THE JOURNEY TO WORK AS A BASIS FOR SIMULATING URBAN TRAVEL

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CHAPTER 1

INTRODUCTION

The journey from home to work plays a singularly important role in urban personal travel. Urban personal travel occurs unevenly throughout the day and the peak period of travel plays the determining role in the planning and design of urban transportation facilities. The concentration of work trips within the peak travel period suggests the possibility of estimating total peak period travel, and from this transportation system needs, based upon a knowledge of work trip patterns.

Such a model is presented here. The input to the model is a table of work trip origins and destinations such as is available in the 1970 Census Urban Transportation Planning Package, and a process to assign these trips to the transportation network. After the trips have been assigned to the network, the model calculates peak hour travel on the links of the network as a function of work trips assigned to the link and other link-specific characteristics.

In order to develop the model, a work trip table and a set of peak period traffic counts is required. No supplementary travel survey data is needed.

The procedure was found to provide an adequate estimation of travel on the urban street system when it was developed for Albuquerque, New Mexico. It has the advantages of requiring less input information, and potentially yields significant savings in the resources necessary to obtain future year traffic estimates. Although developed and applied only to the automobile mode, the procedure should be equally valid in estimating public transit travel.

The estimating model developed here can be compared directly with the traditional planning models currently being used in Albuquerque. The year 1970 was a reevaluation year for these models, for which trip tables and network loadings were obtained and compared with traffic count data to gauge their performance.

The estimation models used in Albuquerque are the traditional models often referred to as the Urban Transportation Planning Process, and referenced herein as the UTP models. They include the sub models, Trip Generation, Trip Distribution, and Traffic Assignment. They were calibrated from a 1962 data base obtained from a 10% home interview Origin-Destination survey.[1] Trip Generation estimates zonal auto trip productions and attractions from aggregate land use data based upon a linear regression model. Trip Distribution distributes these trips for eight purposes by use of the gravity model. The trips are assigned to the network by an all-or-nothing shortest time path assignment. Capacity Restraint is used in an iterative procedure to balance traffic volumes and speeds. After the trips have been assigned four times to the network, the loads are averaged to obtain final estimates of traffic volumes.

The FHWA battery of IBM 360/370 computer programs are used to operate these models. These programs are described further in Appendix A. The procedures used are documented by a series of internal technical papers.[2] Currently. methods are being explored to incorporate simulation of transit operations and modal splits into the methodology.

The following chapters describe the rationale for this procedure and examine the results of applying it to the 1970 Albuquerque street network. Chapter II presents the importance of the journey to work in urban travel and the peak period of travel in transportation facility design. It is suggested here that work trip data may form an adequate base for estimating total urban peak period travel. The 1970 Census Urban Transportation Planning Package, which offers local urban transportation planning agencies a relatively cheap and standardized data base, is also described. Finally, a summary of previous work leading to the model presented here is given.

The third chapter develops in further detail the form of the model and the variables which are to be tested. A method is described in this chapter for comparing the estimates of a travel simulation model with actual counted link flows in an effort to gauge the degree of confidence that can be placed in the model.

The results of the empirical analysis are presented in the fourth chapter. Multiple linear regression was used in an attempt to uncover the underlying relation of the variables. In addition to several definitions of the evening peak period, the model was applied to morning peak period and total daily traffic.

The last chapter discusses the sensitivity of the model to changes in urban trip-making behavior and presents the conclusions derived from the work. Appendix A presents methods for developing and applying the work trip based model using the FHWA battery of computer programs. The remaining appendixes present numerical information arising during the analysis.

FOOTNOTES

[1]The expanded travel data from this survey did not compare well with traffic counts across screen lines. The survey data was 22.3% low on one screen line, and 18.7% low on the other. Larry K. O'dell, Evaluation of 1962 Origin-Destination Survey Data, Tech. Memo. 24, Middle Rio Grande Council of Governments (mimeographed).

[2]Kenneth M. Howell, Building a Trip Table Using Albuquerque Transportation Models, Middle Rio Grande Council of Governments, May, 1973, (mimeographed); James P. Milton, Calibration of the Trip Distribution Model, Nov. 1972 (mimeographed); Kenneth M. Howell, Trip Generation Analysis, April 1973 (mimeographed).

CHAPTER II

A MODEL OF URBAN TRAVEL BASED UPON THE JOURNEY TO WORK

Rationale for a Peak Period Travel Model Based Upon the Journey to Work

The importance of the journey from place of residence to place of work and back has long been recognized by observers of the urban scene. Since the early work by Liepmann and Carroll hypothesizing the relation between the journey to work and urban form, a vast body of research has accrued investigating the nature of work trips and their effect upon the urban environment.[1] What has also been observed and is explored further here is the effect of the journey to work upon the design and investment in the urban transportation system.

A significant part of the total amount of urban travel is a result of the journey to work. The Nationwide Personal Transportation Survey, conducted in 1969-70 found on the peak day of the week, Friday, that 34.8 percent of all automobile trips were home-to-work trips and that this percentage ran to more than 40 percent for other weekdays.[2]

Since the average work trip is longer than the average trip for other purposes, the total amount of travel, measured in vehicle-miles of travel (VMT) is an even greater percentage of total urban travel, amounting to 38% of the total on Friday, and higher percentages on other weekdays.[3]

The significance of the journey to work is further increased by the concentration of work trips in the peak periods of travel during the day. A study of travel surveys for eight U.S. cities taken between 1961 and 1967 showed that for the peak travel hour between 5:00 and 6:00 P.M., home based work trips accounted for between 41 and 51 percent of total VMT. For the morning peak, 7:00 to 8:00 A.M., this range was between 66 and 70 percent.[4] The Nationwide Personal Transportation Survey found that 41.4 percent of automobile travel between 4:00 and 5:00 P.M., and 45.0 percent of VMT between 5:00 and 6:00 P.M. was home-to-work travel. During the morning peak from 7:00 to 8:00 A.M., this percentage was 72.5 percent.[5]

The reason work trips represent a comparatively large portion of total peak hour travel is that most jobs tend to start and end about the same time. More than 50% of the total work trip purpose travel occurs in the hours between 6:00 and 8:00 A.M. and 4:00 and 6:00 P.M.[6] For large urban areas this may be as high as 60 percent or more.[7]

In addition to being concentrated in time, work trips are concentrated in space and direction. They move between clearly defined residential areas and employment centers, surging one way in the morning and the opposite direction in the evening. These surges create the peak loads on the transportation network and thus are critical in determining the design capacity of planned transportation facilities.

The contention that work trips are concentrated in direction is open to some question due to the growing awareness of the importance of reverse commuting and the inter-suburban, peripheral journey to work.[8] In order to test the hypothesis that work trips are highly peaked directionally, the work trips on the most heavily travelled links of the Albuquerque street system in 1970 were observed. The three most heavily travelled sections of the freeway system, and the fifteen most heavily travelled "independent" sections of the major street network were determined from the 1970 Traffic Flow Map.[9] These sections are independent of each other in that no section was chosen if the adjacent section (usually the sections are one-half mile long) had a higher average daily traffic flow. The work trip flows in each direction were obtained by assigning the 1970 census work trip table to a computerized map of the street network.[10] An all-or-nothing, minimum time path assignment without capacity restraint was used. The percent of total work trips from home to work which travelled in the predominant direction of work trip travel was calculated for each of these sections. Thus, a figure of .85 means that 85 percent of total work trips from home to work on a particular section travelled in one direction, and 15 percent travelled in the opposite direction.

These calculations, together with the locations of the high traffic flow sections and the predominant direction of home-to-work travel are shown in Figure 1. Typically, the directional split of traffic during the peak hour is .55-.45 or .60-.40. The previously mentioned study of travel in eight U.S. cities in the 1960's found directional splits ranging between .60 and .72.[11] The split of work trips by

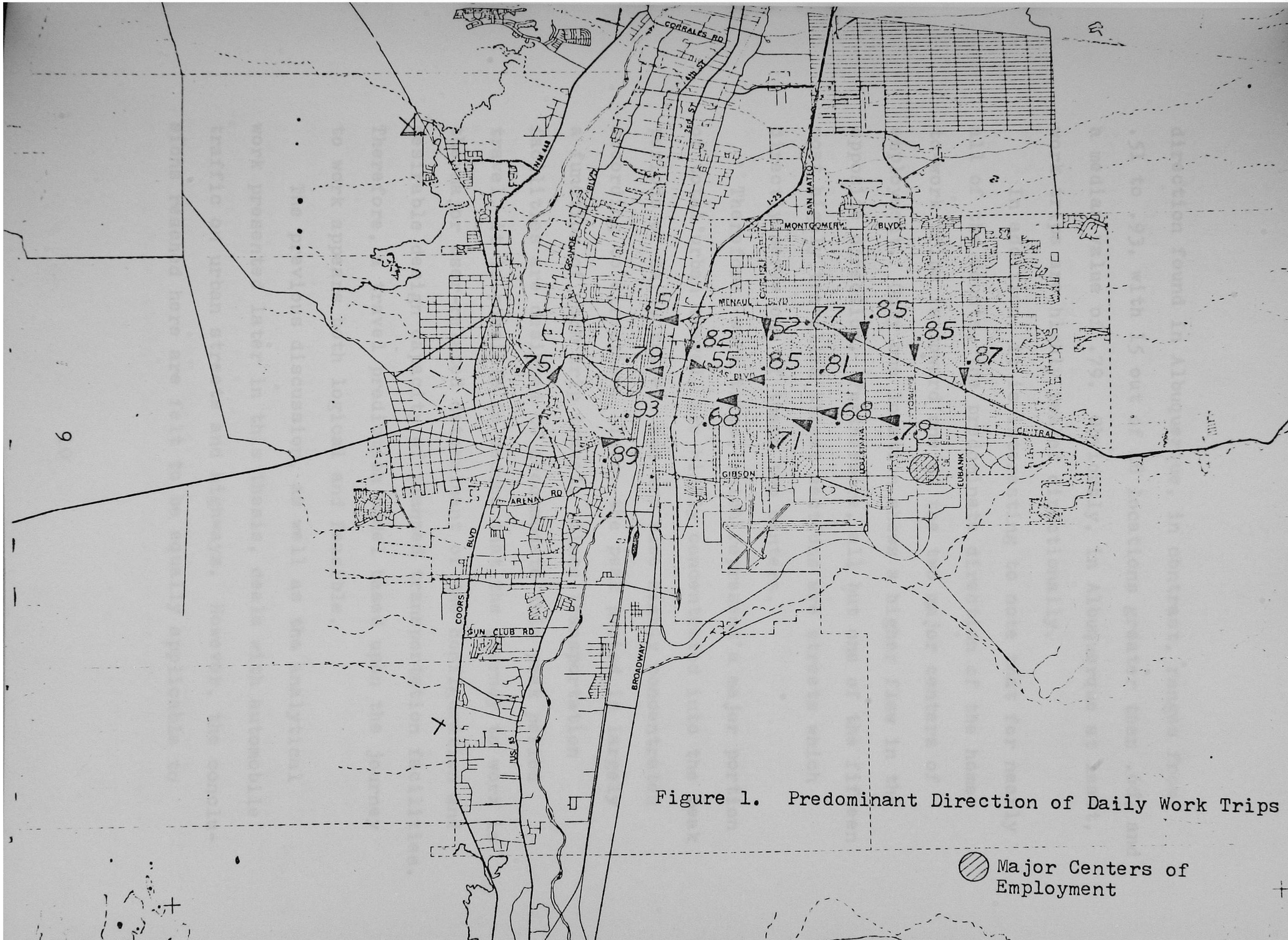

Figure 1. Predominant Direction of Daily Work Trips

direction found in Albuquerque, in contrast, ranges from .51 to .93, with 15 out of 18 locations greater than .66, and a median value of .79. Obviously, in Albuquerque at least, work trips are highly peaked directionally.

In addition, it is interesting to note that for nearly all of the counts, the predominate direction of the home-to-work trips is toward one of the two major centers of employment. Only one location shows a higher flow in the opposite direction. Furthermore, all but one of the fifteen most highly travelled street sections are streets which directly serve one of these two centers.

Therefore, work trips, which represent a major portion of total urban travel, are highly concentrated into the peak periods of daily travel, and are also highly concentrated according to direction. Thus, the peak period is largely a function of work trip travel. Since transportation facilities are designed to accommodate this peak period travel, it is possible to deduce that the journey to work is the major user-related determinant of the configuration and desirable design capacity of planned transportation facilities. Therefore, a travel prediction model based upon the journey to work appears both logical and feasible.

The previous discussion, as well as the analytical work presented later in this thesis, deals with automobile traffic on urban streets and highways. However, the conclusions reached here are felt to be equally applicable to reliable data base for calibrating mode choice models.[15]

The advantages of the work trip purpose over other trip purposes in analyzing the choice of route of automobile drivers has been recognized. Because the work trip is highly repetitive, commuters acquire a good knowledge of the characteristics of alternate routes and can objectively choose between them in order to minimize undesirable aspects of the journey. In contrast, the leisure nature of other trips may make route choice more random. Wachs found that safety, scenery and pavement smoothness were more important in choosing a route for visit trips than for work trips.[16] These factors are difficult to incorporate into simulation models, and thus contribute to "randomness" in route choices. Ueberschaer found that, although different drivers choose different routes between the same two spots, shortest travel time was a very good predictor of the most frequently used route for work trips.[17] This is advantageous since travel time usually forms the primary, and very often the only, criterion used by existing traffic assignment methodologies.

In addition, procedures to model peak period trips have certain technical advantages over daily travel models. First, the speeds on the various sections of the street network are more meaningfully estimated. Travel speeds show a great deal of variation throughout the day, part of which is due to varying levels of congestion experienced at various times during the day.[18] Focusing on the peak period eliminates part of this variation and since peak period travel speeds are useful for traffic engineering purposes, presents a more easily obtained data base than an attempt to estimate the total daily distribution of speeds. The importance of meaningful estimates of network speeds in the estimation of urban travel can hardly be overestimated. It is an input to most of the planning estimation models of what has been dubbed the Urban Transportation Planning Process: trip distribution, modal split, network assignment, and sometimes land use and trip generation models.[19]

Secondly the capacity of the individual street sections is more meaningful when referring to peak hour rather than total daily capacity. This is because street capacity for engineering design purposes has been traditionally expressed as design hourly capacity,[20] and because total daily capacity is a function not only of the physical configuration of the street, but also of the daily temporal distribution of traffic on the facility.

Therefore, an estimation model of peak period traffic based upon the journey to work would incorporate the more successful elements of the current state of the art of urban travel simulation. It could use the work accomplished in the investigation of the nature of work trips and the mode choice of commuters.

A peak period work trip model has other advantages as well. One very important advantage is that the data requirements for a work trip model are much more modest than for traditional urban transportation planning models. Since it is not necessary to estimate other purposes, such as trips to school, shopping, recreation, and so forth, there is a savings in the number of variables for trip generation which must be collected to derive the model, and predicted for the future in order to use the model. In Albuquerque, the total set of trip generation production and attraction equations is based upon twelve independent variables. Work trip equations require only four variables.[21]

Furthermore, the work trip data required to construct the model is easier to obtain. A trip table of primary work trips is included in the Census Urban Transportation Planning Package for all Standard Metropolitan Statistical Areas. This package is available to local planning agencies at a modest charge and is described further below.[22] This provides a recurrent data source for calibrating and updating the estimation procedures. It has, however, been observed that this data base is aggregate in nature, and must remain so due to the census disclosure rules. This makes it inadequate as a data base for disaggregate models,[23] although the relatively more expensive "Worker Files" may offer a solution.[24]

Aside from the census package, it is considerably easier for a local planning agency to obtain data on the primary work trip from surveys than it would be to obtain a whole set of travel information, if even for a one day period, from home interview questions. The work trip survey need ask only two questions, "Where do you work, and where do you live?" to obtain an adequate representation of work trip travel. Such a travel survey could be carried out at place of work, sometimes from company files. The recent interest in carpooling to meet the energy crisis has created a groundswell of interest in employer-based surveys of work trips.[25]

The importance of simplifying the data collection efforts is that the effort involved in collecting and analyzing large quantities of information could be better used in the planning process by analyzing a larger number of proposed alternatives. An international panel of transportation planners, meeting under the auspices of the Organization for Economic Co-Operation and Development (OECD), noted that

> "The expense and time required to acquire the necessary data and to simulate large and complex networks often preclude evaluation of more than a few candidate systems."[26]

The same report also discussed another problem which peak period work trip models may tend to alleviate. This is that

> "The present system of models may be more detailed and thus more expensive and difficult to use than necessary; the degree of precision in the numbers produced may be more than is justified by the underlying population, employment, and trip-making behavior assumptions. Many more alternative systems and policies should be analyzed than most present studies have been

able to do. This may require development of new model systems that are less detailed, easier to use and more relevant to the issues to be studied."[27]

However at the same time that work trip models allow for the development of simpler travel estimating methodologies, it must be remembered that they do so by making simplifying assumptions concerning non work travel. Even during the peak period, this non work travel makes up a substantial portion of the total, and is likely to be moving in different directions and patterns than the work trips.

It has also been noted that the relation between work trips and total trips has not remained constant through time, which creates problems for predicting total travel based on a prediction of work travel. In fact, work trip travel has been seen to be a declining component of total urban travel. For instance, Ashford and Holloway used trip generation production equations developed for Pittsburg from a 1958 home interview survey data to predict 1967 production values. In a comparison of these values against 1967 home interview survey data, work trips were found to be 15 percent overestimated, while home based shopping, home based school and non-home based trips were underestimated by 19 to 28 percent. This resulted from the fact that total home based work trips decreased 6.5 percent in the area studied between 1958 and 1967, while total trips increased 16.4 percent.[28]

It has not been determined whether work trips account for a declining portion of peak period traffic as well as daily travel. It is also uncertain whether the trend will continue into the future if a chronic shortage of gasoline limits autombile use, and thus reduces marginally useful auto trips. This last possibility may have the effect of reducing non work trips by automobile and increasing non work trips by public transit.

In summary, the peak period journey to work has been shown to be the major determinant of the configuration and capacity requirements of planned transportation improvements. A model based upon the peak period journey to work would incorporate the more successful elements of the current state of the art of urban travel forecasting models. The data requirements for such a model are more easily filled. A work trip model offers the opportunity to use a simpler, less cumbersome estimating technique, which by being easier to use allows for a fuller exploration of the transportation alternatives available to the urban region.

The 1970 Census Urban Transportation Planning Package

The 1970 Census Urban Transportation Planning Package resulted from the desire of the Federal Highway Administration and many local planning agencies to utilize the census as a resource for gathering the data required in a continuing transportation planning program. A "standard package" of data tabulations based upon the 15 and 20 percent "long form" census questionnaires is available on computer readable tape for each Standard Metropolitan Statistical Area (SMSA). The data tabulations, which are aggregated from census blocks to whatever data or traffic analysis zones that the local agency specifies, are designed to provide a minimum data set useful to urban transportation studies. The specific procedures, content and format are discussed elsewhere,[29] perhaps best by Manka.[30]

One of the questions asked of the 15 percent census household interview sample was the place-of-work question. Each full and part time worker 14 years old and older who worked during the previous week was asked the address, town, county, and zip code of his place of work. In addition, each worker was asked to specify the chief mode used to get to work the last day he worked of the previous week. No question concerning working hours was asked, however. When coded to census blocks, expanded to the full population, and then aggregated to zones specified by the local planning agency, this forms a zonal level daily home-to-work trip table by mode. This trip table, from zone of residence to zone of work by mode, is included in the 1970 Census Urban Transportation Planning Package. The auto-driver portion of this table is the work trip table used in this analysis.

It should be noted that the definition of home-to-work trip implicit in this trip table is different from that of the home based work trip commonly used in transportation studies. The major difference is that the work trip in the Census Urban Transportation Planning Package can include any number of intermediate stops, such as to pick up passengers or to refuel the auto. The traditional home based work trip goes directly from home to work. If any stop along the way is made, the journey is defined as a non-home based work trip plus some home-based non-work trip.[31] Thus, technically, the census package includes the "primary work trip," or the "journey to work," to distinguish it from the "home based work trip."

The useability of the 1970 Census Urban Transportation Planning Package for Albuquerque was tested in a project reported upon elsewhere.[32] The data relating to residential characteristics was found to be an excellent source of surveillance information, but a problem arose with the work trip information. Although the Census knew the home end of all work trips, since the addresses of the households being interviewed were known, only an average of 65 percent of the work addresses could be coded to blocks and thus to traffic analysis zones.[33] This percentage ranged from 25 to

85 percent.[34] If the work place could not be located at the block level, census coders assigned it to the zip code. If this could not be identified, it was coded to a Universal Area Code (UAC), which identified it by town or county, and if no address at all could be determined, it was coded to a dummy zone 998. The zip code zones, UAC's and dummy zone 998 were included in the home-to-work table in the census package. For Albuquerque, the number of employed persons, after expansion to the full population, in each level of coding is given in Table 1.

TABLE 1

Level of Detail of Coding, 1970 Census
Place of Work Data, Albuquerque

	Number of Persons	Percent
Block level, Traffic Zones	70,914	64.0
Military Base, Zip Codes	12,246	11.1
External Zip and UAC Codes	2,471	2.2
Other Zip Codes	13,570	12.2
UAC	4,239	3.8
No address (998)	7,417	6.7
Total	110,857	100.0

Source: Howell and Davenport, Test of the Standard Package, p.70.

Only 64.0 percent of the trips could be coded directly to a work place. Fortunately, most of the employment at the two military bases was assigned to zip codes. Since each base had its own specific zip code, and each base was represented by a separate traffic analysis zone, it was possible for the local planning agency to assign the 12,246 military base work trips to specific zones. It is likely that similar cases exist in other areas. In large metropolitan areas with many suburbs, UAC's might allow trips to be identified to a particular suburb, and this may be sufficient to assign the trips to a particular traffic analysis zone. Albuquerque, however, has no independent suburbs.

Additionally, the trips to zip codes and UAC's outside the Albuquerque SMSA could be uniquely assigned to external stations. This left a total of 25,226 trips, or 22.7 percent of the total, which could not be assigned directly to a zone of work. During the remainder of this work, the trip table consisting only of the census standard package trips which could be coded directly to analysis zones is referred to as the "incomplete" census work trip table.

Subsequent analysis of these missing trips showed that they were not randomly scattered. It appears that employment at major employment centers is often seriously underestimated, which may result from the respondant not knowing the specific address of his place of work, but giving the address as 'G.E. Plant' or 'Coronado Center' only.[35]

Attempts were made by the local planning agency to complete the trip table by assigning specific zones of work for those missing trips. Two procedures were followed. The first of these completed the trip table using a "gravity model" technique. The idea here was to create a trip table for those trips which could not be directly assigned to a work location. This partial trip table would then be added to the part of the trip table from the Urban Transportation Planning Package which consisted of trips coded to the zonal level, giving a complete home-to-work trip table. The partial trip table is built using the "gravity model," a very common simulation model for which computer software is readily available. The gravity model calculates the number of trips from zone i to zone j as:

$$T_{ij} = \frac{P_i A_j F_{ij}}{\sum_j A_j F_{ij}}$$

where T_{ij} = Trips from zone i to zone j

P_i = Total number of trips produced (originating) in zone i.

A_j = Total number of trips attracted (ending) in zone j (A_j could be alternatively a measure of the relative 'attractiveness' of zone j).

F_{ij} = Friction factor, a measure of the relative accessibility from zone i to zone j. F_{ij} is inversely proportional to travel time between zones i and j in most studies

The P_i are simply the total number of trips for each zone of residence which could not be assigned to a zone of work. The gravity model equation assures that the simulated number of trips produced at each zone is equal to the specified value, P_i. This is a desirable characteristic of the model, since the P_i are in fact known values.

Attractions are calculated incorporating local estimates of employment by zone. For zone j,

$$A_j = L_j - S_j$$
$$\text{if } L_i \geq S_i$$
$$= 0$$
$$\text{if } L_j < S_j$$

where L_j = Local estimate of employment in zone i

S_j = The total number of work trips in the census package which could be assigned to zone i.

A_j then represents the missing employment in zone j, assuming that the local estimate of employment is a good one, and as such is definitionally the appropriate attraction value to go with P_i. Mathematically, it makes no difference that the P_i represent auto-driver trips and the A_j represent person trips. If there is a significant difference in modal split between zones, the A_j could be replaced by $\bar{A}_j$,

$$\bar{A}_j = A_j \frac{a_j}{S_j}$$

where a_j = auto-driver trips to zone j, from codable portion of census trip table.

The friction factors, F_{ij}, could be calibrated from the codable portion of the census trip table, following accepted procedures.[36] In Albuquerque, the previously calibrated friction factors for the work trip model were used when it was found that the trip length frequency distribution of the incomplete census package trip table was nearly identical to that of the 1970 simulated work trip table. This is not a conclusive test, but it is highly suggestive.

The second procedure investigated assigns the missing trips using a mathematical algorithm.[37] Those trips from a given zone which have been coded to a specific zip code or UAC are reassigned on a pro rata basis to all analysis zones contained in that zip code or UAC area. This procedure incorporates all of the data contained in the census package pertaining to place of work. However, it has a few technical problems since zip code area boundaries are seldom congruent with data analysis zones, and it proved more difficult to incorporate locally generated employment information into the procedure.

The trip tables resulting from these two procedures were compared in a series of tests, but the results were inconclusive.[38] The analysis reported here uses the "incomplete" census trip table and the trip table completed by use of the gravity model. There was too little discernable difference between the algorithm trip table and the gravity model trip table to justify the effort of parallel work using both.

Procedures are already being studied for increasing the accuracy of the Urban Transportation Planning Package in the 1980 Census, and it is felt that it has become a regular part of the decennial census.[39] These proposed improvements include measures to assure better coding of major employment centers for which no address is given.

Neither method described above for dealing with the incomplete place of work data includes work trips by those living outside the SMSA and working within it. This information is not included in the 1970 Census Urban Transportation Planning Package, although the question was asked.[40] It has been suggested that this also be included in future years.

A Summary of Previous Work

It is not necessary here to review the work which has been done in studying the journey to work or the models which have been developed to estimate work trip travel. It is sufficient to note that considerable investigation has been done and that estimating procedures for work trips have been more successful than in the remaining areas of urban travel.

However, note can be taken of the work in developing peak period models and in applying the census package work trip table as a data base for urban travel simulation. Although the importance of peak period travel in determining the design of facilities has long been recognized, the development of sophisticated models for forecasting peak travel is relatively new.

The first problem is one of defining the peak period. The general practice in designing facilities has been to look at the highest one-hour directional flow on the proposed facility[41], and this, combined with the fact that one hour is a convenient and readily understood time frame, suggests that the same definition be used for a peak period model. However, the question is not closed. There is some logic in suggesting that the peak period chosen should be that period for which the most accurate model can be constructed. Thus, several definitions are discussed in this analysis.

An extensive study of travel patterns by time of day has been performed by Tittmore, et al. for the Department of Transportation.[42] Data for origin-destination studies conducted between 1961 and 1967 for 8 urban areas was studied in depth. In general, the peak hour of total travel starts between 4:06 and 4:56 P.M.; work trip travel peaks between 7:00 and 8:00 A.M., and non-work travel peaks between 7:00 and 8:00 P.M.

Traditionally, peak hour travel has been estimated by obtaining two-directional average daily traffic (ADT) estimates for the desired location and multiplying this by a ratio, or a factor representing percent of travel in the peak hour (K factor), and percent of peak hour travel in the busiest direction (D factor). Various methods, usually very simple, are used to obtain the appropriate K and D factors.[43] The Penn-Jersey study, however, established a linear relation between K and percent of work trips to ADT by regression analysis.[44] Similarly, D is a linear function of the ratio of work trips by direction. This model can be shown to be very similar to the one proposed herein. The Penn-Jersey basic model is

$$\frac{\text{(Peak hour travel)}}{\text{ADT}} = \underline{a} + b \, \frac{\text{(daily work trips)}}{\text{ADT}}$$

where $\underline{a}$ can be thought of as the percent of ADT occurring in the peak hour but not related to work trips.

Multiplying through by ADT yields

Peak hour travel = $\underline{a}$(ADT) + b(daily work trips)

where $\underline{a}$(ADT) becomes number of trips in the peak hour which are not related to work trips. The second equation holds an important advantage over the first in that, while both require building a daily work trip table and assigning it to the network, the first equation requires also building and assigning a total daily travel trip table.

Two models have been formulated which convert total daily trip tables to peak period trip tables by factoring them. The first of these replicates a two hour peak period from 3:30 to 5:30 P.M. for the Baltimore urban region,[45] the longer peak perhaps a reflection of a higher level of traffic congestion. Each single purpose table is factored to get a single purpose peak period trip table. For instance, daily work trips are factored by a function of family income at home end and employment type at work end. The single purpose peak period trip tables are added together and the resulting total peak period trip table is loaded on the network to obtain peak period traffic flows. Like previous work, this method also requires building an all-purpose trip table.

The second trip table factoring technique is the first procedure specifically designed to utilize the 1970 Census Urban Transportation Planning Package. A daily home-to-work trip table is factored according to trip length and employment at work end to get a peak hour (7:40 to 8:39 A.M.) trip table.[46] This procedure has the advantages of being relatively uncomplicated and eliminating the need for modelling a total trip table. It does, however, require a full origin-destination study to calibrate the model.

Research currently in progress is aimed at investigating several alternative procedures for using the census package in forecasting travel.[47] This work proposes to use 1961 travel survey data to develop the models, and the 1970 Census package and concurrent ground counts to test them. By a set of factors, of daily work trips to peak hour total trips, peak hour trips to total daily trips, and work trip ends in a zone to total zonal trip ends, total daily traffic is estimated. This work should prove interesting in showing whether any change in the relation between work trips and other trips has occurred between 1961 and 1971, and if so, in what direction. The implicit assumption behind the first two methods addressed, namely that the relation between work trips and total trips varies according to the characteristics of the link, is the same as is made here, although the direction of analysis and procedures are quite different.

A different approach was followed by Shunk, Grecco and Anderson in a paper published in 1968,[48] which envisioned data collected by major generator surveys, rather than using the census for replacing the traditional origin-destination travel survey. This study indicated that work trips and peak hour work trips, obtained from a conventional origin-destination survey conducted in 1964 in Indianapolis, yielded an excellent prediction of the total daily traffic. These trips were assigned to a network and compared by regression analysis against total daily travel, with good results. In a comment, Sproules states, "The researchers have presented the statistical tests needed to ascertain that the data now gathered can be substantially reproduced by data collected in a different manner and for a much shorter time period."[49]

This conclusion was applied to use of the Census Urban Transportation Planning Package by Parsonson and Roberts.[50] Although their original work used data from a 1964-65 origin destination study in Columbia, South Carolina to simulate the census package, subsequent work uses the package itself.[51] Primary work trips were assigned to a network by an all-or-nothing, shortest time route procedure. Morning and evening peak hour ground counts were measured, and a linear regression showing peak hour ground counts as a function of assigned primary work trips was performed.

The work reported here is a logical development of this body of previous work. It incorporates those other known characteristics of streets, which have been shown to be significant in studies of the K and D factors, into the basic relation between peak hour traffic and daily primary work trips. It attempts to define the nature and form of that relationship. It seeks to delineate the limits of its applicability as the relation between work trips and peak hour travel changes through time. Although applied here only to the automobile mode, it is felt that the methodology is equally applicable to the public transit mode.

FOOTNOTES

[1]Kate K. Liepmann, The Journey to Work: Its Significance for Industrial and Community Life, (London: Kegan, Paul, Trench and Trubner, 1944); J. Douglass Carroll, Jr., "The Relation of Home to Work Places and the Spatial Pattern of Cities," Social Forces, 30 (March, 1952), Pp.271-282; A concise review of the development of the literature on the work trip is given by Anthony J. Catanese, "Models of Commuting," in New Perspectives in Urban Transportation Research, ed. by Anthony J. Catanese (Lexington, Mass: D.C. Heath and Company. 1972), Pp. 147-208.

[2]U.S., Department of Transportation, Federal Highway Administration, Nationwide Personal Transportation Study, Home to Work Trips and Travel, Report No. 8, Reported by Paul V. Sverel and Ruth H. Asin. (Washington, D.C.: Government Printing Office, August 1973), Pp. 75,76.

[3]U.S., DOT, Home-to-Work Trips and Travel, p.77.

[4]Laurence H. Tittmore, Michael R. Birdsall, Donald M. Hill and Robert H. Hammond, An Analysis of Urban Travel by Time of Day (Washington, D.C.: Government Printing Office, January, 1972) prepared by Peat, Marwick & Mitchell Co. for U.S. Department of Transportation, Federal Highway Administration.

[5]U.S., DOT, Home-to-Work Trips and Travel, P.78.

[6]Ibid., P.78.

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CHAPTER III.

DEVELOPMENT OF THE MODEL

Specification of the Model

Urban travel can be thought of as consisting of two categories: work trips and non work trips. Work trips are highly repetitive, occurring at the same time and over the same route each weekday. They move between clearly definable residential areas and employment centers. Furthermore, they are highly concentrated in time and direction, surging one way in the morning and the opposite direction in the evening. These surges create the peak loads on the transportation network, and are thus critical for design purposes.

Non work trips form an extremely heterogeneous category. With the increasing mobility of urban residents and diffusion of urban activities, non work trips represent a vast mass of trips with irregular directions and lengths, occurring more evenly throughout the day. If there are temporal variations in the number of non work trips on the urban street system, these variations are more like gentle swells than sudden surges. Therefore, during the peak period, travel on the network may be thought of as being a function of work trip travel, expanded by some factor to represent the "background noise" of non work travel. Since the journey to work is more susceptible to successful simulation, this means that a model of peak period traffic can be predicated upon a single purpose work trip model. Such a model would predict travel on a transportation facility (or "link" of the transportation network) as:

$$Y_i = a + b_1 X_{1i} \tag{3-1}$$

where: Y_i = peak period directional traffic on link i.

X_{1i} = directional work trips on link i.

a, b_1 = coefficients determined by regression analysis.

This general form of travel simulation model might be called a "post-assignment" procedure because the expansion to a full universe of trips takes place after the trips are assigned to the network, as distinguished from a "pre-assignment" expansion which factors the cells of a work trip table to get a total trip table.

This model could be estimated, using regression techniques, from the census package primary work trip table, supplemented only (for the auto mode) by peak period traffic count data and a network assignment procedure. For a public transit system, counts of passengers past a certain point would form the data base required for expansion.

For Albuquerque, traffic flow data is available from an ongoing traffic surveillance program which takes 24-hour traffic counts with mechanical recorders activated by a pneumatic tube. In 1970 this was augmented by a screenline study and classification count of all traffic crossing the

Rio Grande and the north-south railroad screenlines.[1] The freeway counts (which averaged 2 days duration) were conducted by the state highway department and gave hourly breakdowns beginning and ending on the hour. A digital recorder on the machines used for the other counts gave a 24-hour total, and the pen-and-ink graphic recorder gave volumes by 15-minute intervals. A total of 32 freeway counts and 193 major street counts were chosen to provide a data base for this analysis.

It has been suggested earlier that the most useful definition of the peak period for purposes of specifying the desired design capacity of proposed improvements is the one hour period of highest traffic flow.[2] Note that the beginning time of the peak hour by this definition will vary from facility to facility. Other definitions of the peak period have also been used in various studies, including a two hour peak period from 3:30 - 5:30 P.M. for a large eastern city, the morning peak hour, and the evening one hour period with the highest number of trips-in-motion according to home interview survey data.[3] It has been suggested that in smaller cities such as Albuquerque, a 15-minute peak period would more adequately reflect the true period of congestion.

Consequently, several definitions of the peak period were chosen for closer examination. It was felt that a significant difference in the ability to replicate counted traffic flow data for varying peak period definitions would be useful in determining the appropriate peak period definition to use for predictive purposes.

Figure 2 shows the distribution of vehicle trips-in-motion on Albuquerque's major street system in 1970. It is obtained by averaging the traffic count frequency distribution by time of day of a sample of traffic ground counts.[4] It shows a sharp peak in the morning hour, mainly occurring between 7:30 and 8:30 A.M. The afternoon peak is wider, occurring roughly between 4:00 and 6:00 P.M., with the highest single hour from 4:30 to 5:30. This provided the basis for picking the following alternative definitions of the peak period, which represent the Y variable in equation 3-1.

1. <u>5:00 - 6:00 P.M.</u> The work day traditionally ends at 5:00 P.M.
2. <u>4:00 - 6:00 P.M.</u>
3. <u>4:30 - 5:30 P.M.</u>, the hour of highest total volume of traffic on the network. The freeway counts are accumulated by hourly instead of 15-minute intervals. Therefore, they are not included in regression runs on this variable.
4. <u>Highest evening hour</u>. This is the sum of the highest four consecutive 15-minute invervals between 4:00 P.M. and 6:00 P.M. for each individual count. The beginning time can and does vary for different locations. For freeways, this is the higher of the hours 4:00 to 5:00 or 5:00 to 6:00 P.M.

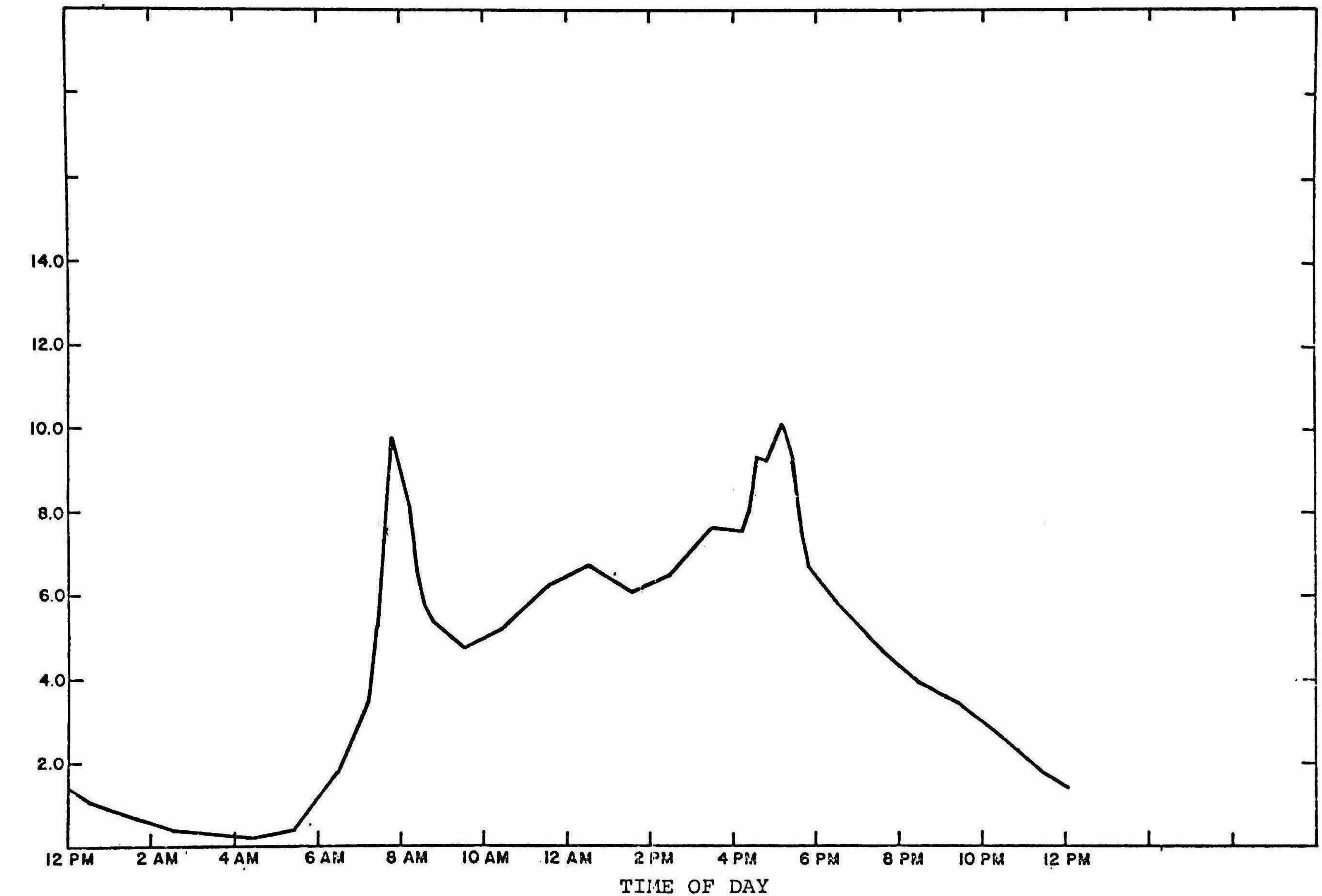


Figure 2. Vehicle Trips in Motion, Albuquerque, 1970

5. Highest 15-minute interval, evening. This is the highest 15-minute interval between 4:00 and 6:00 P.M. Freeways are not included in this analysis.

6. 7:00 to 8:00 A.M. The workday traditionally begins at 8:00 A.M.

7. 7:30 to 8:30 A.M.

8. Highest 15-minute interval, morning.

In addition to these, the relation between work trips and average daily traffic (ADT) also was observed. The average value of each of these variable for the 193 major street and 32 freeway directional ground counts is given below in Table 2.

TABLE 2

MEAN VALUE OF TRAFFIC COUNTS FOR DIFFERENT DEFINITIONS OF PEAK PERIOD

	Time	Major Streets	Freeways
5:00 - 6:00 P.M.	1 hr.	522	1,483
4:00 - 6:00 P.M.	2 hrs.	1,014	3,000
4:30 - 5:30 P.M.	1 hr.	558	--
High hr., evening	1 hr.	588	1,578
High 15 min., evening	$\frac{1}{4}$ hr.	172	--
7:00 - 8:00 A.M.	1 hr.	292	1,504
7:30 - 8:30 A.M.	1 hr.	407	--
High 15 min., morning	$\frac{1}{4}$ hr.	138	--
ADT	24 hrs.	5,389	16,993
Number of Counts		193	32

This tends to generally confirm the distribution shown in Figure 2. It is interesting to note that the mean value for high evening hour, 588, is five percent above the mean value for 4:30 - 5:30 P.M. It is also notable that the evening counts are substantially above the morning counts in all comparable cases, including highest 15-minute peak. Apparently, a greater number of non-work purpose trips are on the network during the evening. Therefore, an evening peak period model would be more useful for evaluation of the capacity requirements of planned facilities.

The work trip variables used in the model are described in Chapter 2*. Several other pieces of information, in addition to assigned work trips, are known about individual segments, or links in the street network, and can be predicted for future years. Incorporation of this knowledge into the model may improve its estimating capability. Thus, equation 3-1 is expanded to:

$$Y_i = a + b_1X_{1i} + b_2X_{2i} + \ldots + b_nX_{ni} \qquad (3\text{-}2)$$

where $X_{2i} \ldots X_{ni}$ = additional independent variables pertaining to link i.

Using this form of the model, these variables may be thought of as accounting for non work trips on the link.

Among the additional independent variables to consider are the functional classification of the street (Freeway, Arterial or Collector), and orientation of the street (radial or circumferential). These variables were found by Tittemore, <u>et al.</u> to be significant in determining K and D factors.[5] It may be that these factors are also significant

*Pages 21-25

in estimating peak hour traffic directly, given that primary work trip journeys are known.

By definition, arterial routes offer continuous, through routes, while collectors are feeder routes which may be blocked by natural or man made barriers, or end at intersections with arterials.[6] This fact alone would cause more non work purpose trips to be attracted to arterials than to collectors. Land use patterns have tended to locate those activities which generate the most non work trips, retail districts, professional and personal services establishments, and public buildings, along arterials, while collector streets serve residential areas which are heavy attracters of evening journeys from work to home.

As Figure 3 shows, the trips-in-motion study presents a sharper evening peak for collector streets than for arterials in Albuquerque. This implies a greater percentage of work trips, which are peak hour oriented, on collector streets and a greater percentage of non work trips, which are not peak hour oriented, on arterials.

Freeways have controlled access and high speeds. Thus, the average length of a trip on the freeway is longer than on other streets. Since work trips are longer than other trips, it follows that a greater percentage of freeway trips are work trips.

Routes leading directly out from major employment centers should carry a greater percentage of home-to-work traffic than those routes running at right angles. On the other

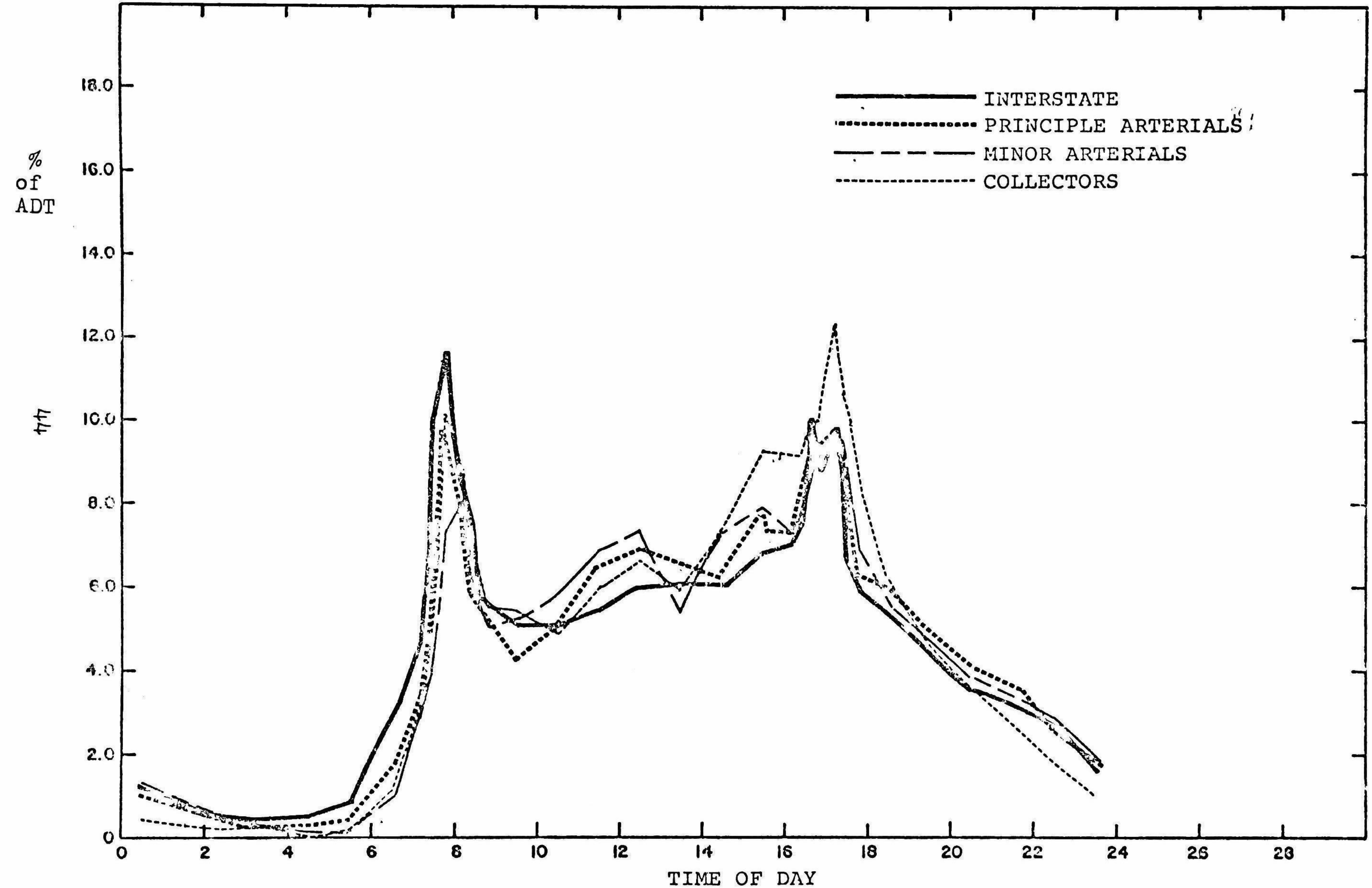
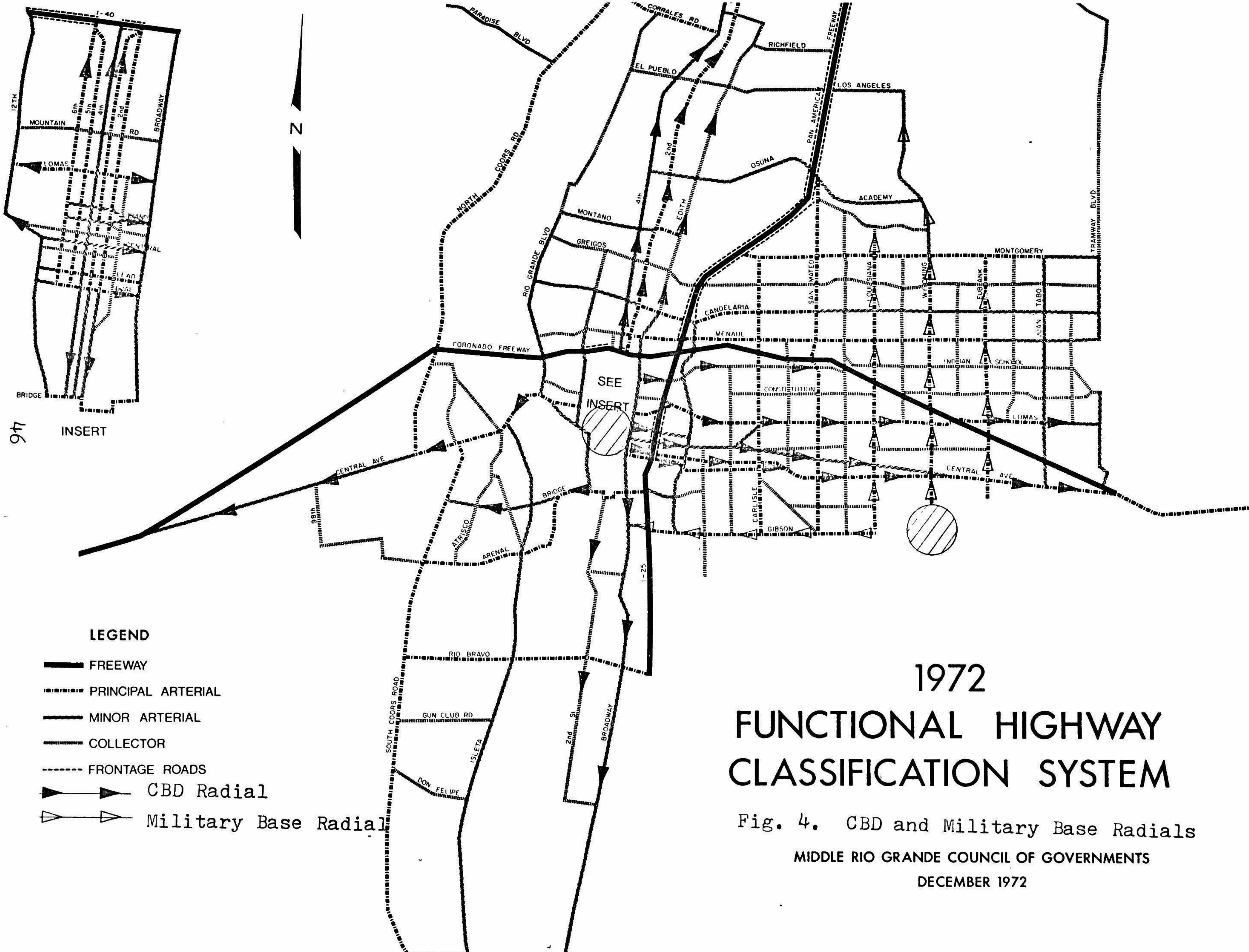


Figure 3. Vehicle Trips in Motion for Four Functional Classifications, Albuquerque, New Mexico 1970

hand, the arguments which apply to arterials apply even more so to these radial routes. Thus, radial routes may tend to attract more non work trips. There are two major employment centers in Albuquerque: the Central Business District and the military base complex. Therefore, there are two independent sects of radial routes, as shown in Figure 4. By coincidence, no route is both a radial to the CBD and to the military base complex.

The basic hypothesis concerning these variables, which are represented in the regression analysis as a set of dummy variables, is that they describe the relation of the link to other links in the system. Those links which are defined by these variables as lying on the "best" routes should have more trips. Although it is assumed to be meaningful, there is a degree of arbitrariness in deciding a route's functional classification, despite set guidelines from the U.S. Department of Transportation.[7] However, once determined, a route does not readily change its classification, and actions by the traffic engineer in street improvements and by zoning boards and land owners in land use tend to reinforce the designation.

The predominant direction of work trips on a link is another variable which can be determined for a future year network based upon a prediction of primary work trip flows. As Figure 5 shows, although a typical street section may show a total traffic flow distribution that approximates the total trips-in-motion distribution for the city, directional



1972 FUNCTIONAL HIGHWAY CLASSIFICATION SYSTEM

Fig. 4. CBD and Military Base Radials

MIDDLE RIO GRANDE COUNCIL OF GOVERNMENTS

DECEMBER 1972

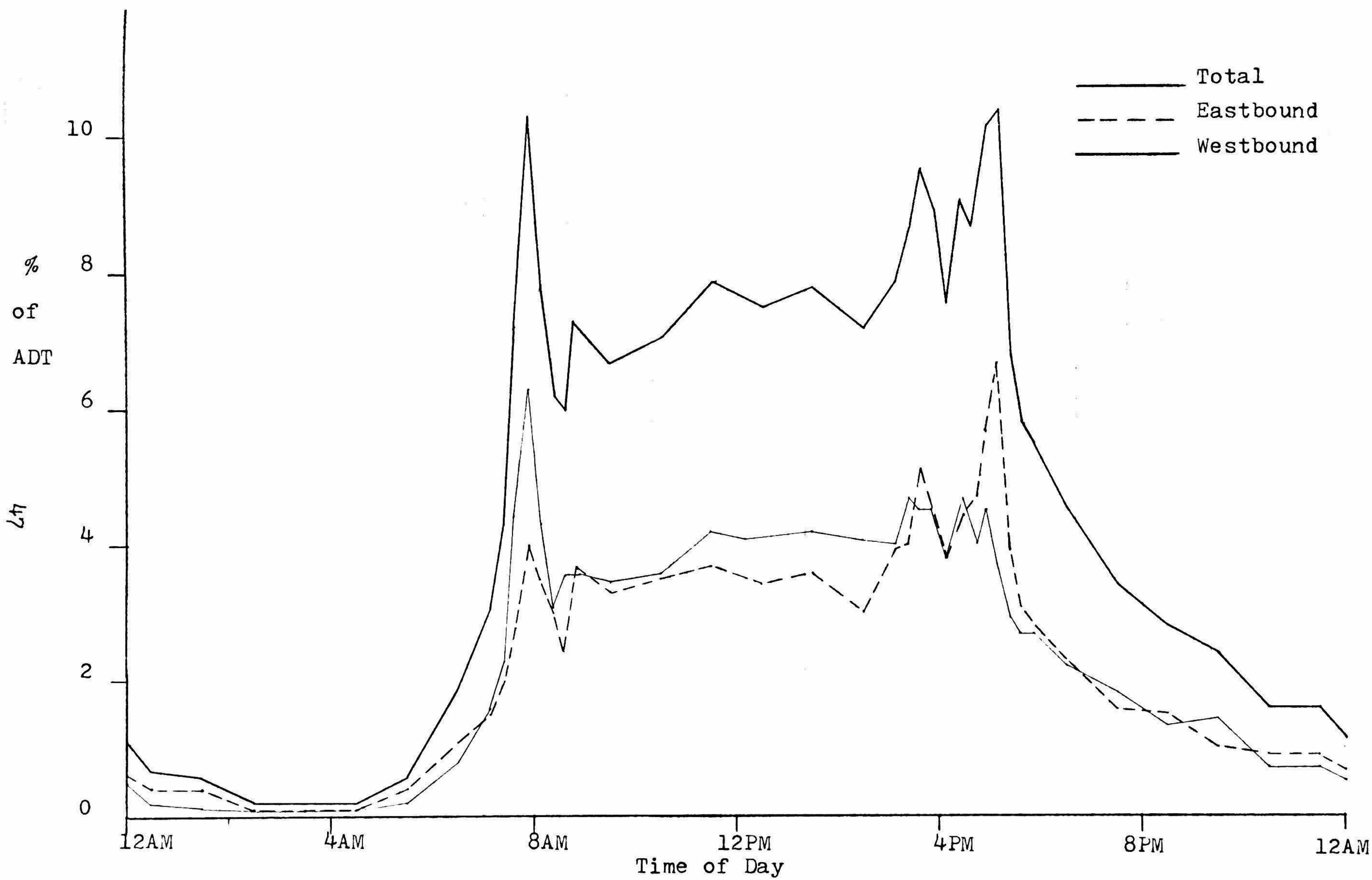


Figure 5. Daily Distribution of traffic by direction and total, Lomas Blvd. at Santa Fe RR Crossing

flows show a much different pattern. The evening peak in one direction is much higher than in the opposite direction, apparently because of the heavy and imbalanced flow of work trips. Wickstrom found that this peak hour directional imbalance could indeed be explained by the imbalance in work trip movement when he showed that the peak hour directional split (D factor) was a function of the ratio of work trips by direction.[8] To the extent that non work trips can more easily choose the time and direction of their travel, they can take advantage of this imbalanced flow to favor routes in the other direction. It is hypothesized that non work trips favor the opposite direction from the main flow of work trips.

Distance from the center of the city is another variable which may effect the relation between work and non work trips, following an observation by Mann that in the built up areas where congestion is highest, the ratio of work to non work trips in the peak hour is higher.[9] However, because Albuquerque is predominantly a low density city with a comparatively low density city center, it is not expected that this variable will have a great amount of significance.

Distance from the city center should affect freeway links in a different manner. Freeway traffic includes a greater number of trips from or to places external to the Albuquerque metropolitan area. The percentage of these trips increases as distance from the center increases. Thus, distance becomes a significant variable in the model, and the expected reliability of the model for freeways should decrease as distance increases.

Another variable for consideration is the kind of development taking access off the street. If the predominant abutting land use has a high attraction to non work trips, then a smaller percentage of the peak period trips will be work trips. The predominant abutting land use was determined from a 1970 land use map which in turn was prepared from zoning maps, aerial photos and field trips. It is represented by a series of dummy variables for insertion in the regression analysis. Here also there is a certain arbitrariness in assigning a land use category to the land adjacent to a street. If two or more land uses appeared equally frequently along a street, the category likely to produce the greater number of trips was said to be predominant. More refined definitions of the variables than the ones used here are, of course, possible. However, more detailed definitions may only increase the arbitrariness of the variable while making prediction more difficult. Since future traffic forecasts are usually based upon some estimate of future land use, it should not prove difficult to include this variable in a predictive model. The variables associated with predominant abutting land use may be thought of as representing traffic generated directly by the street in providing access to urban activities along it .

Since freeways do not directly provide access to land, these variables are inappropriate for estimating freeway traffic. The same holds true if the model is developed for transit lines, other than bus lines.

One additional characteristic of the street is subject to quantification and can be forecast: the street's capacity. As the capacity of the street increases, its ability to handle large volumes of traffic increases, and consequently, larger numbers of trips are attracted to it.

The volume of trips on a link, the capacity of the link, and the speed on the link are interrelated. In general, the greater a street's capacity, the higher its average operating speed. The higher the operating speed, the more trips are attracted to and use the link.

In the network assignment portion of the travel estimation process, a capacity restraint procedure is a submodel which adjusts a street's speed to reflect the level of congestion it is experiencing. If a capacity restraint procedure is used in network assignment, then the capacity of a street segment will directly influence the operating speed, and thus the number of work trips assigned to the link are a function of link capacity. and the capacity of the street alone may not be a significant variable. The relation between capacity and work trips assigned to the link determines the amount of congestion due to work travel. Since non-work trips can more easily substitute alternate destinations or travel times, they may be proportional to the excess peak period capacity of the street.

This variable, X_{ci}, may take the form

$$X_{ci} = C_i - pX_{1i}$$

where C_i = peak period capacity of link i

X_{1i} = work trips assigned to link i

p = proportion of work trips occurring in peak period.

This implies that as capacity increases, so does non work travel. Since p is unknown, only link capacity can be included in the model.

In the analysis presented here, capacity restraint was not used. Therefore, capacity was entered directly into the model. The presence of this variable can to some degree compensate for not using capacity restraint in the assignment process.

Capacity figures used in this analysis are hourly capacity figures obtained from an in-house publication which presents a simplified method to estimate capacities and is based in turn on the Highway Capacity Manual.[10] This procedure incorporates location in the city (CBD, non-CBD, rural), spacing and timing of signals, number of lanes and whether the street is divided and channelized, undivided or one-way, in estimating the capacity. Therefore, these other variables need not be considered explicitly in the model. Likewise, characteristics such as lane width, pavement type, and signalization, which also affect capacity, need not be explicitly considered.

The inclusion of capacity as an exogenous variable in the travel estimating process creates some conceptual problems. This results because usually it is assumed that capacity is an endogenous variable, because the planned capacity of the street or transit facility is determined by the estimated future travel on it. And certainly the form of the model is suspicious if total urban travel can be increased simply by increasing the capacity of the transportation network. Nevertheless, this is precisely the phenomenon that has been observed. As Melvin Webber has noted, "Traffic expands to fill the space available to it."[11] The traffic generating aspects of increases in capacity are well recognized. Inclusion of capacity as a variable in the traffic estimating process only recognizes this fact explicitly.

In fact, inclusion of capacity in a formula to estimate traffic flows is a very convenient formulation of the model. The effects on traffic of an increase in capacity of the facility, perhaps by widening or by limiting access to it, could be estimated simply by inserting the new capacity figure into the formula. This would eliminate the need, using current models, to rebuild the trip table and reassign the trips to the network in order to account for the change in accessibility caused by a change in capacity. Such a simplification is probably invalid and is not proposed here. However, it does point out that capacity is a desirable inclusion in the travel estimating procedure. Street capacity thus joins the previously mentioned link characteristics as exogenous variables in the travel estimating process presented here.

Inclusion of these link-specific variables in the model results in a model of the form specified in equation 3-2:

$$Y_i = a + b_1X_{1i} + b_2X_{2i} + \ldots + b_nX_{ni}$$

where Y_i = peak period traffic on link i

X_{1i} = work trips assigned to link i

$X_{2i} \ldots X_{ni}$ = other variables for link i.

This form of the model implies an independence between the number of assigned work trips and the other variables in the equation. The amount of non work related travel, $b_2X_{2i} + \ldots + b_nX_{ni}$, is independent of the amount of work related travel, b_1X_{1i}. This is a questionable assumption. Therefore, the log-linear form of the model is proposed for examination.

$$Y_i = aX_{1i}^{b_1}X_{2i}^{b_2} \ldots X_{ni}^{b_n} \qquad (3\text{-}3)$$

In this formulation the variables are multiplicative. A doubling of the contribution of one of the variables of the model for instance $X_{ki}^{b_k}$, results in a doubling of Y_i.

Another possible form for the model is given below.

$$Y_i = FX_{1i} \qquad (3\text{-}4)$$

where F = a factor to convert daily work trips to peak period traffic.

The simplest version of this model is

$$Z_i = F_1X_{1i} \qquad (3\text{-}5)$$

where Z_i = total daily travel on link i

F_1 = ratio of total daily VMT over total work trip VMT

Total daily traffic, Z_i, can be converted to peak period traffic, Y_i, by the application of the appropriate peak hour factors, or K factors. This method tests in a preliminary way the relation between work trips and total trips. It also is used as a benchmark to see how much additional explanatory power is added by more sophisticated versions of the model.

The link-specific variables can be included in this formulation of the model as well. In this case, F becomes a function of these other variables. Thus

$$Y_i = (a + b_2X_{2i} + \ldots + b_nX_{ni})X_{1i}, \tag{3-6}$$

or alternatively,

$$Y_i = (aX_{2i}^{b_2}\, X_{3i}^{b_3} \ldots X_{ni}^{b_n})X_{1i}. \tag{3-7}$$

These equations imply that the conversion factor from daily work trips to peak period total trips is a function of the other characteristics of the link, such as functional class, orientation, predominant abutting land use, and capacity. These forms of the model also are included in the analysis.

In the model presented here, the conversion from daily work trips to total peak hour travel occurs after the trips have been assigned to the network. As has been done in other studies this conversion could have occurred before the assignment process by converting the cells of the trip matrix from daily work trips to peak hour trips. No definitive comparison of the two procedures is made here. However, the post-assignment model appears to have certain advantages.

The primary advantage of the post-assignment model is that it does not require a currently applicable origin-destination survey in order to calibrate it. The model requires only a home-to-work trip table, and since such a trip table is available from the Census Urban Transportation Planning Package, the model can be updated after each census.

Secondly, the post-assignment model concentrates directly on the item of interest, the traffic on the individual link of the system, and can incorporate link-specific characteristics which effect link traffic. This allows the post-assignment model to offer some compensation for systematic errors in the assignment process or other earlier steps in the estimating process.

For instance, in Albuquerque it has been observed that the assignment model systematically overestimates traffic on the freeway system, and it can be presumed that it will overestimate future traffic. There is some reason to believe that this effect is not limited to Albuquerque. A study by Humphrey of traffic assignments compared with traffic counts showed that the standard deviation between assignment and traffic count, expressed as a percent of traffic count, showed a general decrease as traffic volume increased. However, at the very highest volumes, six of the ten cities studied showed an increase in percent standard deviation, revealing an increase in errors at the very high volumes.[12] If this increase is a systematic overloading, as in Albuquerque, the post-assignment model could offer some compensation by lowering the coefficients on the model for freeways. Other variables function similarly. Capacity of the street as a variable can reflect some of the effects of the interrelation of speed and congestion on travel volumes. Variables such as abutting land use reflect the traffic generated specifically by the access to urban activities provided by the street segment.

On the other hand, the pre-assignment model has the advantage of incorporating characteristics of zone of origin, characteristics of zone of destination, and the estimate of the total travel impedance along the shortest route from origin to destination into the procedure for converting work trip movements to total peak trip movements. These characteristics are traditionally considered the determining variables for urban travel.

A Procedure for Evaluating the Model

To enhance confidence in forecasting, simulation models should be able to replicate flows, whether vehicles, persons or freight movements, upon particular network links. Usually, there exists data at the time of model development which describes these flows. This may be in the form of counts of passengers past a certain point on a bus route, through a certain station on a subway, or, as in this model and many automobile oriented urban transportation studies, vehicle ground counts on city streets and expressways. A procedure is sought to evaluate how well a model is replicating this data.

Of course, the ability of a model to replicate base-year network flows does not imply that the model can replicate future year flows. In order to do that the model must also be sensitive to changes in the urban environment, and capable of correctly interpreting the effect of these changes on urban travel patterns. Replicating the base year flow data is a necessary but not sufficient condition for a model to forecast future travel. It is reasonable to state that a model can predict future flows no better than it replicates the present; how much worse depends upon the degree to which urban changes occur that are not incorporated into the model.

The procedure for testing the model currently under consideration against ground counts should fulfill several criteria: 1) It should be statistically meaningful; 2) It should be capable of differentiating between alternative model formulations and accurately discovering the one closest to ground count data, and 3) It should present relevant information in an understandable form to non-technical decision-makers. This last criterion seems to have been consistently overlooked or minimized. Decision-makers, as the users of the output of the planning process, need to know the amount of confidence they can place in its results, yet they seldom have a technical background. When a transportation proposal involves controversy or trade-offs of benefits and harms, knowledge of the accuracy of information obtained from transporation models is vital. If a decision-maker cannot determine the amount of confidence that can be placed in these models, he is hard put to justify confidence in the entire transportation planning process.

There is a small number of frequently used procedures for evaluating models against ground counts which are used in most studies. The Federal Highway Administration recommends procedures for checking synthesized link loadings against actual ground counts.[13] They are:

1. Compare vehicle-miles of travel (VMT) computed from the synthetic loadings with VMT calculated from ground counts. These comparisons are stratified by functional classification and area.

2. Compare total synthetic flows versus counted volumes across major screenlines which cut across the entire urban region.

3. Compare total synthetic flow versus counted volumes across auxiliary cutlines, across major corridors and around major traffic generators.

4. Calculate root mean square errors between a set of synthetic values and the corresponding ground counts. This is done: a) for various volume groups; b) across various auxiliary cutlines; c) along major streets through the study area.

5. Physical observation of a network map with synthetic estimates and ground counts listed together. Often, as was done in Albuquerque, this information is presented as the ratio of the synthetic estimate to ground count for each link.

Another procedure which has been used to evaluate synthetic assignments in comparison with ground counts is the Chi-Square Test.[14] In an evaluation of the accuracy of the capacity restraint algorithms using data from ten urban areas, Humphrey added a comparison of total counted volume on all links and total assigned volume on all links.[15] He did not claim that this was a particularly discriminating test.

Many of the original transportation studies performed in the 1960's and late 1950's made few, if any, of these checks, assuming that the models reproduced base year traffic reasonably well.[16]

Design Level Estimation

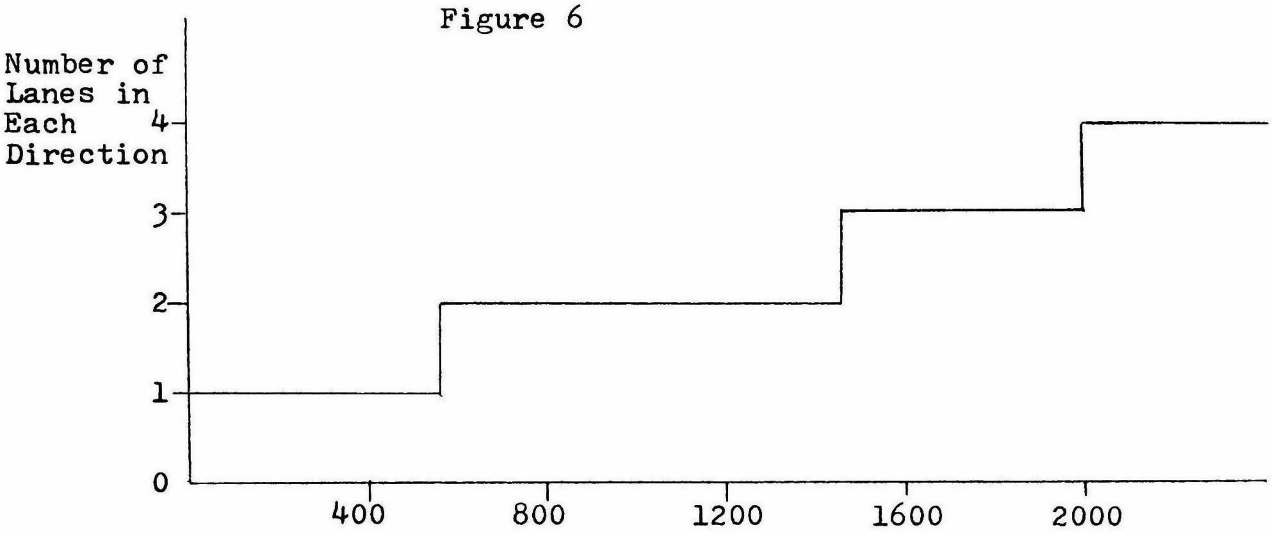
A different evaluatory scheme is proposed here, based upon the observation that the relationship between the level of investment, or design level, of a transportation link and the capacity of that link is in general a stair stepped function. For a given level of service, say an average speed of at least 20 mph, the relation between capacity and design configuration for an urban arterial is given by Figure 6. The design level, or level of investment, is here represented by number of lanes, since construction costs and right-of-way width are determined primarily by this parameter. For urban transportation systems, determination of right-of-way width may be the most important output of the planning process, since acquiring or reserving of the needed right-of-way is the first, most critical step in implementing proposed transportation projects. If a public transit link were under consideration, the design level concept would again be valid, but now the levels might be regular bus service, bus service on exclusive bus lanes, fixed rail line, and 3 or 4 track fixed rail line.

Within the same level of design, improvements can be made to increase the facility's capacity. For instance, improved signalization, channelization, changing striping, resurfacing the pavement or closing off access to local streets will increase the capacity of a street. Likewise, adding additional vehicles will increase the capacity of a transit route. Thus, the stairs of the stairstepped function are actually sloping. However, implementation of those improvements can wait until construction of the facility, or until after the facility is built and is approaching capacity. Specification of the design level of the facility must come as far in advance of construction as possible. Thus, the planner must concentrate on the stairsteps in the capacity function.

Of course the capacity of an urban arterial can be increased by allowing increased congestion and lowered speed without a change in the design level. Figure 7 shows the relation between level of investment and capacity for several levels of service.

For planning purposes it may be preferable to present the information in Figure 7 for a proposed link and, given an expected future year traffic flow, allow the decision-

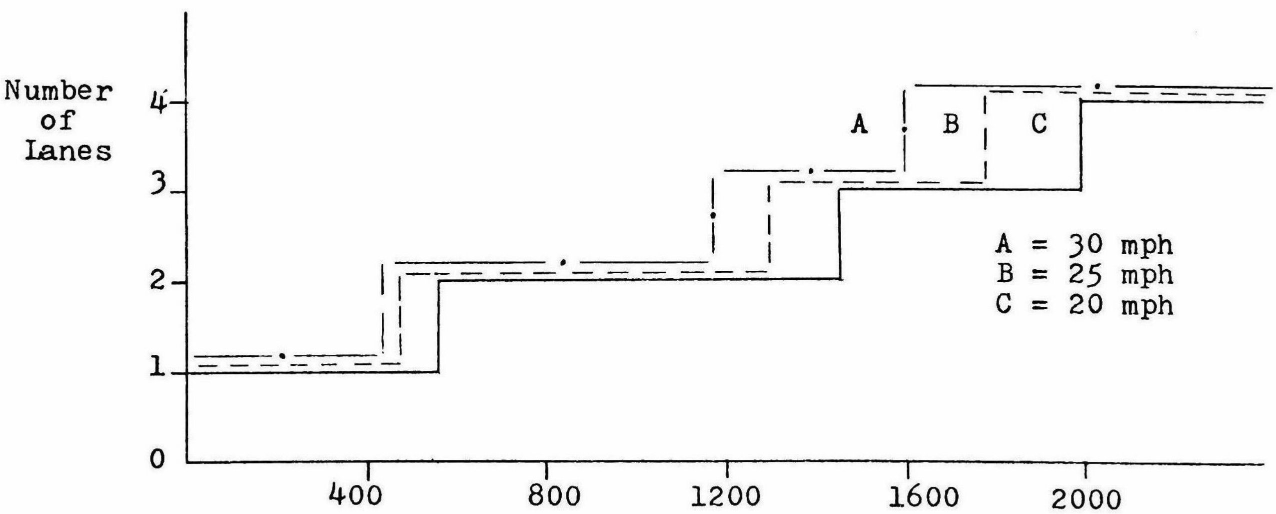
Figure 6



Specified Design Level for Urban Arterials

1-Directional Hourly Flow

Figure 7



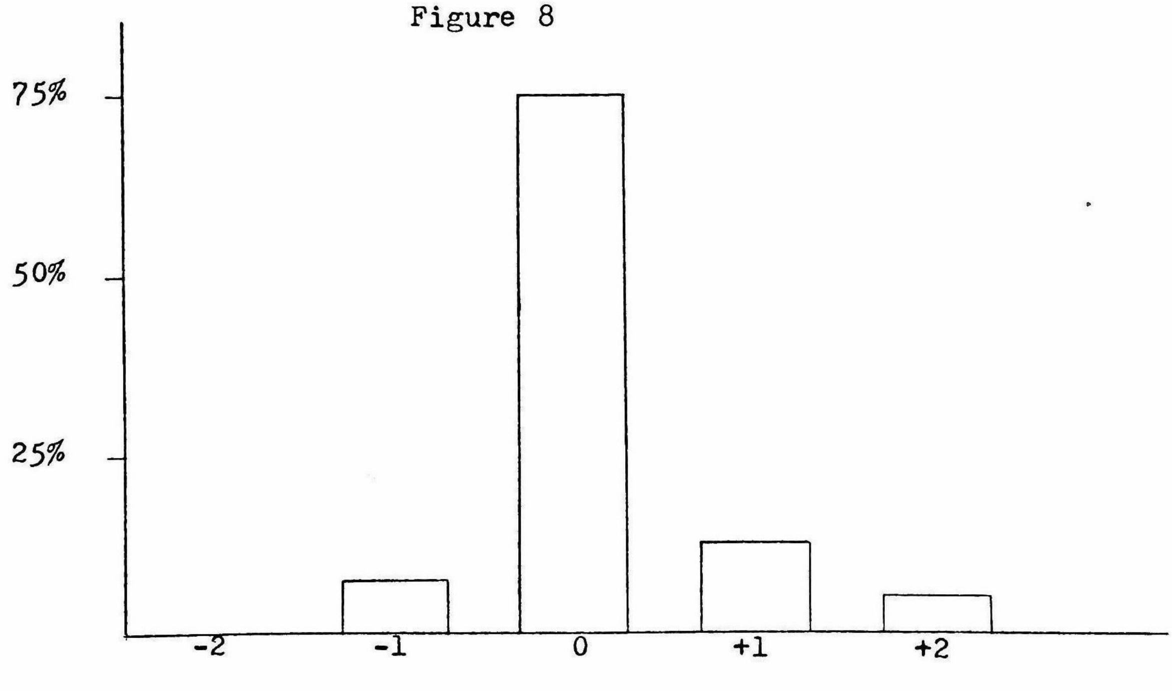
1-Directional Hourly Flow, Residential Area, Urban Arterial

Design Level Requirements for Varying Operating Speeds makers to make the trade-off between level of investment and level of service. However, most transportation simulation models for trip distribution, modal split and traffic assignment, and some for trip generation, imply an initial given level of service for each link. Therefore, Figure 6 is a meaningful motif, at least in the intermediary stages of model development, if not in the final decision making process.

Once the single stepwise structure of Figure 6 is established, a given traffic forecast and service level dictate a certain design level. For example, using Figure 6, a one-way peak hourly flow of 700 requires a 4-lane arterial if a 20 mph average speed is to be maintained. Due to the stepwise nature of the relationship, an estimate of traffic can be in error by a sizeable margin and still specify the same design level. If this is the case, then accepting the estimated value would not lead to an error in analysis, since for many purposes the link level of investment is the crucial output of the planning process. However, if the traffic estimate specifies a different level of investment, then reliance upon the estimate would result in a serious error. If the traffic estimation method is applied to a past or present year, both traffic estimates and reliable ground counts are available for a set of links. Comparison of the two will show for what percentage of the links the model specified the correct level of investment, and how often the model was in error. Figure 8 is an example of a bar graph of the results which might occur from this procedure. This presents a summary of the accuracy of the model in a manner understandable and usable by decision-makers or the general public. It tells a decisionmaker, ceteris paribus, the amount of confidence he can place in the output of the traffic estimation model. Or what is the same thing, it specifies the risk of making an error if he accepts as true the simulation model estimate.

Of course, prediction introduces other problems, and this statement is true only if the form of the model remains as valid for the year of the prediction as it is now. For prediction purposes, this procedure specifies the minimum risk of making an error by accepting as true the model estimate: Unforeseen or unaccounted changes in the urban picture may disrupt the model and thus increase the chances of error.

Figure 8



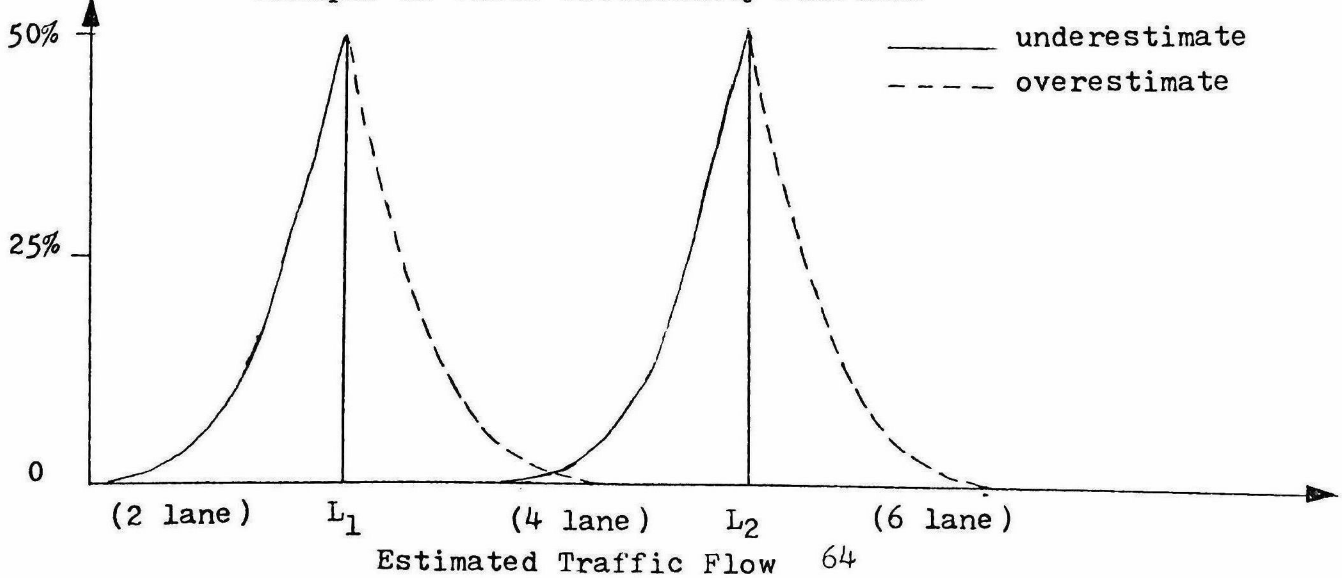
Model Error in Number of Lanes Each Direction

Further information can be obtained by making use of the standard deviation of the calculated link flows around the measured link flows. If the calculated value of the link flow is L, and M is the cutoff point, or breakpoint, in the stairstep function between the design level specified by L and the next higher, then the probability of underestimating the design level is the probability that the true value of L is on the other side of M. Given that the calculated link flows are normally distributed around the actual link flow, with a standard deviation of s, then this probability can be found. It is simply the cumulative frequency distribution of the normal curve from z to infinity, where $z = \frac{M - L}{s}$. This is easily obtained using a tabulation of the normal distribution.

The probability of error is a function of the estimated traffic flow. Therefore, a graph such as Figure 9 can be constructed, showing the probability of underestimating or overestimating design level for any estimated traffic flow.

Figure 9

Example of Error Probability Function



Of course, these statements on the probability of making an error are subject to the same limitations as were discussed above.

This procedure is similar to one used by Creighton, Hamburg Planning Consultants.[17] In their work, however, the estimated design hour volume was classified as being either highly sensitive to traffic error if it were near one of the stepping points on the stairstep function, or in a low sensitivity zone if it were in the middle of a step.

The assumption in the preceding discussion that the error in calculated link flows from the actual link traffic flows is normally distributed can be tested. The residuals about one of the more useful equations presented in the next chapter were calculated for 193 major street locations. A histogram of the frequency distribution of the residuals, expressed in intervals of one-half standard deviation, was prepared and is presented in Appendix C. Comparison of this with the histogram expected of a normal distribution showed the curves to be similar in shape. A Chi-Square test for goodness of fit was performed and showed that the hypothesis that the residuals are normally distributed cannot be rejected at the 2.5 percent level, although it can at the 5 percent level.[18] Since the lack of fit which does occur seems to be related to the presence of several outliers on the lower end, which are up to five and one-half standard deviations low, the assumption of normality appears to be justified.

In the above discussion, the ground count is taken to be the true value of traffic on a link. Most ground counts are of 24-hour duration. There is, of course, some variation in ground counts, and reliance upon a single day's count introduces a certain residue of error. Can this error be measured?

In Albuquerque there are two continuous traffic count recorder stations, one on the Interstate near the CBD and the other on a major street several miles from the city's center. These stations give hourly and daily traffic counts for each day of the year.

Total daily and 5:00 to 6:00 P.M. hourly traffic data was obtained for non-holiday weekdays. Table 3 shows the calculated means and standard deviations.

Table 3

Standard Deviation of Traffic Counts

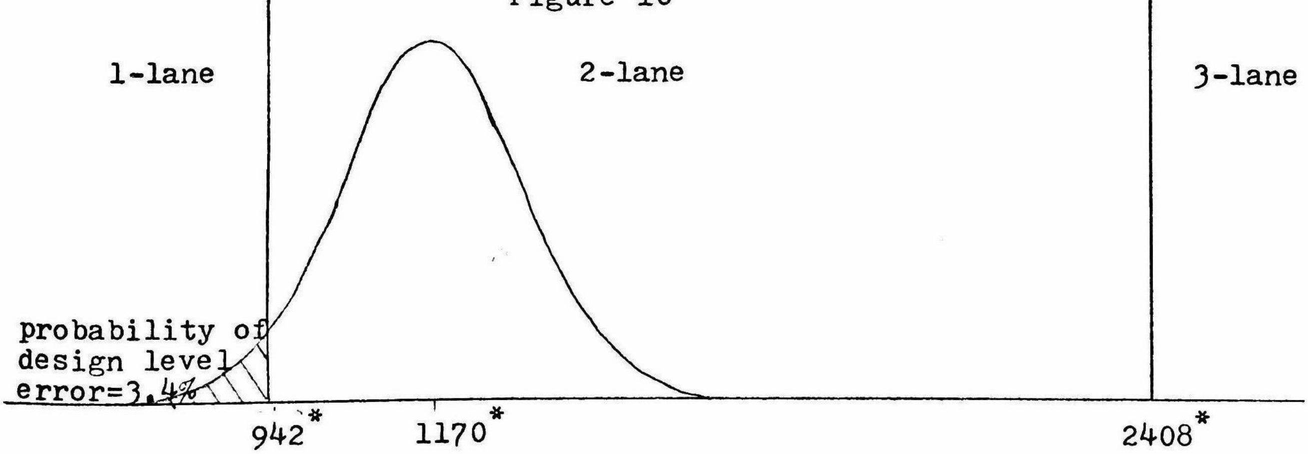
	Total Daily Traffic		5 to 6 PM Hourly Traffic	
Location	Mean	Standard Deviation	Mean	Standard Deviation
N. 4th Street, both directions	13,171	1,402	1,170	125
I-25, Northbound	56,523	3,507	3,092	201

n = 253

Traffic on a link, whether estimated by a model or actually measured, is the sum of a very large number of zone-to-zone traffic movements. The Central Limit Theorem therefore implies that ground counts and estimates should tend to be normally distributed.

Using this information, the distribution of single day ground counts around the mean is shown in Figure 10 for N. 4th Street. From this we calculate that a single day ground count will yield the mistaken design level of one lane each direction 3.4% of the time. The chance of error on the high side is negligible.

Figure 10



2-Directional Ground Counts, Assuming 60-40 Directional Split

Distribution of Single-Day Ground Counts - N. 4th

If the assumption is made that the standard deviation of 125 applies to all urban arterial links in the volume range 942 to 2408, then the probability of design-level error in a single day count can be shown as a function of mean ground count value. The probability of underestimating the design level, given mean ground count = M, is the cumulative frequency distribution of the normal curve from z to infinity, where $z = \frac{M - 942}{125}$. If the further assumption is made that the mean ground count for urban arterial links is evenly distributed in the range between 942 and 2408, then the average probability of an error can be determined as the area under the error curve divided by the distance between 942 and 2408 measured in standard deviations. For urban arterials, this is an average of 3.4% probability of making an error on the low side, and an equal probability of making an error on the high side.

A corresponding analysis can be made for freeways. Using the calculated standard deviation of 201 gives an average probability of 6.0% that a single day ground count will specify a level of investment lower than the mean ground count, and an equal probability of an error on the high side.

This analysis is based upon rather sketchy available information, which makes more detailed analysis inappropriate. The results may not hold for different links, and they are sure to vary with different ranges of ground count values. Nevertheless, the results do indicate the general size of the chances of error in design level estimation introduced by variation in the ground count data. Simulation models cannot be expected to be any more accurate in comparison with single day ground count data than that data is in comparison with mean ground counts. Therefore, the results of this analysis are presented in Table 4 below as a base for comparing the simulation model.

Table 4

Probability of Error in Design Level

	-2	-1	0	1	2
Urban Arterials and Collectors	.00	.03	.94	.03	.00
Urban Freeways	.00	.06	.88	.06	.00

FOOTNOTES

[1]James P. Milton, 1970 Screenline Study in the Greater Albuquerque Area, Technical Memorandum No. 35, Middle Rio Grande Council of Governments, Albuquerque, New Mexico, March, 1971 (mimeographed).

[2]Above, Pp.25,26.

[3]Ockert,et.al.,"Analysis of Travel Peaking," two hour peak period from 3:30 P.M. to 5:30 P.M. for Baltimore; Mann, "Estimating Peak Hour Automobile Travel," p.3, morning peak hour from 7:10 A.M. to 8:09 A.M. for Washington, D.C.; Shunk et.al., "The Journey to Work," P.3, 4:24 P.M. to 5:24 P.M. for Indianapolis, Indiana.

[4]A total of 30 24-hour counts were used to obtain the trips-in-motion distribution. These were in pairs of two, with one count in each direction at each of 15 locations spread throughout the city. There were 4 collector streets, 4 minor arterials, 5 prinicpal arterials, and 2 freeways. Traffic counts by the hour and by 15-minute intervals between 6 and 8 A.M. and 4 and 6 P.M. were added together within each functional classification and weighted according to percent of total VMT in each classification to obtain a total trips-in-motion survey. This was checked against another set of 1971 counts to verify the peak period distributions. VMT was obtained from the 1970 Traffic Flow Map for the Greater Albuquerque Area.

[5]Tittmore, et.al., Travel by Time of Day, Pp. 64-66.

[6]U.S., Department of Transportation, Federal Highway Administration, 1968 Functional Classification Study Manual, (Washington, D.C.: Government Printing Office) April, 1969.

[7]Ibid.

[8]Wickstrom, "Daily Work Travel and Peak Hour Travel." The regression of work trips by direction against D factor observed from ground counts for 10 locations showed an $r = 0.72$. Obviously, other factors are effecting the relationship as well.

[9]Mann, "Estimating Peak Hour Automobile Travel," P.2.

[10]John T. Price and Larry K. O'Dell, Functional Arterial Capacities for Testing Systems, Technical Memorandum 13, Albuquerque Metropolitan Transportation Planning Program, July, 1969. (Mimeographed). Based on, Highway Research Board, Highway Capacity Manual.

[11]Melvin M. Webber, "On Strategies for Transport Planning," in The Urban Transportation Planning Process, (Paris: Publications de L'O.C.D.E., 1971). P. 140.

[12]Thomas F. Humphrey, "A Report on the Accuracy of Traffic Assignment When Using Capacity Restraint," Highway Research Record No. 191., Pp. 53-75.

[13]U.S., Department of Transportation, Federal Highway Administration, Updating of Traffic Forecasting Procedures as Part of Continuing Planning in Urban Areas, Highway Planning Technical Report Number 26, (July, 1971), P.7.

[14]Matthew J. Huber, B.B. Harvey and D.K. Witheford, Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use, National Cooperative Highway Research Program Report No. 58, Highway Research Board, 1968, P.30; Fred N. Starasinic & James J. Schuster, "Comparative Analysis of Capacity Restraint Traffic Assignments," Traffic Engineering, March, 1972, Pp.48-58.

[15]Thomas F. Humphrey, "A Report on the Accuracy of Traffic Assignment When Using Capacity Restraint," Pp.53-75.

[16]U.S., D.O.T., FHWA, Updating of Traffic Forecasting Procedures.

[17]Creighton, Hamburg Planning Consultants, Data Requirements for Metropolitan Transportation Planning, National Cooperative Highway Research Program Report 120, Highway Research Board, 1971.

[18]The equation used was a linear form of the model for major streets, HI HR = 73.35 + .24WKT + .17CAP + 102.43R + 81.56ART + 31.50RCBDXD + 164.31RMB. The Standard Deviation was 202.3. The calculated Chi-Square value was 18.17, which is greater than 16.92 for the 0.95 probability level, but less than 19.02 for the 0.975

level.

Chapter IV ANALYSIS

The Simple Factor Model

The model discussed in the previous chapter was developed using the 1970 Albuquerque major street network and the 1970 Census Urban Transportation Planning Package for Albuquerque, New Mexico. The Albuquerque network has 328 internal traffic analysis zones and 15 external zones and stations. There are roughly 800 street links, not including centroid connectors, which represent all streets of collector or higher classification. These streets form roughly a half-mile grid over the urbanized area. Turning penalties are inserted in the network to represent freeway ramps. Otherwise, they are not included. The FHWA system of computer programs for the IBM 360 or 370 computer is used for analysis and travel forecast.[1] Using these programs, the census package trip table was assigned to the network in a single pass, all-or-nothing assignment based upon minimizing the travel time from origin to destination. Both the "incomplete" census work trip table and the work trip table completed by use of the gravity model were assigned to the network.[2]

The all-or-nothing assignment technique tends to overload certain fast routes, and underestimate traffic on parallel routes. There is no provision for diversion of traffic due to congestion or the inability for all people to perceive the same routes as having the least travel impedance. This introduces a significant source of error into the model.

The trip tables as they were assigned were in the home-to-work format. Most of the subsequent analysis observed the evening peak period, which is dominated by the work-to-home journey. Consequently, work trip loads in the opposite direction of the ground count were used to obtain work-to-home trips. This introduces only a small amount of error into the data, since the shortest route on the network from the point A to point B is the same as in the reverse direction unless there are one-way streets along the way.

The first analytical work was to develop a simple constant factor to describe the expansion from work trip travel to total travel. This model is described in equation (3-5):

$$Z_i = F_1 X_{1i}$$

wkere Z_i = total directional daily travel on link i,

F_i = ratio of total daily VMT over total work trip VMT

X_{1i} = work trips assigned to link i.

Note that multiplying the link loads by F_1 has the same effect as multiplying the trip table by F_1 prior to assignment, except for round off errors. When the individual entries in the trip table are small, as in this case, these round off errors can be serious. Experience in this case has shown that even for a total daily trip table, most entries are less than 10.

Total daily travel is used in this model instead of peak period traffic because a 1970 survey of total daily vehicle-miles of travel (VMT) was available while no peak period VMT study had been made. A factor to convert from daily work travel to peak period VMT could have been used if a peak period VMT estimate was available. However, no additional explanatory power is gained by that procedure. Such a model would simply be a constant proportion of the model presented here, as is shown below.

$$Y_i = KF_1 X_{1i} \qquad (4\text{-}1)$$

where Y_i = peak period travel on link i

K = proportion of daily travel occurring in peak period

This model is similar in form to the traditional prediction models, which first solve for daily travel and then obtain peak period traffic by applying a K factor according to the characteristics of the link.

In order to solve for F_1, all that is needed are estimates of daily work trip VMT and total daily VMT. In order to obtain work trip VMT, the 1970 census work trip table completed using the gravity model was assigned to the 1970 network and a computer program run to sum up the VMT on all links by functional classification.[3] The total work trip VMT on collectors, arterials and freeways was found to be 445,220. From the 1970 VMT study the total daily VMT for the area on collectors, arterials and freeways was 3,202,116.[4] The resulting ratio, F_1, is 7.192.

VMT on local streets was not included because the use of centroid connectors on the computerized network made local street VMT a somewhat artificial measure. Local VMT is very difficult to measure on the actual street system also. Because of the paucity of local street counts, an average ADT figure is applied to total local street mileage. As is typical in working with urban planning data, even the number of miles of local streets is not fully known, and an estimate is used. Besides being based upon imprecise measurements, local street VMT is unimportant to the model because it is very rarely necessary to estimate travel on a functionally local street.

The calculated VMT for work trips appears to be a very small percent of total VMT, since nationally the figure is around forty percent, as was described in Chapter 2. However, the one-directional work trip mileage was calculated here. Total work trip journey VMT is twice this figure. Additionally, work trips originating outside the study area and working in Albuquerque were not included in the census work trip table, and so are not reflected in the work trip VMT figure.

Applying the factor of 7.192 directly to the work trips assigned to the individual links in order to get average daily traffic (ADT) turns out to be an error. The factor was applied in this manner to 126 freeway and major street links for which ground count data were available. These links had more work trips flowing in the work-to-home or the evening direction than in the opposite direction. The ratio of ADT derived from the simple factor technique and

24-hour ground counts was calculated and a histogram of the resulting distribution is given in Figure 11.

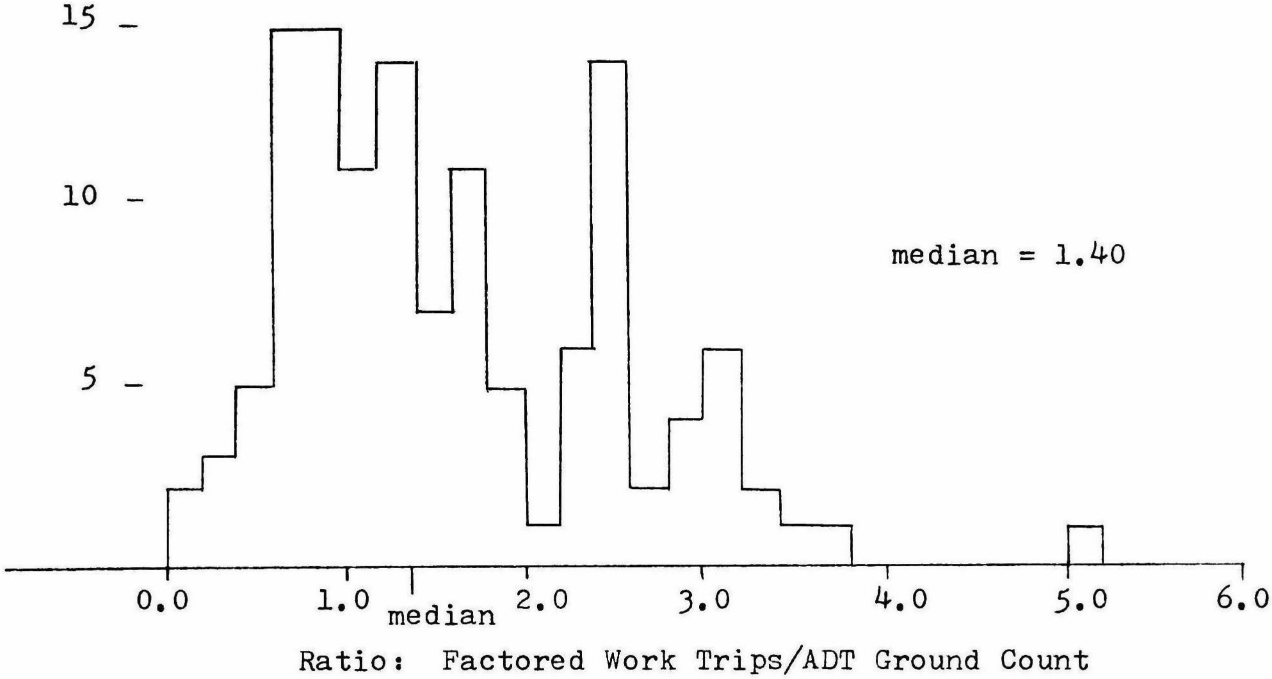


Figure 11. Performance of Simple Factor When Applied to Evening Work Trips, for 126 Cases Where Work to Home Trips Are Greater than Work Trips in the Opposite Direction

This model does not appear to be a good estimator. The fact that only evening work trips were used introduces a bias into the model. The cases considered were those where there were more evening work trips flowing in the measured direction than in the opposite direction. Naturally, these work trips represent a greater percentage of total travel than travel in the opposite direction. Assuming that total daily traffic is equal in each direction, use of the expansion factor on evening work trips alone should overestimate trips, and the median ratio of 1.4 seems to support this.

The ADT model should be based upon total daily work trips. In order to do this, work trips assigned in each direction on the link were added to get total daily work trips. Work trips in the opposite direction of the evening work-to-home trips are morning home-to-work trips in the same direction of the count. Since all work trips, both the journey to work and the journey home from work, are now considered, work trip VMT has doubled from the figure used previously. Therefore, the expansion factor is halved to 3.596.

This new factor was applied to total work trips for the entire set of reliable ground counts, 209 counts on collector and arterial streets, and 32 counts on freeways. This was enough counts to separate out the freeway cases and the major street cases. Ratios of ADT obtained by this simple factor to 24-hour ground counts were calculated and histograms of their frequency distributions are labelled Figures 12(a) and (b). It can be seen that the model is generally a better estimator than it was when using only evening work trip VMT. It can also be seen that freeway links are still significantly overloaded, reflecting the aforementioned tendency of the assignment model to over-assign trips to the freeway system. These models over-estimated most freeway links by 60 to 90 percent.

The model could be enhanced somewhat by calculating a separate factor for each functional classification. This

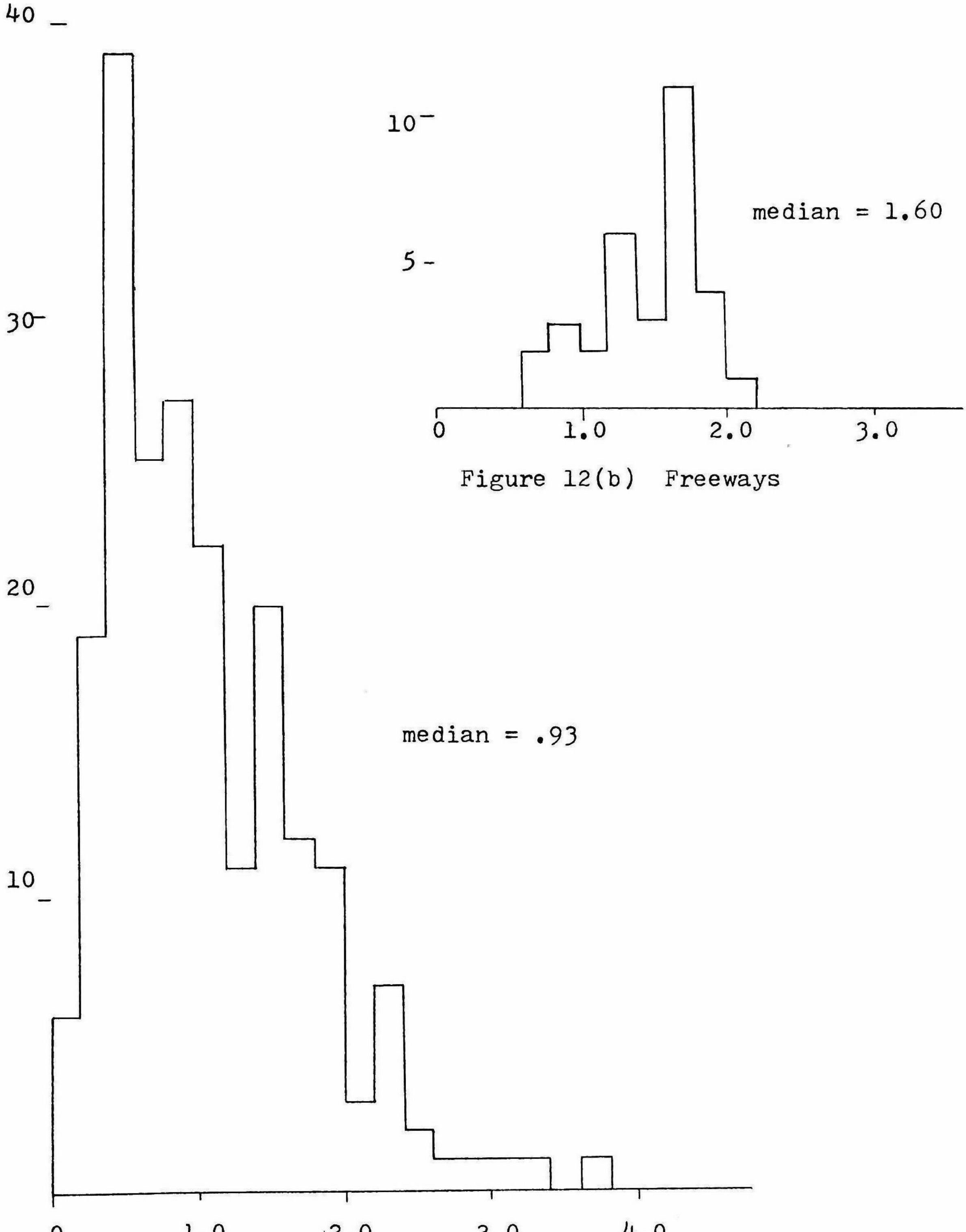


Figure 12(b) Freeways

Ratio: Factored Work Trips/Ground Counts

Figure 12(a) Collector and Arterial Streets

FIGURE 12. Performance of Simple Factor When Applied to Total Daily Work Trips

could alleviate the overestimation of freeway links. Further testing of the simple factor model, and comparison with multiple regression models and the traditional urban transportation planning models, is presented later in this chapter.

Development of the Model Using Multiple Linear Regression

Multiple linear regression techniques were used to develop the more complex forms of the model for expansion or conversion of work trip link assignments to total trip link assignments. Regression was chosen as a method for several reasons. First, it is a readily available technique, for which a number of computer programs have been written. This analysis used one of the more popular of these programs, BMD02R, the stepwise multiple regression program developed by the UCLA School of Medicine.[5]

There exists a large body of work describing and interpreting least-squares regression analysis which is contained in several excellent textbooks.[6] Regression analysis offers a means, using the computer for data processing, to derive underlying linear relationships between variables from a data set consisting of a series of observations. This kind of data set is available here in the form of traffic counts and associated link work trip loadings and other link specific variables. Regression analysis also allows the user to gauge the accuracy of the resulting equations in estimating values for data obtained from the same universe as the data set used in developing the model. There are a number of assumptions involved in the regression process, and these can be checked to see which if any appear erroneous. Statistical measures are available to help the user decide which among various formulations of the model appears to be the best.

Table 5 defines the dependent and independent variables used in the further analysis. The rationale for testing these variables was presented in Chapter 3. The description and development of the work trip tables used in obtaining link work trip loads is presented in Chapter 2.

The first attempt to use multiple regression to describe the model for estimating evening peak period traffic looked at 266 cases representing all freeway and major street locations with good traffic count data. In this first run, abutting land use and capacity were not considered. The R^2 values of the results are presented in Table 6. In all cases the variables in the linear equation were ART, FWY and either WKT or GMT. The equations using the trip table completed using the gravity model, GMT, show only a very slight improvement in their ability to explain the variation in the data around the mean of the dependent variable.

The fact that this model, which is one step removed from the simple factor model, explains such a high proportion of the total variation in the data verifies the validity of attempting to explain total travel based upon a knowledge of work trips. The equations obtained from this run are

TABLE 5

DEFINITIONS OF VARIABLES

Variable	Definition
	- Dependent variables
ADT	Average Daily Traffic, total 24-hr. directional traffic count
5-6 PM	Traffic count from 5:00 PM to 6:00 PM.
4-6 PM	Traffic count from 4:00 PM to 6:00 PM.
4:30 PM	Traffic count from 4:30 PM to 5:30 PM
HI HR	Sum of the highest 4 consecutive 15 minute interval traffic counts between 4:00 and 6:00 PM.
15 MPM	Highest 15 minute interval traffic count between 4:00 and 6:00 PM.
7-8 AM	Traffic count from 7:00 AM to 8:00 AM.
7:30 AM	Traffic count from 7:30 to 8:30 AM.
15 MAM	Highest 15 minute interval traffic count between 7:00 and 9:00 AM
	- Independent Variables
WKT	Work trips from work to home assigned to the link, from "incomplete" work trip table.
GMT	Work trips from work to home assigned to the link, from trip table completed by gravity model.
AMT	Work trips from home to work, from "incomplete" trip table.
GM-AM	Work trips from home to work, from trip table completed.by gravity model.
ART	Arterial = 1, otherwise 0.
FWY	Freeway = 1, otherwise 0.
DIR	If WKT $\geq$ AMT, DIR = 1, otherwise 0.
DIST	Distance of link from center of city, rounded to full miles.

TABLE 5

(Cont.)

RCBD	If link lies on a radial to the CBD = 1, otherwise 0.
RMB	If link lies on a radial to the military base = 1, otherwise 0.
V	If predominant abutting land use is vacant, V = 1, otherwise 0.
H	If predominant abutting land use is single family housing, H = 1, otherwise 0.
MT	If predominant abutting land use is multi-family and mobile housing, MT = 1, other wise 0.
R	If predominant abutting land use is Retail, R = 1, otherwise 0.
O+C	If predominant abutting land use is other commercial and offices, O+C = 1, otherwise 0.
CAP	One directional, hourly capacity of street at level of service C.
WK/AM	Ratio of WKT divided by AMT
RCBDXD	RCBD multiplied by DIST.

TABLE 6

R^2 VALUES OF EQUATIONS FOR ALL FREEWAY AND MAJOR STREET CASES

	WKT	GMT
5-6 PM	.730 (236)	.734 (241)
4-6 PM	.774 (298)	.780 (309)
HI HR	.752 (264)	.757 (272)

Numbers in parentheses below R^2 values are the corresponding F statistics.

presented in Appendix B. The R^2 values for these equations are higher than those obtained after freeways were separated from other major streets for analysis. This is not due to any loss in explanatory power of the less aggregate models, but instead because a large portion of the total variation is lost when the freeway cases are separated from the other major streets. The total sum of the squares about the mean of HI HR is 75×10^6 for 266 cases. For major streets alone it is 30×10^6, and for freeways alone it is 14×10^6.

Freeway Equations

The 32 freeway counts were separated out for special analysis. This was done because a number of the link-specific variables which are to be tested do not apply to freeways, such as abutting land use. Additionally, the traffic count data on the freeways was collected for hourly intervals instead of 15 minute intervals, which means that the freeway data could not be regressed against certain dependent variables. Finally, it was hypothesized that freeway links and other links differed significantly enough that separate models would be required for each.

Regression runs were made on the 32 freeway cases not only for the linear model, but also for the log-linear model and the linear factor model described in equation 3-6. This last model has the form:

$$Y_i = (a + b_2X_{2i}t\ldots tb_nX_{ni})X_{1i},$$

and the dependent variable in the regression run is Y_i/X_{1i}.

The log linear forms of the model require a logarithmic transformation of the data before the regression program is run. In this case the dummy variables (those whose values are either 1 or 0) were not transformed since there is no logarithm for 0. Such a transformation is not needed. Thus, the log-linear model actually estimated is:

$$Y_i = X_{1i}^{b_1} X_{2i}^{b_2} e^{(a+b_3X_{3i}+\ldots+b_nX_{ni})} \qquad (4\text{-}2)$$

The R^2 values for these runs are presented in Table 7. Except in the case of the linear factor run, these values represent the inclusion of only the main variable, WKT or GMT in the equation. The addition of other variables may increase the R^2 value to over .70. The most interesting freeway equations are presented in Appendix B.

TABLE 7

R^2 VALUES FOR FREEWAY REGRESSION EQUATIONS

	Linear		Log Linear		Linear Factor
	WKT	GMT	WKT	GMT	WKT
5-6 PM	.646 (54.7)	.679 (57.2)	.621 (49.1)	---	---
4-6 PM	.660 (58.2)	.680 (63.7)	.643 (54.0)	.643 (53.9)	---
HI HR	.658 (57.6)	.680 (63.9)	.629 (50.8)	---	.584 (15.2)

Numbers in parentheses below R^2 values are the corresponding F statistics.

The R^2 values from the linear formulation cannot be directly compared with the log linear or the linear factor formulations. The 4-6 PM period seems to have a slight but probably not significant edge over the other definitions of peak hour in amount of variation explained.

The slight edge that GMT (work trips completed using the gravity model) has over WKT ("incomplete" work trip table) in the linear case has disappeared in the log linear case.

The variables entering the equation in the linear factor equation are DIST and DIR. The factor to convert work trips to peak hour trips increases with distance from the center of the city, due to the greater percent of external traffic, and decreases if the direction of the traffic flow is the predominant direction of work travel. This later may reflect the hypotheses that non work travel tends to seek the less congested direction of travel, which is the direction with the least work trips.

As shown in Appendix B, the most common variable entering the log linear equations besides work trips is DIR, always with the expected negative sign. DIST also sometimes enters these equations. Another variable which enters several equations is highway capacity. Capacity always carries a negative coefficient, which reflects the decreasing capacity and decreasing traffic on the freeway system as one moves out from the central freeway interchange. Although it has statistical significance, this relationship must be considered to be only incidental, and not logical for inclusion in a forecasting model. If capacity carries a negative coefficient, then increasing freeway capacity would yield a decrease in freeway traffic!

In order to make a reasonable determination of which form of the equation is best for describing freeway traffic, some statistic common to each alternative form is needed. Therefore, a root mean square error, RMSE, was calculated for the difference between the calculated HI HR peak period value and the observed HI HR value for the 32 freeway cases. Root mean square error is given as:

$$RMSE = \sqrt{\frac{\sum(Y - Y_i)^2}{n}} \qquad (4\text{-}3)$$

The smaller this value, the more accurate is the model in replicating traffic count data. Table 8 shows equations tested.

TABLE 8

FREEWAY EQUATIONS FOR RMSE COMPARISON

Equation	Coefficient-Variable	F	R^2
linear (4-4)	948.61^{*} $+ \; .30^{*}$ WKT -290.05 DIR	32.2 (29)	.690
log linear (4-5)	28.99^{*} x $WKT^{.53^{*}}$ x $.77^{**DIR}$	31.1 (29)	.682
linear factor (4-6)	($.70^{*}$ $-$ $.60^{*}$ DIR $+$ $.15^{*}$ DIST) x WKT#	15.2 (29)	.584
simple factor (4-7)	3.596(.11)(WKT+AMT)	no statistics - see Pp.73-80.	

* Significantly different from 0 at .01 level
** Significantly different from 0 at .05 level
\# This variable not regressed upon.
Degrees of freedom shown in parentheses under F statistic.

In addition to these, the 1970 estimated traffic from the traditional set of simulation models was used. These models, designated as UTP models, produce estimates of ADT, which are multiplied by .11 to obtain peak hour estimates. These UTP models are described in Chapter 1 above.[7] Table 9 also shows the root mean square error, RMSE, expressed as a percentage of the mean value for HI HR. The ratio of calculated value divided by observed value was determined for each of the 32 freeway cases for each alternate form, and the highest and lowest values are presented in the Table 9 also.

TABLE 9

RMSE'S FOR FREEWAY MODELS

	Linear	Log Linear	Simple Factor	Linear Factor	UTP
RMSE	371.68	364.06	888.38	758.22	1599.64
% RMSE	24%	23%	56%	48%	101%
ratio: $\hat{Y}/Y$					
-highest	2.05	1.59	2.34	2.00	3.20
-lowest	0.67	0.60	0.52	0.27	0.99

Because of the transformations performed, there is no statistic to show the significance of the various models, except in the linear case. However, the RMSE's can be compared from model to model, and lower RMSE's can be interpreted as more accurate models.

As can be seen, the UTP models are extremely poor estimators of freeway traffic, and the range of the ratios indicates a significant upward bias. The problem of overloading the freeway system which these models experience has been discussed earlier.

The simple factor technique shows improvement over the traditional UTP models. However, the root mean square error is still very large, and a very large percentage of the mean value for peak period traffic. The simple factor overestimated twenty-two of the thirty-two freeway cases.

The linear factor shows additional explanatory value, although its estimates still ranged from as much as 100 percent above to 73 percent below traffic count data. The linear and log linear show the best results by far, with a percent RMSE of only half that of the linear factor. No clear choice can be made between these two equations on the basis of these statistics.

The log linear and linear equations have percent RMSE's of 23 and 24 percent, respectively. These values are low enough to suggest that the model can be used for providing information for decision making purposes. A study by Humphrey of network assignments using Capacity Restraint showed that the highest volume links ranged from 12.2 to 59.7 percent of the mean for the ten cities studied. The median value was 28.9 percent.[8]

The root mean square errors presented here can be used to predict the probability of making a design level error following the procedures discussed in the previous chapter. Therefore, they can be used to gain some idea of the confidence with which the model can be used.

The predominant direction of work trips variable, DIR, is represented in the model as a dummy variable, taking on either the value of 1 or 0. A more discriminating variable would have been WKT/AMT, the ratio of work trips in one direction over those in the other. However, this variable could not be used in the regression equation because of its correlation with another independent variable, WKT. However, when applying the model, a better fit may be obtained by using a more precise variable in place of DIR. Such a variable might be DIR$'$:

$$DIR_i' = \frac{(WKT_i/AMT_i) - B}{A - B} \qquad (4\text{-}8)$$

where A = mean value of WKT_i/AMT_i for those cases where DIR=1

B = mean value of WKT_i/AMT_i for those cases where DIR=0.

No test of this variable was carried out.

Major Street Equations

The largest amount of regression analysis was performed on the major street cases. The R^2 values of the resulting equations are presented in Table 10. This table shows the R^2 values for the last significant step in the stepwise regression run (the criterion used here is whether the partial F value for the most recently entered variable, which shows whether the variable has explained a significant amount of variation over that removed by previous variables, is greater than 2.0). Often the last variables entered may not improve the fit of the model enough to justify collection of the additional data, or they may be measuring incidental relationships in the data instead of underlying functional relationships, or they may not be significantly different from 0. Therefore, the 'best' equation will often have a slightly lower R^2 value.

The more interesting and useful equations determined from this analysis are also presented in Appendix B. It is not implied that these equations will be applicable elsewhere.

TABLE 10

R^2 VALUES FOR MAJOR STREET REGRESSION RUNS

	Linear		Log Linear		Linear Factor		Factor (Log)
	WKT	GMT	WKT	GMT	WKT	GMT	WKT
5-6 PM	.635 (42.5)	.638 (55.8)	.676 (55.1)	.666 (57.0)	---	---	---
4-6 PM	.654 (52.2)	.661 (53.9)	.698 (53.2)	---	.140 (7.6)	---	.313 (28.8)
4:30 PM	.676 (66.0)	.680 (67.5)	.711 (56.5)	.693 (64.4)	.136 (7.4)	---	.294 (26.3)
HI HR	.674 (65.7)	.677 (66.4)	.713 (57.3)	---	.137 (7.4)	.107 (9.0)	.297 (26.6)
15 MPM	---	.654 (59.9)	.689 (58.4)	.687 (62.7)	.134 (7.3)	---	.292 (26.0)

Numbers in parentheses below R^2 values are the corresponding F statistic.

but the variables found significant may be significant elsewhere, and the variation explained (R^2) and the coefficients of the variables may be typical.

As in the case of the freeway equations, the R^2 values for each form of the model cannot be directly compared with other forms, but they do provide valuable information in assessing equations using the same model forms. The R^2 values for HI HR and 4:30 PM are marginally better in the linear and log linear cases. In the factor forms of the model, 4-6 PM is slightly better. In all cases here, 5-6 PM and 15 MPM appear to be slightly inferior in their susceptibility to estimation. This finding was supported by the freeway regression runs which were able to explain slightly more of the variation in 4-6 PM and HI HR than in 5-6 PM. The conclusion appears to be that HI HR is the preferred variable to use for the evening peak period because of its traditional use for facility design and capacity calculations, and because no other variable offers higher explanatory value.

The completion of the trip table by use of the gravity model appears to have had little if any effect upon the R^2 values. The coefficient of determination (R^2) for GMT is slightly better in the linear form of the model, but a .003 increase is not exciting. In the log linear and linear factor forms of the model, the "incomplete" trip table had higher R^2 values. This was an unexpected result, and casts considerable doubt upon the value of expending time and resources to complete the census package trip table.

In all regression runs of the linear and log linear form of the model, the work trips assigned to the link was the first variable to enter the equation and accounted for the majority of the total variation explained by the model. The R^2 values with the inclusion of only the work trips assigned to the link (WKT or GMT) ranged from .462 to .522 for the linear case, and from .486 to .505 for the log linear case. In both cases, the highest values were for the HI HR definition of the peak period, suggesting that the highest hour of total traffic is also the highest hour of work trip traffic.

In most of the linear model runs presented in Appendix B capacity was not allowed to enter the equation. When it was allowed to enter, it was the second variable in the equation, and carried the positive coefficient as was expected. The other most common variables in the linear case equations are ART, RCBD and RMB, representing variables describing the location of the link in the network. Each of these variables has a positive coefficient. Two variables representing abutting land use are found to be significant in several of these equations. Retail abutting land use, R, increases traffic on the link, and vacant abutting land, V, means less traffic, as was expected.

In the log linear form of the equation, WKT, CAP and ART are always the first three variables in the equation, and they show a good deal of consistency from equation to equation in the size of their coefficients. It is interesting to note that the coefficient for the "incomplete" trip table load, WKT, is nearly the same in the log linear case as it is in the linear case, even though it carries a different interpretation. ART and RMB are also found to be significant variables, although a new variable RCBDXD was found to be more significant than RCBD in all log linear equations, but one. The variable RCBDXD is distance from the Central Business District in miles along CBD radials. Since it carries a positive sign, it suggests that non work travel makes up a larger portion of the total traffic on CBD radials at greater distances from the CBD. Because of Albuquerque's low profile development, the total traffic along CBD radials does not decrease significantly as distance from the city's center increases.[9] However, work trip traffic leaving the downtown employment center does disperse. Therefore, the variable RCBDXD appears to be a reasonable inclusion in the model.

In some equations of the log linear form, the distance from the center of the city, DIST, enters the equation also. When it does, it carries a negative sign, which implies that non CBD radials have a decreasing percentage of non work trips as distance from the city's center increases. Retail and vacant land use enter some of these equations with the same sign on the coefficients as in the linear model.

Three variables are found significant in each of the linear factor and log linear factor equations. Capacity has a negative coefficient, suggesting that as capacity increases, the percentage of non work trips on the link decreases. This is an unfortunate result since it means that if this model is used for forecasting, total VMT can be decreased by increasing capacity.

In addition to Capacity, DIR and RCBD enter these equations. DIR is a dummy variable set equal to 1, if the direction of the traffic flow being estimated is in the predominant direction of work travel. It carries a negative coefficient in the equations, which means that non work trips tend to flow in the opposite direction of the work trips. This is precisely as hypothesized. The coefficient for RCBD has a positive sign, which means more traffic flows on CBD radials. This is consistent with the results of the other regression runs.

Comparison of the Equations

In order to provide a common base for comparison, a set of 193 major street ground counts were selected from the 230 available. These cases had good morning as well as evening traffic count data. Furthermore, those counts which had less than 150 vehicles in the peak evening hour were deleted. It was felt that these low volume links did not contribute substantially to the analysis since very large errors in them would not result in an error in the planned design configuration of the facility. Including cases with a very large tolerance to error does not contribute very much to an analysis to test the sensitivity to error of alternative estimation models.

A design level error comparison as described in Chapter 3 was made upon these 193 cases. A simplified design level function was constructed and is shown in Figure 13. This function was applied to each of the cases being tested, and might be thought of as a simplified decision rule to determine the need for 2,4,6 or 8 lane facilities. In actual use, different decision rules would be constructed for facilities at different locations, reflecting the interrelation of capacity, traffic flow, and concomitant effects of transportation facilities.

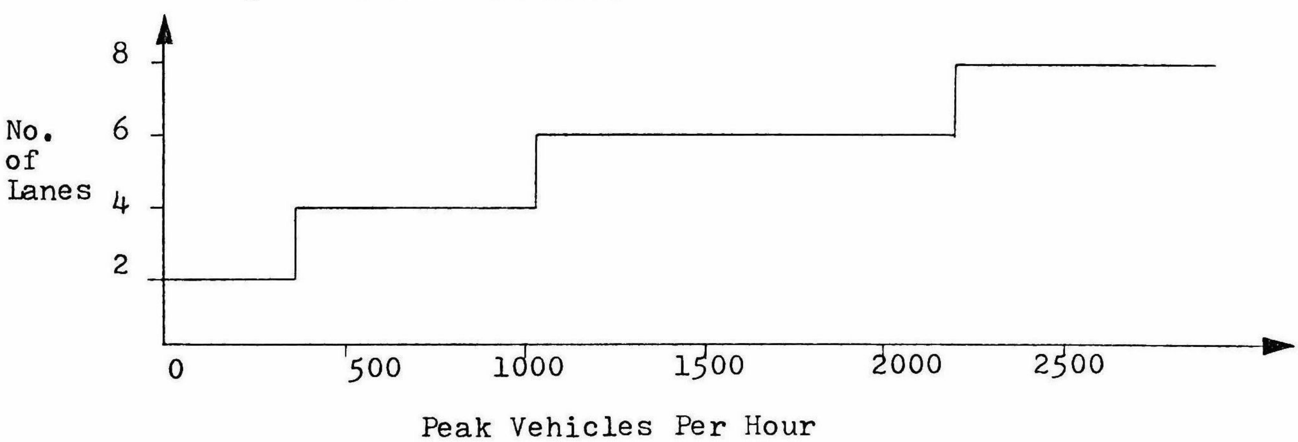


Fig. 13. Simplified Design Level Function

The design level error comparison was subdivided into three levels to determine the effect of increased volume upon the accuracy of the models. The three levels were 1) those cases whose traffic count specified a 2-lane facility, i.e., less than 485 peak hour ground count; 2) those whose traffic count specified a four lane facility; and 3) those whose traffic count specified a six lane facility. There were no traffic counts over 2200 in the peak hour, which would specify an eight lane facility.

The peak period definition used in the analysis is HI HR. The equations chosen for the design level error comparison are given in Table 11.

TABLE 11

MAJOR STREET PM PEAK EQUATIONS FOR DESIGN LEVEL AND RMSE COMPARISONS

Equation	Coefficient-Variable	F	R^2
linear (4-9)	73.35* + 0.24* WKT + 0.17* CAP +102.43** R + 81.56* ART + 31.50* RCBDXD +164.31* RMB	62.3 (186)	.667
log-linear (4-10)	14.25^{*} $\times\ WKT^{.25^{*}}$ $\times\ CAP^{.25^{*}}$ $\times\ 1.32^{*ART}$ $\times\ 1.34^{*RMB}$ $\times\ 1.06^{*RCBDXD}$	82.7 (187)	.689
factor(log) (4-11)	$e^{3.50*}$ $\times\ e^{-.93*DIR}$ $\times\ e^{.33*RCBD}$ $\times\ CAP^{-.39*}$ $\times\ WKT^{\#}$	26.6 (189)	.297
factor(add)	(6.62* - 3.06** DIR + 1.98* RCBD - 0.0022* CAP) x WKT#	7.4 (189)	.137
simple factor	3.596(.11)(WKT)	no statistics - see Pp.73-80.	

*significantly different from 0 at .01 level.

**significantly different from 0 at .05 level.

#this variable not regressed upon.

Degrees of freedom shown in parentheses under F statistic.

In addition, the traditional UTP models were tested in order to provide a base for comparison. The design level comparison was made for the 193 cases and the percentage errors for each model by each traffic volume group are presented in Table 12.

The first observation that can be made is that the highest percentage of correct choices that any of the models achieve is a little over 80%. This level is achieved by the linear and log-linear equations in the middle traffic volume category, and by the log-linear and simple factor equations in the lowest traffic volume category.

TABLE 12

DESIGN LEVEL ERRORS IN ALTERNATIVE MODELS, 193 MAJOR STREET CASES

Number of Lanes from Ground Count	Model Error in No. of Lanes Each Direction	% by category Model				
		Linear	Log-Linear	Simple Factor	Factor(log)	UTP
	0	72	81	83	69	62
2	+1	28	19	15	30	36
n = 90	+2	0	0	2	1	2
	+3	0	0	0	0	0
Total		100%	100%	100%	100%	100%
	-1	13	14	39	21	25
4	0	83	83	36	41	45
n = 84	+1	4	3	25	33	30
	+2	0	0	0	5	0
Total		100%	100%	100%	100%	100%
	-2	0	0	5	0	5
6	-1	37	63	32	21	37
n = 19	0	63	37	63	47	58
	+1	0	0	0	32	0
Total		100%	100%	100%	100%	100%

The UTP models perform poorly, specifying the correct design level less than 50 percent of the time in the middle volume category. However, they do comparatively well in the highest volume category, correctly identifying the design level in 58 percent of the cases, compared with 63 percent for the best performing equations. The simple factor replicates the data as well as the UTP models. However, it has very low percent of correct responses in the middle category. The log linear factor equation offers no improvement, and is the only equation which overestimates design level in the highest traffic volume category.

The best results are from the linear and log linear equations. The log linear equation does better in the lower volume group, where the linear equation specifies an overdesign 28 percent of the cases, versus 19 percent for the log linear model. Both equations tend to underestimate design level in the highest volume group, but the tendency is significantly less in the linear equation.

These observations are confirmed by the root mean square errors of the various equations and models, which are presented in Table 13. The RMSE's for the total collection of 193 cases are presented, as well as breakdowns by volume group corresponding to two-lane, four-lane and six-lane facilities. In addition, the cases where the traffic count is in the major direction of work trip travel are separated out. This was to test the hypothesis that models could better estimate travel in this direction than in the opposite.

Table 14 presents the same information expressed as percentages of the mean value of peak hour traffic.

TABLE 13

RMSE'S FOR MAJOR STREET MODELS

	n	mean	linear	log linear	simple factor	factor (log)	UTP
Total	193	589.70	201.75	198.36	366.54	534.03	340.40
150-484	90	304.16	157.95	130.89	221.91	271.64	277.62
485-1034	84	726.83	157.15	159.95	402.20	611.04	329.28
1035 & over	19	1336.05	431.36	454.23	645.19	960.63	576.72
DIR = 1	95	686.64	215.31	223.56	388.08	575.81	369.45
DIR = 0	98	487.38	187.67	170.43	344.38	490.13	309.66

TABLE 14

RMSE'S AS PERCENT OF MEAN FOR MAJOR STREET MODELS

	Linear	Log-Linear	Simple Factor	Factor (Log)	UTP
Total	34%	34%	62%	89%	57%
150-484	52%	43%	73%	91%	91%
485-1034	22%	22%	55%	84%	45%
1035 & over	32%	34%	48%	72%	43%
DIR = 1	31%	33%	57%	84%	54%
DIR = 0	38%	35%	71%	101%	64%

Root mean square error values for the linear factor form of the model were calculated also. The equation used was

$$\text{HI HR} = \text{WKT}(6.62-3.06\text{DIR}+1.98\text{RCBD}-.0022\text{CAP}) \quad (4\text{-}12)$$

The RMSE for the total sample of 193 cases was 1272.37, or

216 percent of the mean. The negative coefficient on capacity allowed the equation to calculate negative trips for some cases. In light of these results, no further analysis was felt necessary for this equation.

The lowest overall root mean square error belongs to the log linear equation, which is slightly less than the linear equation. This is significant since the linear equation is being applied directly to the data from which it was derived by the least squares method. Thus, for another set of traffic counts derived from the same universe, the linear equation should have a higher RMSE. This is not the case with the log linear equation because of the transformation of the data. Thus, for equal RMSE values, the log linear case should be favored.

The log linear case again shows a slight edge in the lower volume group, while the linear model shows an edge in the higher volume group. The three other models, UTP, simple factor, and factor (log) consistently carry much higher RMSE values.

The study of capacity restraint techniques by Humphrey showed that the percent standard deviation for all links on the network for ten cities studied ranged from 30.9 to 55.3 percent.[10] It should be recognized that the analysis included both the low traffic flow links (under 150 in peak hour) and the high traffic freeway links which are excluded here. Nevertheless, it is interesting to note that the percent RMSE for the total number of cases from Table 14 shows 34 percent for the linear and log linear cases, which is near the bottom of that range. The UTP models, on the other hand, have an RMSE of 57 percent, which is at the top of the range.

The RMSE's for the cases where DIR = 1 were consistently higher than they were for DIR = 0. However, so was the mean traffic count. When expressed as a percent of the mean, the RMSE values for DIR = 1 were from 2 to 15 percent less than when DIR = 0. This increased hopes that equations developed using only those cases whose traffic count is in the predominant direction of work trip travel would prove valuable.

The ratios of calculated value to observed traffic count were determined for the 193 case data base for each of the five models analyzed here. Frequency distributions of the resulting values are presented in Appendix C.

Based upon the analysis above, either the linear or log linear forms of the model appear to be valuable for the purposes of estimating traffic flows on major streets. As in the analysis of the freeway models, both are significantly more accurate than the traditional UTP models, If a choice between the two were to be made, the log linear form might be favored, partly on the basis of the data presented, and partly because the log linear equation used, equation 4-10, has one less independent variable than the linear equation, 4-9. Finally, there appears to be value in examining equations based upon only those counts taken in the predominant direction of peak hour flow, which is

TABLE 15

R^2 VALUES FOR EQUATIONS BASED UPON THOSE CASES WHERE DIR = 1

	Linear		Linear-All Cases		Log Linear	Log Linear-All Cases
	WKT	GMT	WKT	GMT	WKT	WKT
5-6 PM	---	---			.716 (31.4)	.676 (55.1)
4-6 PM	---	.629 (45.0)		.661 (53.9)	.723 (32.4)	.698 (53.2)
4:30 PM	.650 (49.2)	.645 (48.2)	.676 (66.0)	.680 (67.5)	.738 (30.2)	.711 (56.5)
HI HR	.640 (37.1)	.634 (42.5)	.674 (65.7)	.677 (66.4)	.732 (29.4)	.713 (57.3)
15 MPM	---	.629 (29.3)		.654 (59.9)	.745 (31.5)	.689 (58.4)

Numbers in parentheses below R^2 values are the corresponding F statistic.

nearly always the most heavily travelled direction of peak period travel.

Equations for the Predominant Direction of Work Trips

Traffic estimating equations for major streets were developed using as a data base those cases for which the direction of the traffic count was the predominant direction of work travel flow on the link, DIR = 1. The R^2 values for the equations containing all significant values are shown in Table 15. The most useful of the equations are found in Appendix B.

R^2 values for corresponding equations based upon the complete set of cases are included in Table 15 for comparison. There has obviously been no improvement in the linear case, but the log-linear case shows some increase in R^2 values.

The root mean square errors for two of these equations were calculated and are compared in Table 17 with those obtained from earlier analysis. The equations used here are listed in Table 16.

TABLE 16

MAJOR STREET EQUATIONS FROM CASES WHERE DIR = 1

Equation	Coefficient-Variable	F	R^2
linear (4-13)	103.76^{*}	37.1 (89)	.640
	$+\ .22^{*}$ WKT		
	$+\ .18^{*}$ CAP		
	$+\ 119.12^{*}$ RCBD		
	$+\ 211.93^{*}$ RMB		
	$+\ 84.69$ (O+C+R)		
log linear	$WKT^{.25^{*}}$	29.4 (88)	.732
	$\times\ CAP^{.35^{*}}$		
	$\times\ e^{2.14^{*}}$		
	$\times\ e^{.28^{*}RMB}$		
	$\times\ e^{-.32^{*}V}$		
	$\times\ e^{.17^{**}R}$		
	$\times\ e^{.07^{*}RCBDXD}$		

*Significantly different from 0 at .01 level

**Significantly different from 0 at .05 level

Degrees of freedom shown in parentheses under F statistic

TABLE 17

RMSE'S FOR CASES WHERE DIR = 1

	From DIR = 1 Data		From Total Data		
	Linear	Log Linear	Linear	Log Linear	UTP
RMSE	223.66	204.90	215.31	223.56	369.45
% RMSE	31%	30%	31%	33%	54%

Although there has been some improvement in the size of the RMSE in the log linear case, it is not clear that this improvement is significant. If an analyst wished to use the log linear form of the model, he might choose the equation which best fits the DIR=1 data. This is because the form and coefficients of the equations always specify that the direction of predominant work trip flow has the higher peak period traffic. All other variables are the same for each direction on the link, so the direction with the most work trips has the most estimated travel. The design of a facility is generally based upon this peak hour flow in the busiest direction, and the facility is then usually designed to handle the same peak hour load in the opposite direction. So, for the purposes of specifying design, it is most important to estimate peak directional peak hour travel, and the model which best estimates this should be favored.

Probability of Design Level Error Function

In the last portion of the preceding chapter it was shown that the probability of an error in specifying the design configuration of a planned facility is a function of the estimated travel flow on the link and the standard deviation. Given that the estimation errors are normally distributed about the actual traffic values, the probability of error is the cumulative distribution function of the normal distribution at z where

$$z = \frac{M - L}{S}$$

where L = Estimated link travel

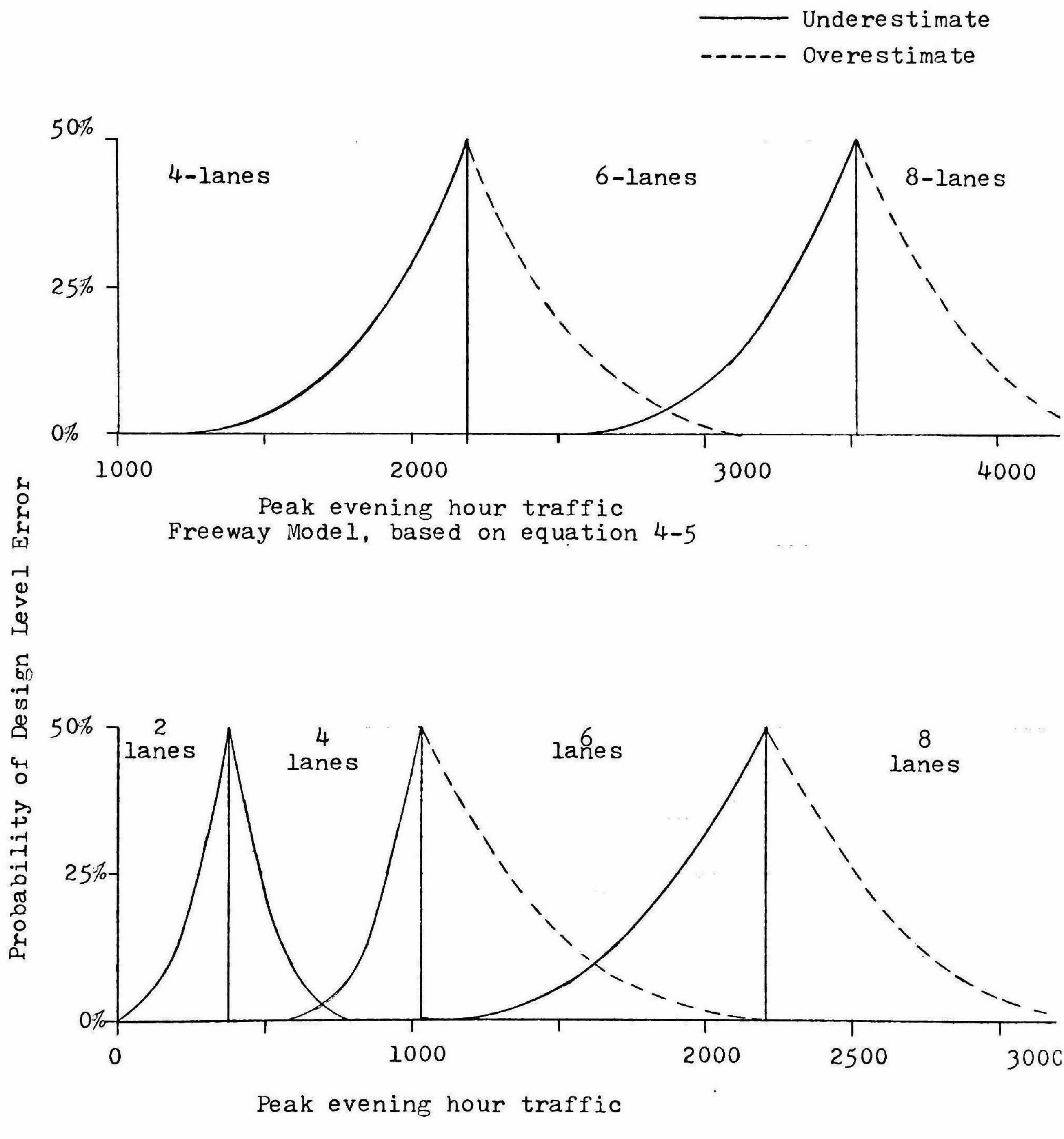
M = Breakpoint on the capacity-design level function

S = Standard deviation of the estimation errors.

Using the calculated RMSE values for an approximation of S, it is now possible to specify the error probability functions for selected equations. Figure 14 presents the design level error probability functions for the log linear freeway equation, equation 4-5, and the linear major street equation, 4-9.

It is assumed that the calculated RMSE value for freeways is equal throughout. An alternative assumption which could have been made based upon the log linear form of the model is that the RMSE expressed as a percent of estimated traffic flow is constant. The root mean square errors for the major street cases were assumed to apply throughout the volume group for which they were calculated. From Table 13, the RMSE is 158 below 485 volume, 157 in the volume range between 485 and 1035, and 431 over 1035.

It should be remembered that the probability function presented here is the probability of error in estimating data from the same universe of data from which the model was developed. When used as a predictive model, changes which have not been accounted for in the estimating models may well increase the probability of error of the model, and may bias the direction of the estimates. This probability function then represents the maximum amount of confidence which can be placed in the model.



Major Street Model, based on equation 4-9

FIGURE 14. DESIGN LEVEL ERROR PROBABILITY FUNCTIONS FOR FREEWAY AND MAJOR STREET MODELS

Nevertheless, it can provide useful information to the decision making process. The function is highly peaked at the "steps" of the stairstep function, and falls off from there more or less rapidly according to the size of the standard deviation. Therefore, a highly sensitive zone can be established, where there is a large chance of error. If the cost of underdesign is greater than the cost of overdesign, the planner may suggest that for a certain "sensitive" region to the left of the peaks of the functions, the higher design level should be chosen.

Recently, however, it has become apparent that overdesign of facilities in urban areas also bears a high cost due to the concomitant environmental effects of the facility, as well as the added construction costs of the higher design level. Therefore, the planner may favor underdesign in the sensitive area, preferring the risk of congestion or crowding on a transit line.

If both the cost of overdesign and the cost of underdesign can be quantified, a new cutoff point in the decision rule can be determined which would minimize the expected cost of a design level error. This point is the traffic estimate at which

$$P(H)H = (1 - P(H))L \qquad (4\text{-}15)$$

P(H) = Probability that the actual travel value specifies the higher design level

H = Cost of underestimating design level

L = Cost of overestimating design level

As Figure 14 shows, there is an area in which a measurable probability exists for either an underestimate or an overestimate in design level. If the standard deviation of the residuals were large enough, or if the steps of the capacity-design level function were close enough together, there would be a region with a measurable probability of being in error by two or more levels of design.

Morning Peak Period and ADT Models

It was hypothesized that the work trip based model would be a better estimator of morning peak period traffic than evening travel. This results from the observation that there are less non work trips on the network in the morning than in the evening peak periods. In addition, it has been noted that the work trip assignments used in this analysis are directionally home to work, which is more indicative of the morning than the evening peak period. The need to use work trip loads in the opposite direction was thought to have introduced some error in the evening peak data which is not present in the morning data.

Table 18 presents the R^2 values for the morning peak period runs, based upon the last significant step of the stepwise regression analysis. The most significant morning peak equations are presented in Appendix B.

Obviously, the original hypothesis was not born out by these results. The coefficients of determination were .10 or more lower than corresponding evening peak period equations. Similar results were found by Parsonson and

TABLE 18

R^2 VALUES FOR MORNING PEAK PERIOD MODELS

	Freeway, Log Linear	Major Streets, Linear	
	Using AMT	AMT	GM-AM
7-8 AM	.557 (18.2)	.531 (42.5)	.519 (40.5)
7:30 AM	---	.570 (41.3)	.555 (38.8)
15 MAM	---	.552 (38.4)	.543 (37.1)

Numbers in parentheses below R^2 values are corresponding F statistics.

Roberts in Columbia, South Carolina. They found that evening work trips explained evening peak travel with a .04 increase in R (.07 higher R^2) over the explanation of morning work trips in the morning peak hour. They determined from home interview data that work trip travel represented the same percent of total travel in the evening peak hour as in the morning peak hour.[11]

In addition, the R^2 values for the Albuquerque data show that AMT, the work trips from the "incomplete" census package work trip table, is marginally better than GM-AM, the work trip table completed using the gravity model. The evening peak hours had slightly higher R^2 values for the gravity model completed work trip table. In either case, the effort to improve the census trip table by assigning work trip ends to these trips which the census could not code does not seem to have been very successful.

The variables which entered the morning peak hour model are similar to those in the evening peak hour. Work trips and DIR are the significant variables in the freeway equation. Capacity entered the freeway equation on the third step with a negative coefficient. As has been discussed before, this is an illogical and only incidental relationship. Therefore, this last step was discarded as not meaningful.

In the major street equations, RCBDXD and ART are the most common variables after work trips. Radials to the CBD and Arterials showed greater numbers of trips. DIR entered two equations, and a variable representing abutting residential land use entered one equation. Interestingly, street capacity was not usually a significant variable, and entered only the fifteen minute peak equation.

Even if a separate peak period model is operable, a total daily traffic model could provide valuable information for calculating total user costs, total user time savings, and pollution emissions from roadways. For transit systems it could provide data for projecting revenues, as well as estimating demand for off peak service. For this reason, a model to estimate total daily traffic was developed. It was expected that the average daily traffic (ADT) would not perform as well as the evening peak hour model, since a smaller percentage of total daily trips are to or from work. As Table 19 shows, this was not the case.

TABLE 19

R^2 VALUES FOR ADT EQUATIONS

	Freeway	Major Streets	
	Log Linear	Linear	Log Linear
Using AMT & WKT	.840 (35.3)	.696 (60.7)	.711 (56.6)
Using TOTWKT	.813 (62.9)	---	.697 (60.9)

Numbers in parentheses below R^2 values are corresponding F statistics.

The R^2 values for the ADT equations for major streets are as high as those obtained for peak hour equations. The values for the freeway are significantly higher. Apparently the R^2 values are significantly increased in the ADT model by the inclusion of two portions of total travel--the journey from home to work and the journey from work to home. The peak hour models can only include one of these portions of work travel.

The variable TOTWKT represents total morning and evening work trips added together. This shows the expected slight decrease in R^2 from the equations in which both AMT and WKT appear. The R^2 values shown represent the equations resulting from the inclusion of all statistically significant variables. The equations appearing to be most useful are presented in Appendix B.

In all of the linear form equations the coefficient for AMT is significantly higher than that for WKT.[12] The reason for this is not known. The coefficients for these two variables are nearly identical for the freeway and log linear major street forms of the models. If the coefficient of WKT is different from that of AMT, then there is an implied directional imbalance of total daily traffic. This is the opposite of the usual assumption.

Besides WKT and AMT, DIST enters the freeway equation, with the proper positive coefficient. Capacity is a significant variable in each of the major street equations. Other variables entering the major street equations are the same ones which were found in the evening peak period models: Radials to the CBD and to the military base, arterial streets, and abutting retail or vacant land use (RCBD, RMB, RCBDXD, ART, V, and C).

The success achieved in using work trips to estimate total daily travel suggests that two levels of traffic estimation can be achieved. Both an evening peak hour model and a total daily traffic model can be constructed, using the same procedures and most of the same independent variables. The fact that an ADT model can be developed does not mean that peak hour travel should be measured as a percentage of estimated ADT using the traditional K factor approach. Since accurate peak period travel estimates are more critical for design level specification than is ADT, the more efficient and accurate procedure is to develop a model to directly estimate peak period travel.

FOOTNOTES

[1]U.S., Department of Transportation, Federal Highway Administration, Urban Transportation Planning, General Information and Introduction to System 360 (Washington, D.C.: Government Printing Office, March, 1972); U.S., D.O.T., FHWA, Program Documentation, Urban Transportation Planning (Washington, D.C.: Government Printing Office, March, 1972).

[2]These are described above, Pp. 19-24.

[3]Program FORMAT from the FHWA IBM 360 battery was used. See FHWA, Program Documentation, Pp. 319-350.

[4]James P. Milton, 1970 Vehicle Miles of Travel in the Greater Albuquerque Area, Technical Memorandum No. 34, Middle Rio Grande Council of Governments, 1971 (mimeographed).

[5]University of California at Los Angeles, Health Services Computing Facility, School of Medicine, Bio Medical Computer Programs, edited by W.J. Dixon (Los Angeles: UCLA, 1965).

[6]N.R. Draper and H. Smith, Applied Regression Analysis (New York: John Wiley and Sons, Inc., 1966); J. Johnston, Econometric Methods (New York: McGraw-Hill Book Co., 1963). An explanation of the method and some of the pitfalls of Regression Analysis which is understandable to laymen is found in U.S., Dept. of Transportation, Federal Highway Administration, Guidelines for Trip Generation Analysis, (Washington, D.C.: Government Printing Office, June 1967, Reprinted Jan. 1972).

[7]Above, P. 2.

[8]Humphrey, "A Report on The Accuracy of Traffic Assignment."

[9]MRGCOG, 1970 Traffic Flow Map.

[10]Humphrey, "A Report on the Accuracy of Traffic Assignment."

[11]Parsonson and Roberts, "Peak Hour Traffic Models Based on the 1970 Census," P.40.

[12] For instance, for the first major street ADT linear equation listed in Appendix B, coefficient of $AMT=B_1=2.10$; coefficient of $WKT=B_2=1.16$. $H_o: B_1=B_2$

$$\underline{t} = \frac{B_1 - B_2}{\text{Est.Std.Error } B_1} = \frac{2.10 - 1.16}{.22} = 4.25$$

$t(191,.999)=3.29$, which is less than $\underline{t}$, so the hypothesis that $B_1=B_2$ is rejected. This result is typical of the linear equations.

CHAPTER V

LIMITATIONS OF THE MODEL AND CONCLUSIONS

A serious limitation to the usefulness of a peak period model based upon work trips is the extent to which the model can account for the changing relationship between work trips and non work trips.

Changes in the relation between work trips and peak period travel may arise in three areas. The first area of possible changes is in non work trip-making behavior. One such change would be a general increase in the number of non work trips being made, resulting in a decrease of the proportion of peak period trips that are work trips. It has been suggested by Ashford and Holloway, among others,[1] that this is occurring presently.

The second area of changes lies in the temporal distribution of work trips. The effects of staggered work hours, four day work weeks, and split shifts upon the model may prove debilitating. The number of work trips occurring during the peak period would be a preferable data base. However, this variable is not available from the census package, and forecasting peak period work trips may be more difficult than total daily work trips. This problem is complicated by the likelihood that changes in the temporal distribution of work trips will cause changes in non work trip making behavior also.

The third area of changes is in the distributional characteristics of work trips. If work trips become shorter in length, or if more or less work trips are made per employed person, then the relation between work trip travel and peak period travel may be changed.

In order to test whether the model remains stable over time, it should be developed for a year other than 1970 for comparison. No crystal ball is available to test the model against future year travel. However, a 1962 work trip table, street and highway network, and ground counts for major streets are available from the 1962 Origin-Destination Study. If the form of the peak period model can be shown to change while going backwards in time, it can be concluded that the relationship may very well change when going forward from 1970 as well.

A set of 82 major street hourly ground counts for 1962 was available for analysis. Home based work trips from the 1962 travel survey were assigned to the network using the same all or nothing technique as was used in 1970. The data was prepared for multiple regression runs against two evening peak periods, one morning peak period, and ADT traffic. The independent variables included in the analysis were, in addition to work trip assignments, those variables which describe the link's position in the network. The variables DIST, RCBD, RMB, ART, RCBDXD and DIR were included in analysis.[2] No capacity or land use data were available, and regression runs were made for only the linear form of the model. The significant resulting equations are listed in Appendix B. The R^2 values of these equations are commensurate with those developed from the 1970 data.

Since several significant variables were not available from the 1962 data, the most useful comparison is to look at the coefficients of the work trip variables in the simple two variable linear equation between work trips and traffic flow. These are presented in Table 20.

TABLE 20

COMPARISON OF COEFFICIENTS FOR WORK TRIP LOADS, 1962 AND 1970

	1962	1970	Ratio:1970/1962
5-6 PM	.22	.33	1.50
4-6 PM	.42	.61	1.45
7-8 AM	.20	.27	1.35
ADT	1.45,1.66	1.13,2.08	0.78,1.25

The first observation is that the two coefficients for the morning and evening work trips in the ADT equation are much closer in the 1962 models than in the 1970 models. Where the 1970 ADT coefficients are significantly different, the 1962 coefficients are not.[3] This is a reasonable finding, since it is expected that these two quantities should contribute equally to the average daily traffic on the facility.

The 1970 coefficients in the three peak period models are consistently and considerably higher than the 1962 coefficients. However, the 1970 data is based upon the "incomplete" census trip table which includes only about

77 percent of the total number of work trips. The 1962 data presumably represents the entire set of 1962 work trips. Thus, to be expanded to the full set of work trips, the 1970 data would be multiplied by one over .77, or 1.30. If there had been no change in the relation between work travel and total travel, the 1970 coefficients could be expected to be thirty percent higher than their 1962 counterparts. In fact, the three peak hour coefficients were from 35 to 50 percent higher, although this does not apply to the ADT model. Therefore, there is some indication that the coefficient on work trip assignments is increasing with time. Whether it will continue to do so in a period of high gasoline prices and short supply is a matter for additional consideration elsewhere.

Other variables found significant in the 1962 equations were RCBDXD, DIST, and DIR. Interestingly enough, the variable RMB entered only the ADT equation. This variable, representing radials to the military base, was found to be significant with a positive coefficient in many of the 1970 equations. In the 1962 case, however, it had a negative sign. The switch in the sign of the coefficient is explained by the observation that several of the military base radials experienced considerable residential and retail development along them, between 1962 and 1970. However, this does point out that great care should be exercised in choosing which variables should be included in a model for forecasting future travel.

Several significant conclusions can be drawn from the body of this work. The first is that it appears feasible to estimate the total quantity of peak period urban personal travel based upon a journey-to-work trip table such as is available in the 1970 Census Urban Transportation Planning Package. The method for doing so can make no claim to comprehensiveness in analyzing the factors that contribute to urban travel. It is not based upon an explanation of the behavior of persons or interrelationship of forces in the urban setting. However, a series of pragmatic concerns and observations build a rationale for estimating travel in this manner. The result is a procedure which appears to be as accurate as those currently in use, and which offers a possible substantial savings in time, resources, and ease of operations to the planning agency.

The statistical measures presented here show that the peak period model based upon the journey-to-work better replicates traffic count data than do the traditional urban transportation planning models. There are several reasons for this. First, the journey-to-work model is based upon 1970 census sample data, while the traditional UTP models are calibrated on older, 1962 trip survey data. Secondly, the UTP models, although considering the whole range of urban travel, are in fact, often insensitive to changes in the urban milieu due to a relatively unsophisticated theoretical basis. Finally, and perhaps most importantly, the journey-to-work model attempts to replicate peak period travel directly. while the traditional UTP models estimate average daily traffic which then has to be converted to peak hour traffic.

These results lead to the main conclusion which can be derived from this work. That is, the development of simpler estimation models, based upon simpler assumptions and incorporating fewer independent variables than those commonly used now, can lead to promising results. Such models use less data to operate and so the cost of obtaining and preparing forecasts of the required data is greatly reduced. This in turn means that more alternative urban development possibilities can be subjected to analysis. In addition, simpler models provide potential savings in computer space and time and thus expedite the simulation process. Finally, simpler estimation procedures should be easier to explain to layman decision-makers who are asked to act upon the products of these procedures.

This does not necessarily mean that the form of estimating model presented here is the most promising. Complications in the network assignment process were found while using these techniques. These complications are described in Appendix A. In addition the change in the coefficient for work trip assignments from 1962 to 1970 suggests that the model may not be stable through time.

In addition, a method was presented for describing the probability of making a significant error in the planned design of a facility when using the output of a forecasting model. The models considered here were subject to substantial chances for error, and it appears that other estimating models are also. This suggests that more consideration should be given to means of minimizing the costs of design level errors arising from estimation errors. Given that substantial chances for error exist in travel estimation procedures, what can be done to reduce their effect?

Considering specifically the model presented in the preceding pages, several observations can be made. Considerable effort was spent by the local planning agency in an attempt to improve the accuracy and usefulness of the census package work trip table by assigning work end zones to those primary work trips for which the census could not code a zone of work. No increase in explanatory power appears to have been gained thereby. The planning agency would be better advised to accept the trip table as is, or to add to it from locally collected data specifying the zone-of-residence of workers who are employed in zones which the census data did not estimate well. Because of recent concern for carpooling, this sort of information may be readily available. Even data lagged two or three years from the census may prove useful supplementary material to fill the holes in the census package.

In the analysis for Albuquerque, New Mexico, the evening peak hour was found to be the best peak period for modelling purposes. Not only did it have higher traffic volumes than the morning hour and thus is more critical in determining capacity requirements, but the regression equations gave a better fit to the evening peak hour data than to morning peak data.

Variables describing the location of the particular link to the rest of the network were found to be significant. Thus, dummy variables representing arterial streets, radials to the CBD and to the military base along with distance from the city's center were found to be significant in a number of regression equations. This suggests that it may be valuable to develop other, more descriptive variables describing a link's position in the transport network. A model of average daily traffic based upon work trip loads was found to be significant, although this does not obviate the need for a peak period model.

The model presented here dealt with automobile traffic on the urban street and highway network. The rationale for the method, however, appears to be equally valid for estimating travel on public transportation systems. The procedures described here can be applied with minor revision to estimating transit ridership. Since some mode split models are designed specifically for determining the modal choice of home-to-work trips, this procedure may prove valuable in multimodal transportation analysis.

FOOTNOTES

[1]Ashford and Holloway. "Time Stability of Zonal Trip Production Models."

[2]See above, P.82 for definitions of the variables.

[3]See Chapter IV, Footnote 11 for t-test for the 1970 coefficients. For the 1962 equation, coefficient of WKTAM = $B_1 = 1.45$, coefficient of WKTPM = 1.66. H_o: $B_1 = B_2$

$$\underline{t} = \frac{B_2 - B_1}{\text{Est.Std.Error } B_1} = 1.17$$

t(80,.999)=3.46, which is greater than $\underline{t}$. Therefore, the hypothesis that $B_1 = B_2$ cannot be rejected.

APPENDIX A

The battery of transportation planning programs developed for, available from and supported by the Federal Highway Administration, U.S. Department of Transportation, is the set of computer programs most commonly used by urban planning agencies. One recent study found 47 out of 70 planning agencies queried were using these programs.[1] This package is supplemented for transit planning by the Urban Transportation Planning System (UTPS) of the Urban Mass Transportation Administration.[2] Both sets of programs are available from FHWA and UMTA at no charge to governmental bodies, and nominal charge for others. Both sets operate on the IBM 360 or 370 computer, under full Operating System. Documentation of the FHWA package is readily available from FHWA.[3]

Unfortunately, although a great number of options have been incorporated into this package, it presently is not fully capable of operating the model presented here. As discussed below, the major problem is that no program in the current version of the battery can perform exponential operations upon data associated with network links. This effectively rules out the use of the log-linear forms of the model, although the linear forms can still be used.

Figure A-1 presents a flow diagram for developing the work trip model using the FHWA package. This procedure differs somewhat from that used in this work, but it is recommended as a better procedure based upon the experience

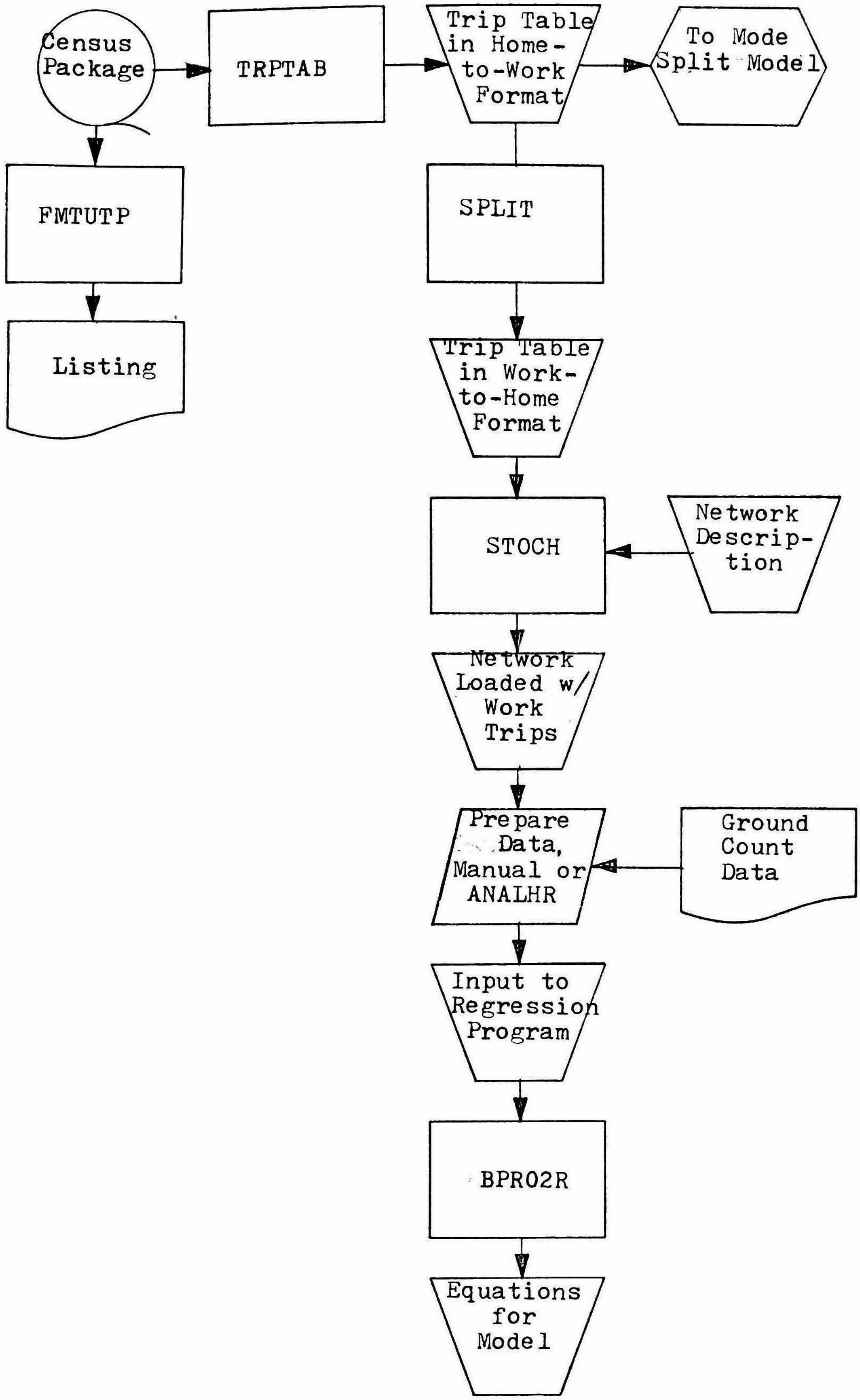


Figure A-1. Developing the Model Using the FHWA Battery of Urban Transportation Planning Programs of this model.

Program FMTUTP, written in COBAL Level U, is found on the 1970 Census Urban Transportation Planning Package, and can be used to obtain a listing of the package data.[4] TRPTAB, from the FHWA package, converts the trip table in the census package to the trip table format used by the FHWA programs. This can be built with up to eight modal trip tables as listed in the census package. (Auto-driver, Auto-passenger, Bus or streetcar, Subway or elevated, Railroad, Taxicab, Walked, and Other). These tables can provide the data base for developing a modal split model.

The auto-driver trip table is the table of interest for the model presented here. A transit mode trip table would be the table used if a transit model were being developed. In its present form, however, the census work trip table is a table of trips from home to work, while during the evening peak period, the predominant flow of work trips is from work to home. In order to properly reflect this, the trip table must be reversed. This can be done using program SPLIT with a Factor card having the parameters PROFAC equal 0, and ATTFAC = 100. Now

$$T'_{ij} = T_{ji}$$

where T'_{ij} = the trips from zone i to zone j in output trip table,

T_{ji} = the trips from zone j to zone i in input trip table,

and the trip table is in the proper work to home format for the evening peak hour.

Two assignment procedures are included in the FHWA package. The most commonly used, and the one used in this work, is the all-or-nothing assignment. This method first determines the minimum time or impedance routes from program BUILDVN, and then loads the trips on these fastest routes in an all-or-nothing assignment using program LOADVN. This allows substantial errors in assignment, because there is no diversion of trips from the single fastest route to other routes, and there is no procedure reflecting the balancing of speed and traffic volume which is brought about by congestion. To overcome this, a Capacity Restraint procedure is used whereby trips are loaded and travel times balanced to reflect the resulting loads in an iterative process.[5] The most common procedure loads the network four times and uses the average of the four loadings.

The difficulty in using Capacity Restraint in this procedure is that the total traffic on the network is needed to determine the effects of congestion on speeds. However, only a work trip table is available.

Figure A-2 shows a way around this problem. Here the original work trip table is factored by a constant to form a total trip table. As was discussed in the main body of this work, this is not an adequate method for estimating total trips from knowledge of work trips. However, it may be approximate enough for obtaining accurate work trip loadings. The factor to use must be determined independently. The simple factor used in this work is described earlier.[6]

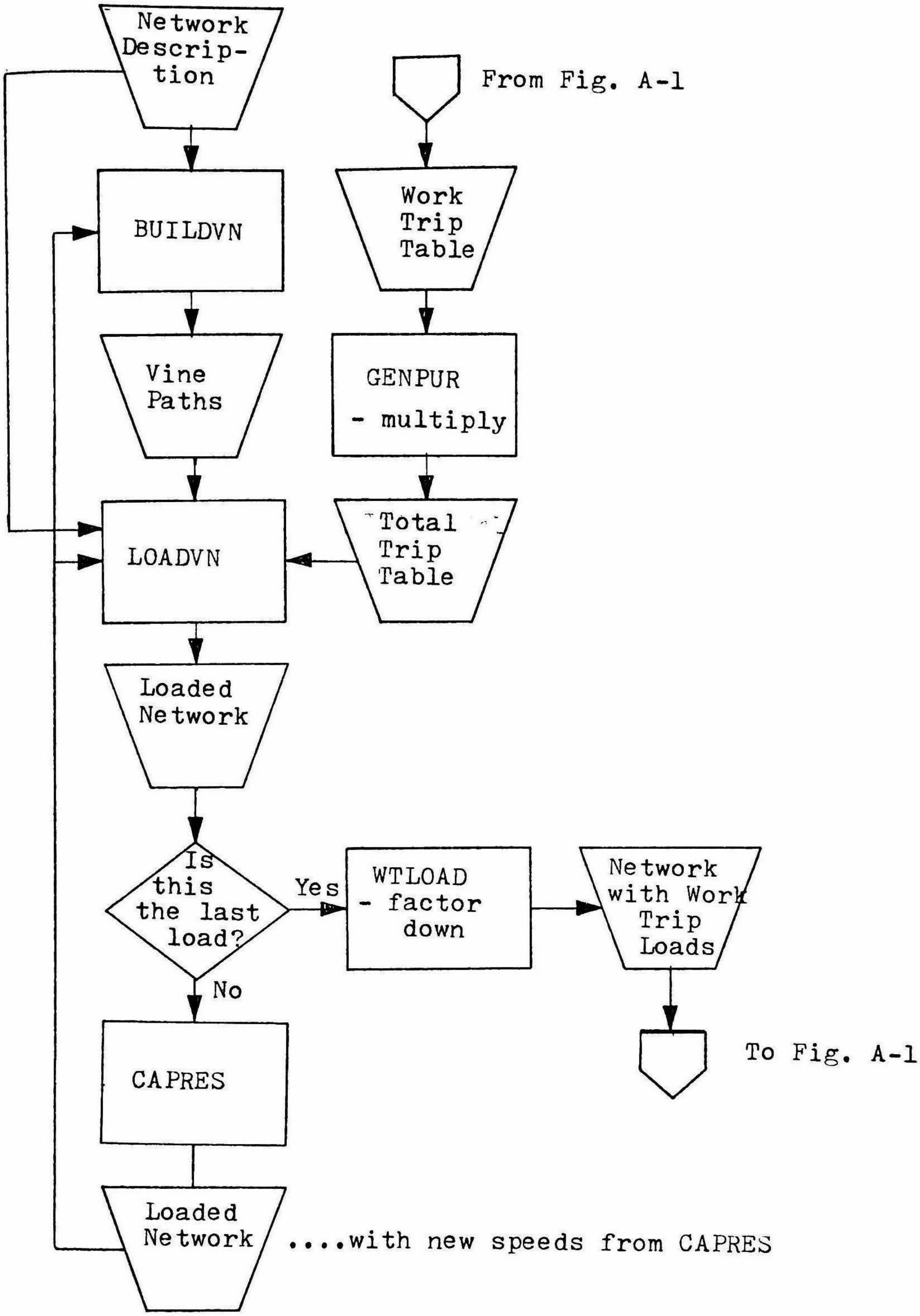


Figure A-2. Using All-or-Nothing Assignment to Assign Census Work Trip Table to a Computer Readable Network

After the trip table has been factored, the method proceeds in the normal way. After a sufficient number of iterations, program WTLOAD averages the loads and factors back down from total trips to work trips. For instance, if the expansion factor is 5, and the table is loaded four times, then the proper weight to give each load would be

$$1/4 \times 1/5 = .04.$$

The RATIO parameter for WTLOAD would then be .04 for each load, and the result would be a network loaded with work trips ready for the further development of the model.

Figure A-1 presents a faster procedure for obtaining the work trip loads using the second assignment procedure available in the FHWA battery. This makes use of Dial's multipath probabilistic assignment technique,[7] which is incorporated in program STOCH. This procedure assigns trips to all reasonable routes. The relative probability of a trip taking a given route is determined according to an exponential function of the travel time between that route and the shortest time route. The program requires about twice the computer running time of a single loading of the all-or-nothing assignment.[8]

For the base year, for which the census work trip table is available, the observed travel times on the network are the actual result of the interaction of street capacity and traffic flow. So a multipath assignment for the base year, using observed travel times, is not dependent upon a capacity restraint procedure for a reasonable traffic assignment.

Therefore, the base year assignment using program STOCH does not require a Capacity Restraint procedure, and since no Capacity Restraint is required, the work trip table can be loaded without expansion. This procedure places greater importance on the accurate measurement of base year network speeds, but results in a correspondingly more accurate assignment, as well as simpler and faster computer operations.

The STOCH program requires the user to specify an input dispersion parameter, theta. The proper value of this parameter is not presently known, and is the subject of current experimentation.[9] If a full trip table were available, the user could make network assignments using varying values for theta, comparing the results against ground counts until a reasonable fit is achieved. This is a long, expensive, but time-honored procedure. For cities with a full origin-destination survey at some time in the past, the resulting trip table could be used on its contemporary network. The assumption here is that theta remains constant over a long period of time, even if other parameters do not.

After the work trip loaded network is obtained, it is input to the multiple regression process, as Figure A-1 shows. The data for those links with good ground counts can be prepared manually, as was done here, or by using program ANALHR. If the computer program is used, the other link-specific data must have been coded into the historical record. In either case, only those links with good ground counts should be used. Although estimates of traffic flows can be obtained for other links, using them only introduces an additional source of error into the data, and may bias the data by reflecting the assumptions used in estimating the ground counts.

Program BPR02R in the FHWA battery is a revision of the BMD02R program developed at UCLA. Whichever program the user chooses can be used, and the choice is not limited only to multiple regression techniques for determining the form of the model and the value of its coefficients.

Figures A-3 and A-4 show how the model, once it is developed, can be applied to a future year work trip table and network to obtain an estimate of future traffic. Figure A-3 presents the procedure using the STOCH assignment process; Figure A-4 presents the procedure using the all-or-nothing assignment. It is possible to switch procedures, using one assignment method for developing the model and the other for applying it.

Once a predicted future year trip table is prepared, it is loaded on the network using program STOCH following the procedure outline in Figure A-3. The resulting loaded network is expanded to include the full universe of trips by applying the model developed above by the user. Program ANALHR can operate on the entries in the input historical record (an historical record is a link by link description of a loaded network) and output a new historical record which includes peak period link loads.

A serious problem arises here because ANALHR is limited to the arithmetic operations of addition, subtraction,

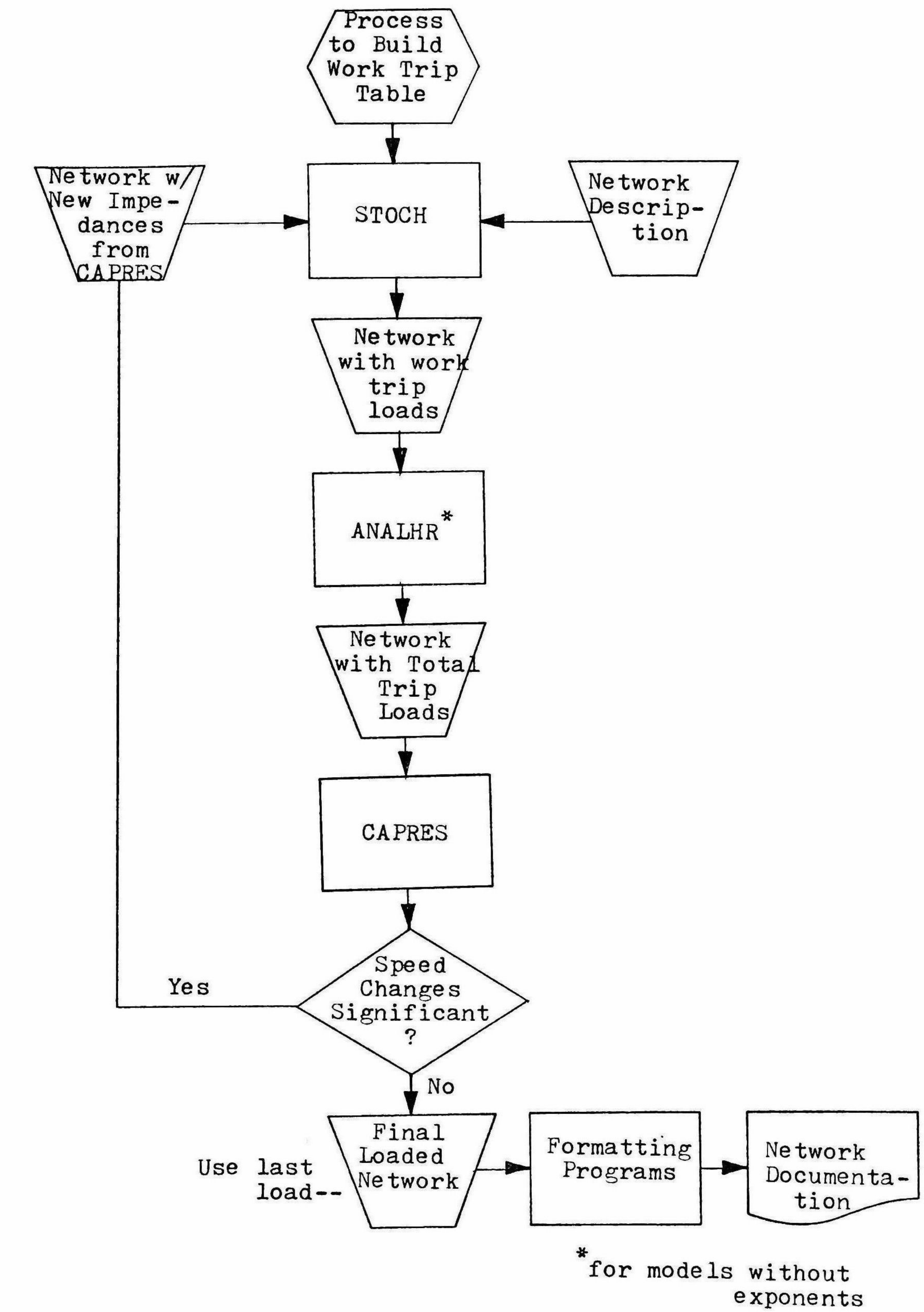


Figure A-3. Applying Model Using FHWA Battery, Assignment by Program STOCH

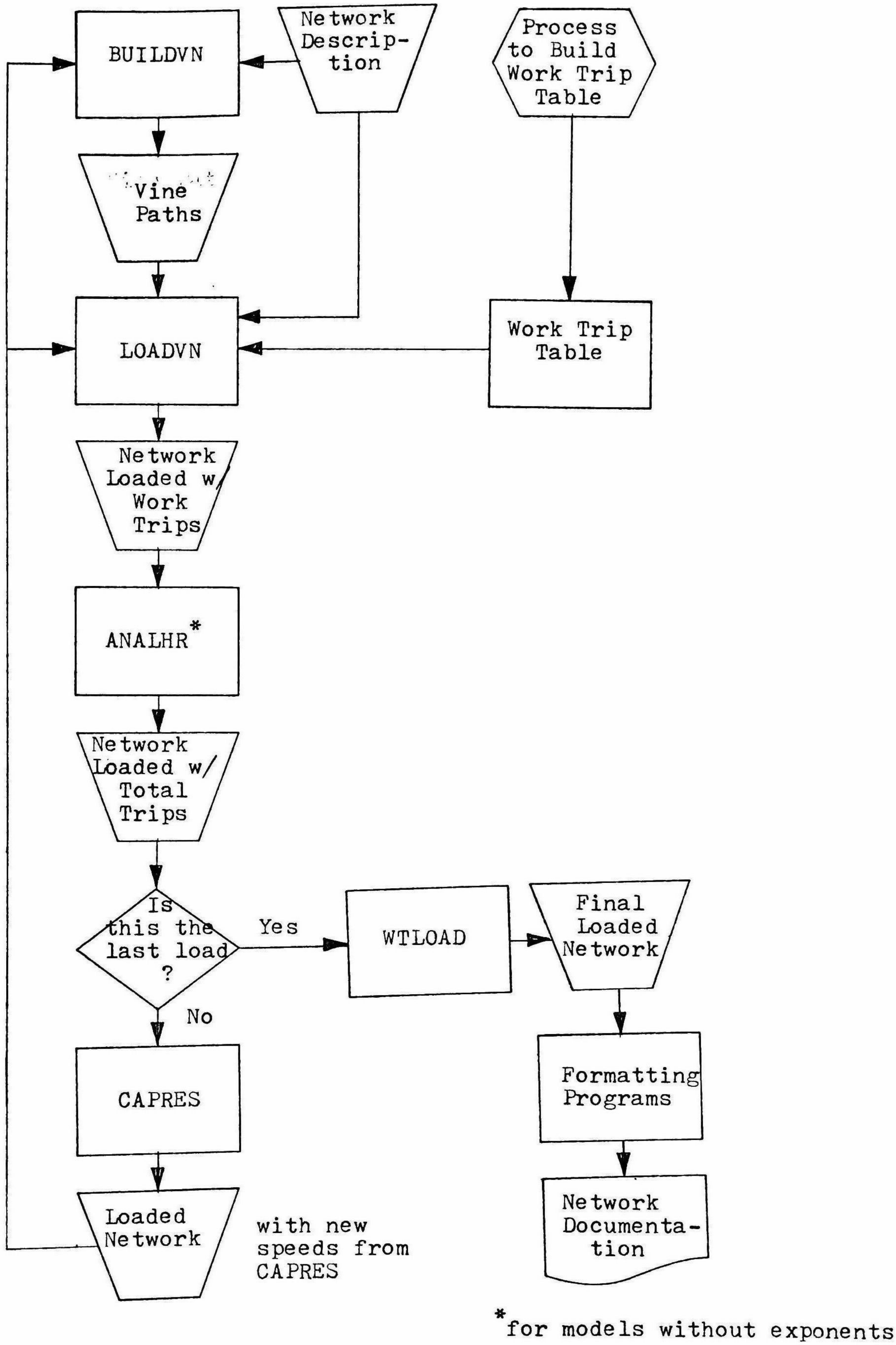


Figure A-4. Applying Model Using FHWA Battery, All-or-Nothing Assignment multiplication, and division. If the user has specified an exponential or log-linear model, this program can not perform the required expansion. This problem could be eliminated in future versions of the battery by incorporating the ability to evaluate exponential functions into the program, or by allowing the user to write his own fortran or fortran-like subroutines for adding new variables to the historical record.

Program LNKCOST may have some use here. This program allows the user to insert a "cost" word which is a non-linear function of "speed" into the historical record. Since any word currently in the historical record can be defined as "speed," this in effect allows one exponential function to be evaluated. The user can specify up to five curves, and each link will choose one of these curves. The curves are defined by a number of points on the "speed-cost" curve, and the program interpolates between them. The resulting "cost" is multiplied by "speed" before being inserted into historical record. However, if more than one variable in the model has an exponential, LNKCOST cannot evaluate the equation. In this case, there appears to be no easy method for using the FHWA battery to apply the model.

After the trips have been expanded to a total peak period network load, program CAPRES is used to adjust link speeds to properly reflect link traffic. If CAPRES significantly changes network impedances, then the input values for STOCH in the previous assignment are no longer valid, and the traffic assignment process has to be repeated until a balance is reached.

This appears to be a judgment decision on the part of the user. Fortunately, CAPRES prints a considerable amount of data which can aid in this decision. For instance, one table presents the number of links by the change in miles per hour. If very few links have been changed more than 5 miles per hour, it can be concluded that no significant change in network impedances has occurred. CAPRES also prints a detailed link report showing loads, capacity, previous speed and new speed for each network link.

Of course, variations of this procedure are possible, including the incremental loading of the network following closely the procedures used in the all-or-nothing assignment.

When the final loads are obtained, they can be prepared for presentation and analysis by any of the network formatting programs. The most useful of these are PRINTLD, FORMAT and ANALHR. The network can be prepared for machine plotting by programs GEPREP and GEPLOT.

As Figure A-4 shows, the procedure applying the model using the all-or-nothing assignment is very similar to that used in developing the model, Figure A-2. The one addition is the inclusion of ANALHR, or some other program for expanding the assignment to total peak period trips, after LOADVN. Also, WTLOAD simply averages the loads instead of also factoring the trip table down to represent work trips. This procedure is actually an incremental loading process, and is similar to the loading procedure for the traditional urban transportation planning models.

The difficulty encountered in making operational the model presented here is alleviated when using the UMTA-sponsored Urban Transportation Planning System (UTPS) computer programs.[10] The highway network loading program from this battery, UROAD, allows the user seven entry points at which he may insert fortran-written sub-routines.

This program can load the network using an all-or-nothing, all-shortest-paths, or probabilistic multipath assignment technique. It also can use capacity restraint and equilibrium-seeking procedures for iterative assignment. The program reads network built by BUILDHR and trip tables in FHWA format, as well as trip tables output by program UMODEL from the UTPS package.

FOOTNOTES

[1]City of San Diego, Community Development Department, Computer Programs for Transportation Planning in the City of San Diego, Phase I: Selection of a Program Battery, January, 1972, Pp. 6,7.

[2]U.S., Department of Transporation, Urban Mass Transportation Administration, New Systems Requirements Analysis Program, (Course notes). October, 1972.

[3]U.S., Department of Transportation, Federal Highway Administration, Urban Transportation Planning, General Information and Introduction to System 360, (Washington, D.C.: Government Printing Office, March 1972); U.S., D.O.T., FHWA, Program Documentation, Urban Transportation Planning, (Washington, D.C.: Government Printing Office, March 1, 1972).

[4]Program FMTUTP is described in several places: Sword & Fleet, Updating Using the 1970 Census Data; U.S. Dept. of Commerce, Bureau of the Census, 1970 Census UTP Package, Pp. 32-33; Howell and Davenport, Test of the Standard Package, Appendix I.

[5]FHWA, General Information and Introduction to System 360, Pp. III-14 to III-18; FHWA, Program Documentation, Pp. 181-208; FHWA, Traffic Assignment, Pp 34-38; Mathew J. Huber, Harvey B. Boutwell, and David K. Witheford, Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use, National Cooperative Highway Research Program Report 58 (Washington, D.C.: Highway Research Board, 1968).

[6]Above, P. .

[7]Robert B. Dial, "A Multipath Traffic Assignment Model," Highway Research Record 369 (1971) Pp 199-210; Robert B. Dial, A Probabilistic Multi-Path Traffic Assignment Model Which Obviates Path Enumeration, (National Technical Information Service, 1971).

[8]FHWA, Traffic Assignment, P. 40.

[9]FHWA, Program Documentation, P. 701.

[10]U.S., Department of Transportation, Urban Mass Transportation Administration, UTPS Reference Manual, (Washington, D.C.: Urban Mass Transportation Administration, April 1, 1974.) This reference manual is included on the tape containing the UTPS programs.

APPENDIX B

EQUATIONS OBTAINED USING 266 MAJOR STREET AND FREEWAY CASES

Dependent Variable	R^2	Std. Error	F	Equation
5-6 PM	.73	268.5	236	195.15 + 0.27WKT + 586.35FWY + 201.33ART
5-6 PM	.73	266.3	242	189.49 + 0.22GMT + 513.13FWY + 191.98ART
4-6 PM	.77	474.8	299	380.73 + 0.51WKT + 1300.89FWY + 404.37ART
4-6 PM	.78	468.2	310	369.54 + 0.42GMT + 1157.48FWY + 385.62ART
HI HR	.75	266.1	264	221.19 + 0.28WKT + 627.54FWY + 245.65ART
HI HR	.76	263.2	272	449.16 + 0.23GMT + 311.32 FWY + 230.25ART

n = 266

All coefficients are significantly different from 0 at the .01 level

FREEWAY EQUATIONS, EVENING PEAK PERIOD

Dependent Variable	R^2	Std. Error	F	Equation
- Linear				
5-6 PM	.65	419.1	58	$809.17 + .25WKT$
5-6 PM	.66	413.1	57	$724.49 + .22GMT$
5-6 PM	.68	406.0	31	$489.59 + .23GMT + 61.09^{**}DIST$
4-6 PM	.66	780.0	58	$1706.83 + .50WKT$
4-6 PM	.68	756.9	64	$1533.95 + .42GMT$
HI HR	.69	390.4	32	$948.61 + .30WKT - 290.05^{**}DIR$
HI HR	.72	379.6	24	$1352.77 + .31WKT - 318.32^{*}DIR - .18^{**}CAP$
HI HR	.68	389.4	64	$822.80 + .22GMT$
HI HR	.74	365.8	26	$1285.08 + .25GMT - 276.24^{**}DIR - 0.20^{**}CAP$
- Log transformation				
5-6 PM	.62	.308	49	$WKT^{.47}e^{3.65}$
5-6 PM	.73	.275	18	$WKT^{.65}CAP^{-.33^{**}}e^{(4.80-.05^{**}DIST-.31DIR)}$
4-6 PM	.76	.235	30	$WKT^{.60}CAP^{-.46}e^{(7.09-.32DIR)}$
4-6 PM	.74	.248	26	$GMT^{.59}CAP^{-.44^{*}}e^{(6.78-.25DIR^{*})}$
4-6 PM	.70	.262	33	$WKT^{.54}e^{(3.93-.26DIR^{*})}$

*Not significantly different from 0 at .01 level

**Not significantly different from 0 at .05 level

All other coefficients are significantly different from 0 at .01 level.

(Cont.)

Dependent Variable	R^2	Std. Error	F	Equation
HI HR	.68	.266	31	$WKT^{.53} e^{(3.37 - .26DIR^{*})}$
- Linear factor				
HI HR/WKT	.58	.353	20	$.70 + .15DIST - .60DIR$

n = 32

*Not significantly different from 0 at .01 level

All other coefficients are significantly different from 0 at .01 level.

MAJOR STREET EQUATIONS, LINEAR FORM, EVENING PEAK PERIOD

Dependent Variable	R^2	Std. Error	F	Equation
5-6 PM	.61	216.4	70	169.43 + .25WKT + 95.24*ART + 120.54RCBD + 168.26R
5-6 PM	.62	214.8	72	165.05 + .20GMT + 87.53*ART + 122.07RCBD + 230.39RMB + 169.49R
4-6 PM	.64	376.5	67	351.94 + .45WKT + 241.80ART + 221.86RCBD +400.68RMB - 199.99*V + 248.13R
4:30 PM	.66	204.6	88	171.26 + .27WKT + 124.43ART + 144.47RCBD +212.86RMB + 130.32R
4:30 PM	.67	203.4	90	166.74 + .22GMT + 116.39ART + 146.38RCBD + 211.50RMB + 131.69R
15 MPM	.65	64.8	69	54.34 + .07GMT + 32.66ART + 49.90RCBD + 68.61RMB - 47.43MT +37.51R
HI HR	.68	210.4	66	194.35 + .23GMT + 128.14ART + 148.05RCBD + 249.35RMB - 114.22V* - 142.48*MT + 120.75 R
HI HR	.66	215.1	87	184.72 + .28WKT + 128.59ART + 146.29RCBD + 217.72RMB + 152.68R
HI HR[1]	.60	223.4	141	65.60 + .26WKT + .26CAP
HI HR[1]	.62	217.8	102	80.57 + .26WKT + .23CAP + 131.14R

*Not significantly different from 0 at .01 level

[1] n = 193. All other equations, n = 230

All other coefficients are significantly different from 0 at .01 level.

(CONT.)

Dependent Variable	R^2	Std. Error	F	Equation
HI HR[1]	.67	205.0	62	73.35 + .24WKT + .17CAP + 102.43R + 81.56*ART + 31.50RCBDXD + 164.31RMB
HI HR[1]	.67	204.4	54	81.07 + .24WKT + .17CAP + 93.78R + 82.03*ART + 30.75RCBDXD + 172.02RMB - 86.30**V

*Not significantly different from 0 at .01 level

**Not significantly different from 0 at .05 level

[1] n = 193. All other equations, n = 230.

All other coefficients are significantly different from 0 at .01 level.

MAJOR STREET EQUATIONS, LOG LINEAR FORM, EVENING PEAK PERIOD

Dependent Variable	R^2	Std. Error	F	Equation
5-6 PM	.68	.367	55	$WKT^{.27}CAP^{.21}e^{(2.71+.21ART+.35RMB-.26V+.11R+.06RCBDXD)}$
4-6 PM	.63	.365	109	$WKT^{.25}CAP^{.31}e^{(2.82+.34ART)}$
4-6 PM	.69	.338	60	$WKT^{.24}CAP^{.24}e^{(3.38+.27ART+.30RMB-.25V+.54RCBDXD+.10^{*}R)}$
4:30 PM	.64	.365	113	$WKT^{.25}CAP^{.32}e^{(2.12+.34ART)}$
4:30 PM	.71	.334	64	$WKT^{.24}CAP^{.22}e^{(3.04+.24ART+.40RMB+.13^{*}R+.07RCBDXD-.05DIST)}$
HI HR	.65	.356	117	$WKT^{.26}CAP^{.31}e^{(2.27+.34ART)}$
HI HR	.69	.337	83	$WKT^{.25}CAP^{.25}e^{(2.66+.28ART+.29RMB+.06RCBDXD)}$
HI HR	.70	.332	72	$WKT^{.25}CAP^{.23}e^{(2.93+.26ART+.38RMB+.06RCBDXD-.030DIST)}$
HI HR	.71	.326	57	$WKT^{.24}CAP^{.21}e^{(3.09+.25ART+.37RMB-.17^{**}V+.12^{*}R+.06RCBDXD-.03DIST)}$
15 MPM	.68	.347	78	$WKT^{.25}CAP^{.26}e^{(1.36+.21ART+.26RCBD+.33RMB)}$

*Not significantly different from 0 at .01 level

**Not significantly different from 0 at .05 level

n = 193

All other coefficients are significantly different from 0 at .01 level.

MAJOR STREET EQUATIONS, LINEAR AND LOG FACTOR FORMS, EVENING PEAK PERIOD

Dependent Variable	R^2	Std. Error	F	Equation
- Linear factor				
4-6 PM/WKT	.14	9.62	8	$11.21 - 5.57DIR + 3.03^{*}RCBD + 5.18^{**}MT - 0.0036CAP$
4:30PM/WKT	.12	5.47	9	$6.39 - 2.98DIR + 1.93^{*}RCBD - .0021CAP$
HI HR/WKT	.12	5.59	9	$6.62 - 3.06DIR + 1.98^{*}RCBD - .0022CAP$
HI HR/GMT[1]	.11	4.18	9	$4.06 - 2.34DIR - .27DIST + 3.25MT$
- Log linear factor				
4-6 PM/WKT	.31	.798	29	$CAP^{-.38}e^{(4.07-.98DIR+.30RCBD)}$
4:30PM/WKT	.29	.804	26	$CAP^{-.37}e^{(3.34-.93DIR+.33RCBD)}$
HI HR/WKT	.30	.799	27	$CAP^{-.39}e^{(3.50-.93DIR+.33RCBD)}$
15MP M/WKT	.29	.806	26	$CAP^{-.38}e^{(2.22-.92DIR+.34RCBD)}$

*Not significantly different from 0 at .01 level.

**Not significantly different from 0 at .05 level.

[1]Based on sample of 230 cases. All other equations are based on a sample of 193 cases.

All other coefficients are significantly different from 0 at .01 level.

EQUATIONS FOR PREDOMINANT DIRECTION OF WORK TRAVEL

Dependent Variable	R^2	Std. Error	F	Equation
-Linear				
4-6 PM	.63	4.07	45	$154.99 + .29GMT + 190.83^{*}RCBD + 328.94^{*}RMB + .37CAP$
4:30 PM	.65	2.26	49	$83.41 + .21WKT + 136.6RCBD + 191.08^{*}RMB + .20CAP$
4:30 PM	.65	2.27	48	$76.29 + .17GMT + 141.14RCBD + 197.95RMB + .20CAP$
HI HR	.60	2.53	80	$84.28 + .24WKT + .27CAP$
HI HR	.64	2.42	37	$103.76 + .22WKT + .18CAP + 119.12RCBD + 211.93RMB + 84.69^{**}(O+C+R)$
- Log linear				
5-6 PM	.66	.343	45	$WKT^{.33}CAP^{.30}e^{(1.84+.27R+.06RCBDXD)}$
4-6 PM	.67	.327	46	$WKT^{.28}CAP^{.38}e^{(2.36+.23R-.38V)}$
4:30 PM	.74	.302	30	$WKT^{.27}CAP^{.28}(WKT/AMT)^{.01^{**}}e^{(2.56+.19^{*}R-.22^{**}V+.42RMB-.05DIST+.07RCBDXD)}$
HI HR	.71	.314	35	$WKT^{.25}CAP^{.35}e^{(2.14+.28RMB-.32V+.17^{*}R+.07RCBDXD)}$
15 MPM	.70	.324	42	$WKT^{.30}CAP^{.38}(WKT/AMT)^{.02}e^{(.24+.25R+.06RCBDXD)}$

*Not significantly different from 0 at .01 level

**Not significantly different from 0 at .05 level

For linear equations, n=95. For log transformation, n=95

All other coefficients are significantly different from 0 at .01 level

MORNING PEAK PERIOD EQUATIONS

Dependent Variable	R^2	Std. Error	F	Equation
-freeway				
7-8 AM	.56	.36	18	$AMT^{.54}e^{(3.00+.26DIR)}$
- major streets				
7-8AM	.51	174.6	65	52.82 + .25AMT +16.16RCBDXD
7:30 AM	.52	211.2	103	112.33 + .31AMT
7:30 AM	.56	202.9	48	204.11 + .28AMT + 106.00ART - 74.54* DIR + 21.35RCBDXD - 76.35* (MT+H)
15M AM	.54	68.1	45	31.63 + .08AMT + 26.91ART - 33.66DIR + 6.96RCBDXD + .03CAP

*Not significantly different from 0 at .01 level

n = 32 for freeway, n = 193 for major streets

All other coefficients are significantly different from 0 at .01 level

ADT EQUATIONS

Dependent Variable	R^2	Std. Error	F	Equation
- Freeway				
ADT	.81	.19	41	$WKT^{.36}AMT^{.36}e^{(4.01+.08DIST)}$
- Major Streets				
ADT	.68	1772.9	81	$172.82 + 1.16WKT + 2.10AMT + 313.17RCBDXD + 1492.19R + 1.87CAP$
ADT	.61	1947.5	101	$250.97 + 1.13WKT + 2.08AMT + 2.32CAP$
ADT	.71	.329	57	$WKT^{.13}AMT^{.15}CAP^{.24}e^{(4.75+.28ART+.19RCBD+.23RMB-.23^{*}V+.19R)}$
ADT	.65	.359	115	$(WKT + AMT)^{.30}CAP^{.33}e^{(3.81+.34ART)}$

*Not significantly different from 0 at .01 level

All other coefficients are significantly different from 0 at .01 level

1962 Equations

	R^2	Std.Error	F	Equation
5-6 PM	.66	206.6	156	165.04 + .22WKTPM
5-6 PM	.68	201.8	84	150.51 + .21WKTPM + 45.53RCBDXD*
4-6 PM	.66	390.0	158	359.93 + .42WKTPM
4-6 PM	.71	368.0	63	387.11 + .42WKTPM + 89.30RCBDXD* - 175.93DIR*
7-8 AM	.57	227.32	105	96.02 + .20WKTAM
7-8 AM	.58	225.8	54	168.29 + .19WKTAM - 17.69DIST**
ADT	.74	2000.2	74	1017.19 + 1.45WKTAM + 1.66WKTPM - 3204.46RMB

WKTAM = 1962 morning direction work trips

WKTPM = 1962 evening direction work trips

*Not significantly different from 0 at .01 level

**Not significantly different from 0 at .05 level

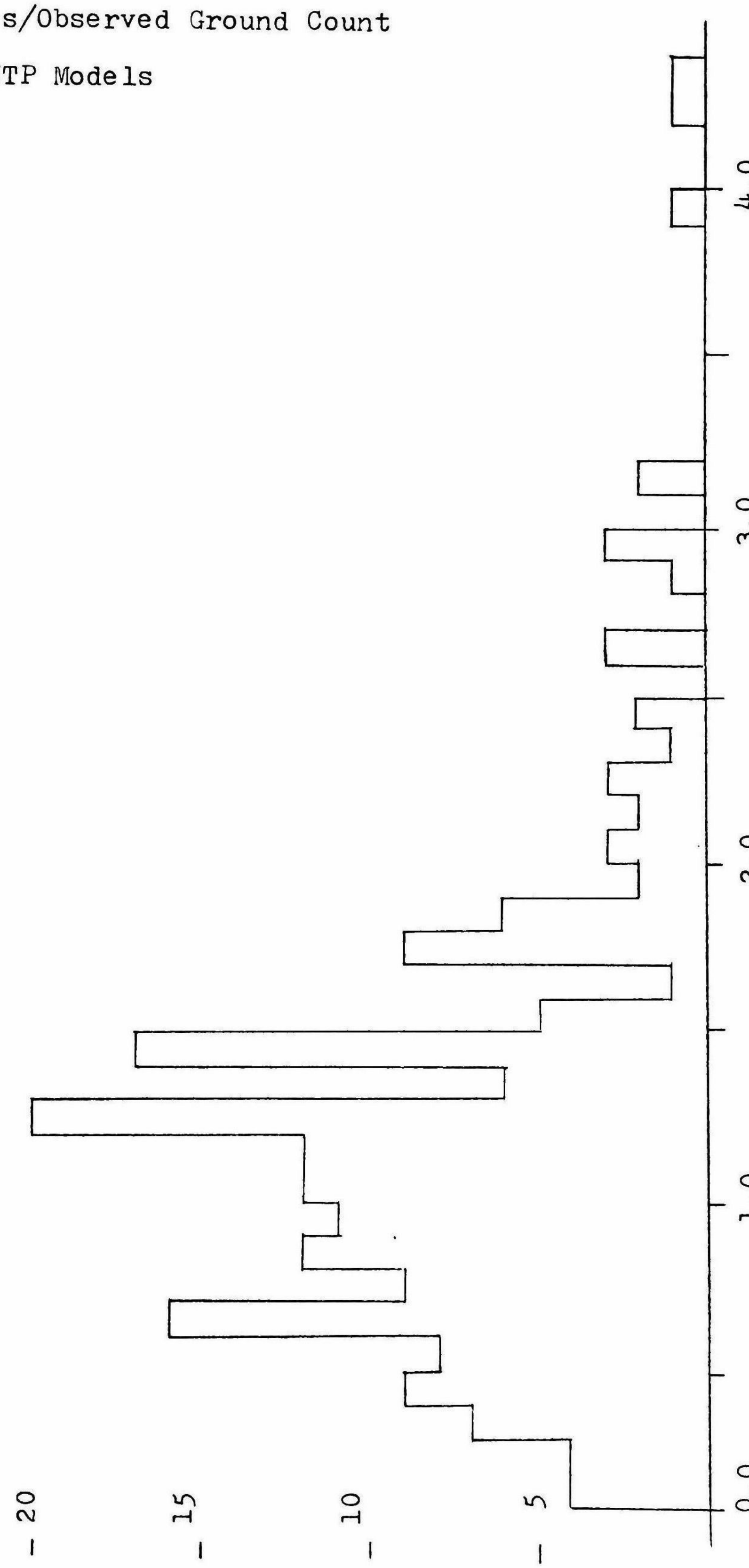
n = 82

All other coefficients are significantly different from 0 at .01 level

Distribution of Ratios,

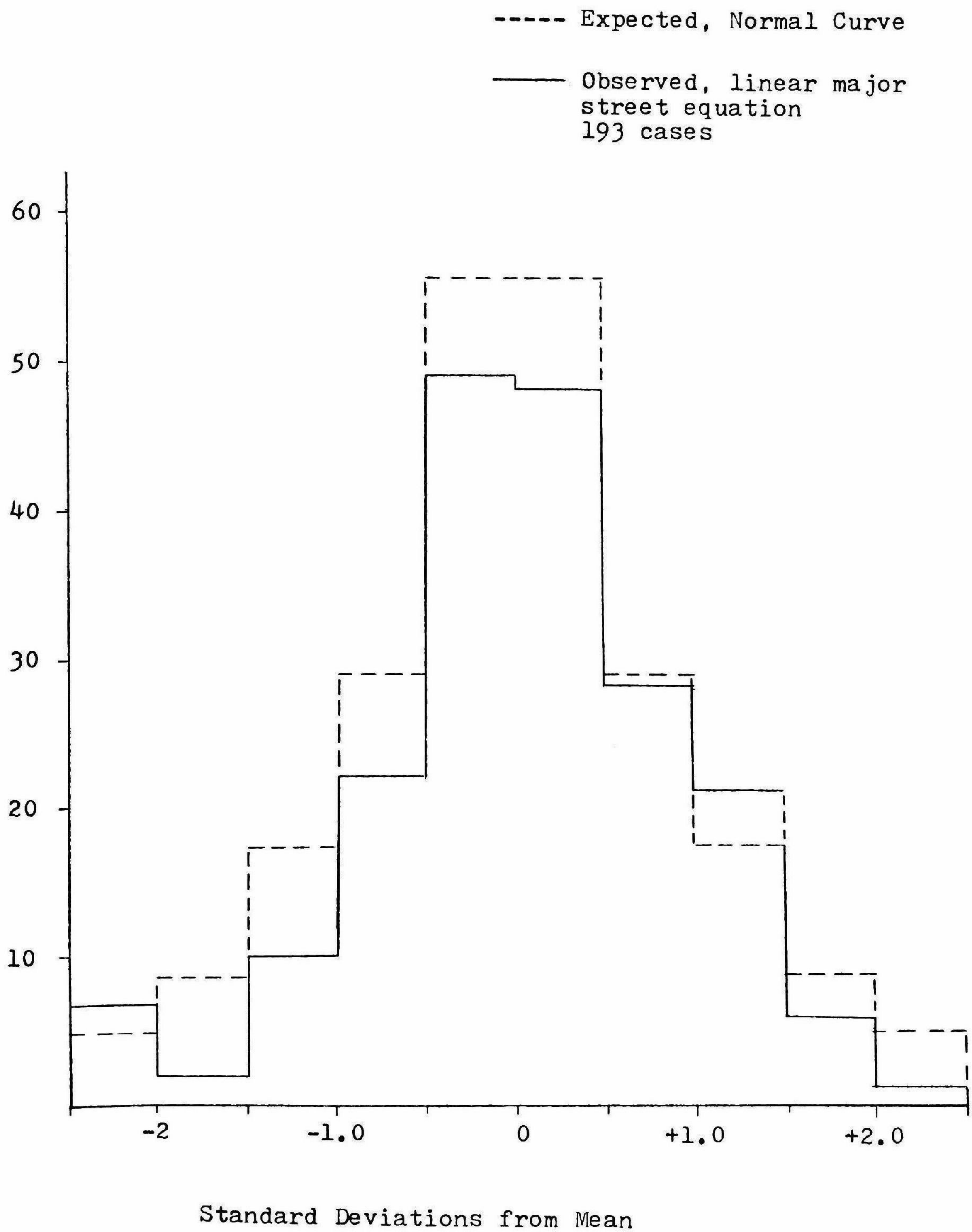
Calculated Values/Observed Ground Count

UTP Models



APPENDIX C

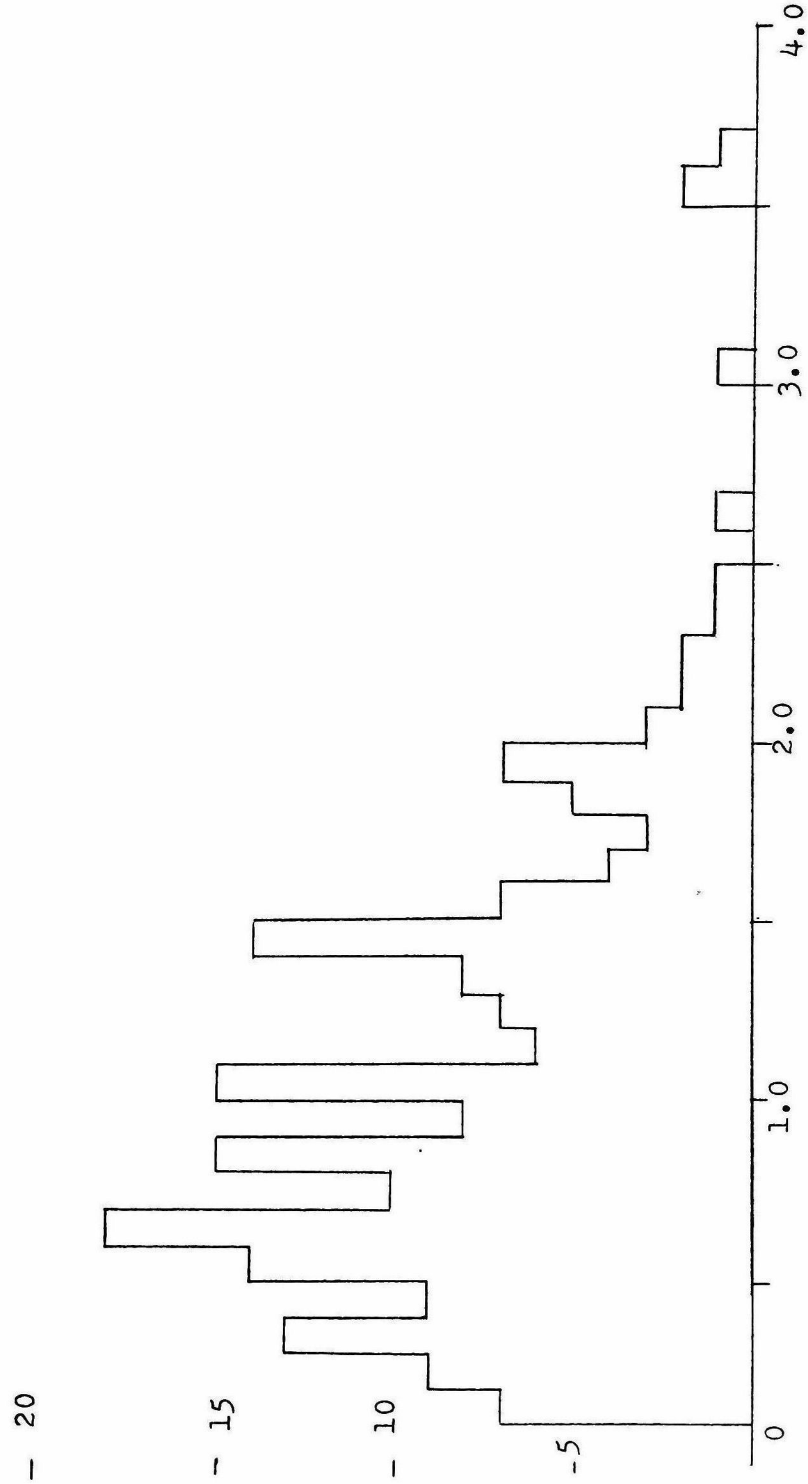
FREQUENCY DISTRIBUTION OF DEVIATIONS OF CALCULATED VALUES FROM OBSERVED VALUES



Distribution of Ratios,

Calculated Values/Observed Ground Count

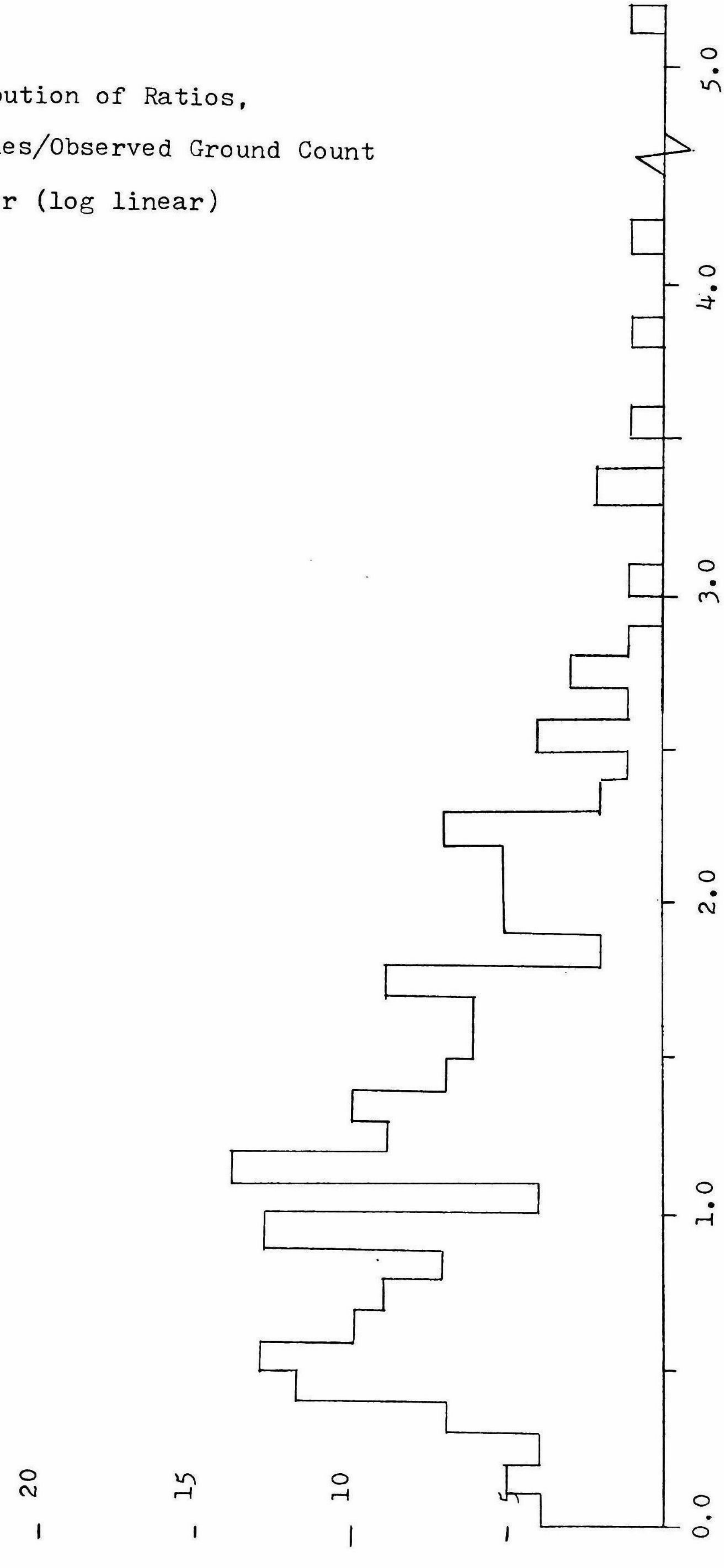
Simple Factor



Distribution of Ratios,

Calculated Values/Observed Ground Count

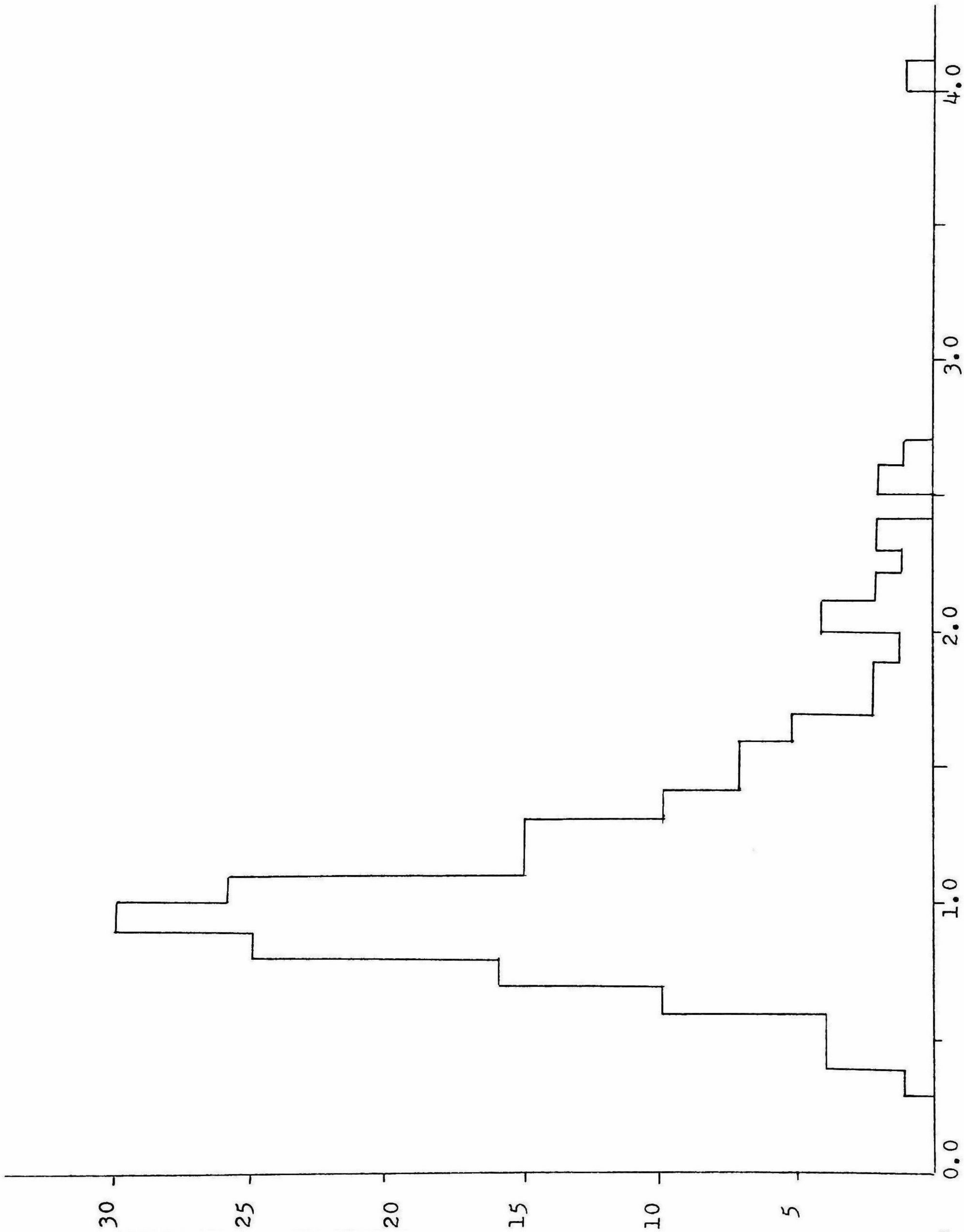
Factor (log linear)



Distribution of Ratios,

Calculated Values/Observed Ground Count

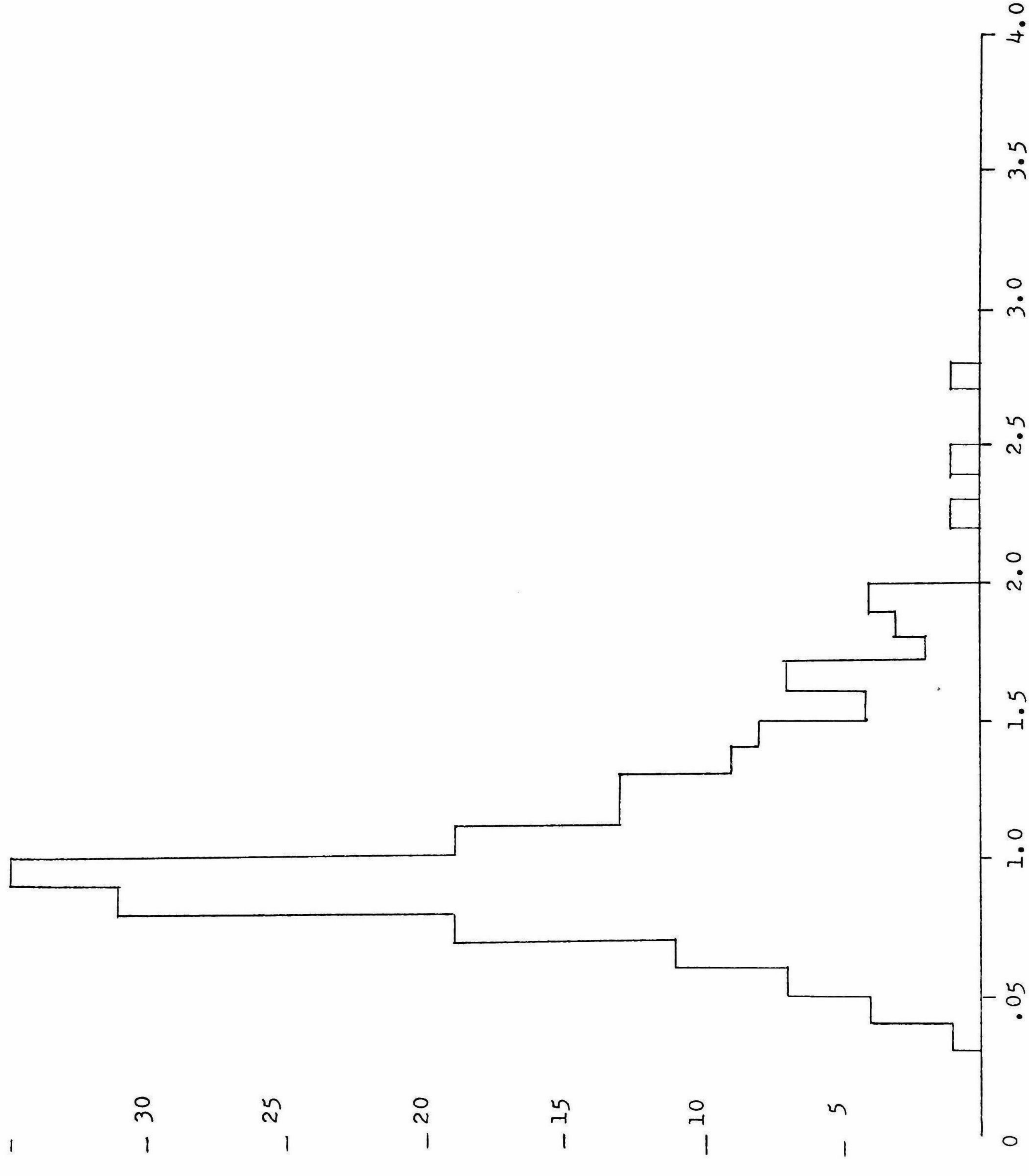
Linear Equation



Distribution of Ratios,

Calculated Values/Observed Ground Count

Log Linear Equation



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2. Home-to-Work Trip Table Expansion by the Use of an Algorithm, June 1973.