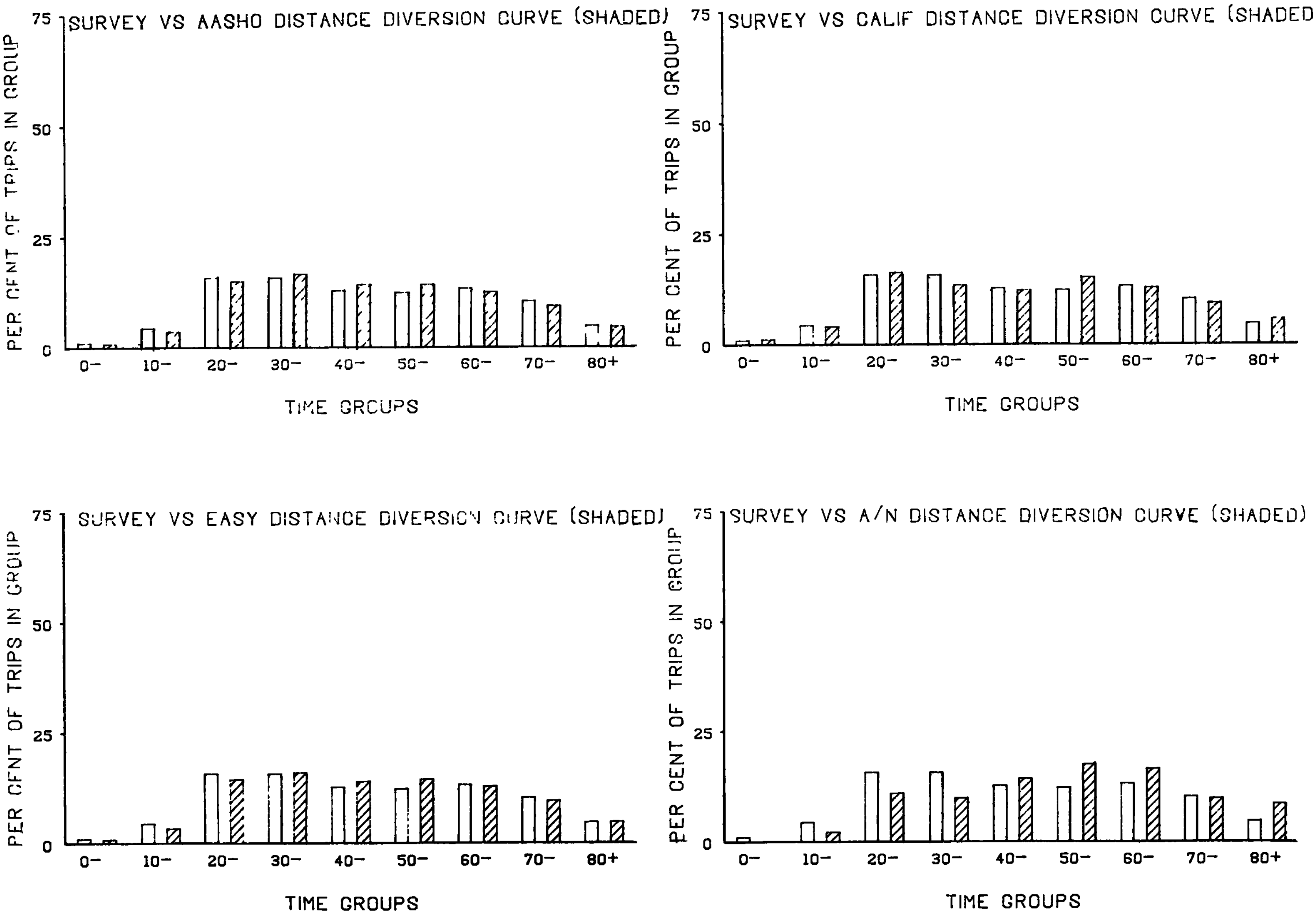

Figure C-18. Comparisons of travel time distribution by distance for 1963 trips assigned to I-91 Bridge.

APPENDIX D

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