Calibrating & Testing a GRAVITY MODEL for Any Size Urban Area

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PREFACE

Trip distribution is an important and complex phase of the transportation planning process. It provides the planner with a systematic procedure capable of estimating zonal trip interchanges for alternate plans of both land use and transportation facilities. These zonal interchanges constitute a basic part of the travel information necessary for transportation planning.

This manual documents in detail the process of trip distribution utilizing the gravity model as it is now defined. Since automated trip distribution techniques have only become available in the last decade, the details involved in the various steps are still being improved. However, every attempt has been made to include in this manual the most up-to-date information available.

A companion manual, the <u>Traffic Assignment Manual</u> (1)[1], was published by the Bureau of Public Roads in June 1964. Together, these manuals document two of the basic steps necessary for transportation analysis and forecasting.

The techniques described in these manuals have functioned satisfactorily when used by the Bureau of Public Roads and several urban transportation studies. The programs and procedures have proven to be quite efficient in handling large as well as small urban systems.

The computer programs that are described in the text are, with the exception of some peripheral IBM 1401/1410 programs, designed for use on the high speed binary IBM 7090/7094 computer.

Actually, the analytical procedures could have been developed for use on any of the several computer systems of the required capacity. In fact, programs to accomplish these procedures have been developed for exclusive use on the IBM 1401 (16K) and the IBM 1620 (60K) computers. They differ principally in their focus on different sized urban areas. The latter two systems have been documented in a form similar to this volume (2) (3) and are available for distribution.

1/ The numbers in the parentheses identify references listed in the bibliography.

In addition similar programs have been written for the Control Data Corporation 3600 computer[2] and for various Univac computers.[3]

The computer program descriptions, containing all of the information necessary for program use, are described in the appendix of this manual.

The system described in this volume is designed to edit, sort, and link a set of detailed trip records from basic travel inventories. It will build complete tables of zonal trip interchanges from origin-destination survey data for any combination of trip purposes or travel modes desired. The system will compute the actual trip length frequency distribution for a given set of data. It will completely develop multipurpose gravity models to simulate existing or future trip distribution patterns. Finally, the system will compare the base year zonal interchanges computed by the gravity models with those obtained from the travel inventories.

It is possible by combining these programs with those concerned with traffic assignment, to complete most of the analytical phases of a comprehensive transportation planning study. In addition, it is possible to examine interim computer results at almost any phase of the process. This is a significant advantage, particularly in the developmental stages of a study.

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[2] Transportation Planning System for the Control Data 3600 Computer, Data Centers Division, Control Data Corporation, May 1965.

[3] Information is available from Univac Division of Sperry Rand Corporation, New York 19, New York.

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Chapter I
BACKGROUND

A. <u>General Introduction</u>

Federal, State, and municipal agencies concerned with making decisions on when and where to construct new urban roads and streets, or to improve existing ones, must consider many factors in reaching sound decisions. Consequently, considerable time, money, and effort are usually expended in the planning and design of such improvements. For the most part, the planning work is carried on within the framework of an urban transportation study.

Since the end of World War II urban transportation studies have been conducted in an increasingly comprehensive manner. Significant improvements in both basic study philosophy and analysis methodology have greatly contributed to a better understanding of the urban transportation problem. Urban traffic patterns now, and in the future, are a function of:

1. The type and extent of the transportation facilities available in an area;

2. The pattern of land use in an area, including the location and intensity of use; and

3. The various social and economic characteristics of the population of an urban area.

The transportation planning process utilizes these interrelationships to provide quantitative information on the travel demands generated by alternate land use patterns and transportation systems. Such information can then be used to make decisions on when and where improvements should be made in transportation networks, thus satisfying the present and future travel demands and promoting desirable land development patterns.

Analysis of many travel habit studies, particularly the home interview origin-destination surveys, in relation to the use of land and the various social and economic characteristics of trip makers, indicates that zonal trip interchanges can be estimated, within reasonable limits of accuracy, by mathematical formulas called "trip distribution models." When these same characteristics for the future urban area can be predicted, it is possible to compute a forecast of that area's trip distribution patterns through mathematical model techniques.

The use of trip distribution models in transportation planning offers certain advantages over other trip distribution forecasting techniques. Earlier it was suggested that a basic aim of the transportation planning process was to provide decision makers with quantitative information about the consequences of their decisions concerning the type, location, size, and timing of transportation improvements. Mathematical trip distribution models provide a common base for simulating the travel patterns expected to result from a variety of different highway or mass transit systems. This allows public officials to estimate and judge, in advance, the probable consequences in terms of travel patterns of a variety of different transportation systems.

Although several different types of traffic models are now in existence and currently being utilized in transportation studies around the country, this volume is concerned solely with the gravity model. A discussion of the theory and practical application of this traffic model will be presented on subsequent pages. This discussion, however, should not be interpreted to imply that the Bureau of Public Roads favors the gravity model over other traffic models. In fact, the Urban Planning Division of the Bureau of Public Roads is planning to prepare similar volumes for other traffic models as well. A project conducted by the Urban Planning Division to test, evaluate, and compare four major trip distribution techniques has recently been completed (4).

B. Gravity Model Theory

To date, the most widely used trip distribution model has been the so-called "gravity model." As the name implies, this model adapts the gravitational concept, as advanced by Newton in 1686, to the problem of distributing traffic throughout an urban area (5). The gravity model has been the most widely used formula mainly because it is simple in concept and because it has been well documented.

In essence, the gravity model says that trip interchange between zones is directly proportional to the relative attraction of each of the zones and inversely proportional to some function of the spatial separation between zones. This function of spatial separation adjusts the relative attraction of each zone for the ability, desire, or necessity of the trip maker to overcome the spatial separation involved. Mathematically, the gravity model is stated as follows:

$$T_{ij} = P_i \frac{\dfrac{A_j}{d_{ij}^{\,b}}}{\dfrac{A_1}{d_{i1}^{\,b}} + \dfrac{A_2}{d_{i2}^{\,b}} + \cdots\cdots \dfrac{A_n}{d_{in}^{\,b}}}$$

Where: T_{ij} = trips produced in zone i and attracted to zone j

P_i = trips produced by zone i

A_j = trips attracted by zone j

d_{ij} = spatial separation between zones i and j. This is generally expressed as total traveltime (t_{ij}) between zones i and j.

b = an empirically determined exponent which expresses the average areawide effect of spatial separation between zones on trip interchange.

C. Gravity Model Application

In applying a gravity model trip distribution formula to urban studies, it is necessary to develop the parameters in the gravity model formula for each urban area under study. Furthermore, these parameters are developed for each of several different categories of trips. These categories take into account the basic purpose for making trips and are generally referred to as trip purpose categories. Past experience has demonstrated that the exponent of traveltime is not constant for all intervals of time. Thus it is necessary to work with a gravity model formula which differs from that shown previously. This revised formula is expressed as follows:

$$T_{ij} = \frac{P_i \; A_j \; F_{ij} \; K_{ij}}{\sum_{j=1}^{n} A_j \; F_{ij} \; K_{ij}}$$

Where: F_{ij} = empirically derived traveltime factor which expresses the average areawide effect of spatial separation on trip interchange between zones which are t_{ij} apart. This factor approximates

$$\frac{1}{t^n}$$

where n would vary according to the value of t, and where t is the traveltime between zones.

K_{ij} = a specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation.

And where: T_{ij}, P_i, and A_j are the same as previously described.

The use of a set of traveltime factors to express the effect of spatial separation on zonal trip interchange, rather than the traditional inverse exponential function of time, simplifies the computational requirements of the model. It also takes account of the fact that the effect of the spatial separation on trip making generally increases in a more complex manner than can be represented by the single exponent.

Chapter II
HISTORY OF THE GRAVITY MODEL

A. Early Uses of the Gravity Theory

The theory of gravity was introduced by Issac Newton in 1686. Newton postulated that the gravitational force which acts between two bodies in space was in direct proportion to the mass of the two bodies and in inverse proportion to the square of the distance between the bodies.

It was not until the first half of the 19th Century that the theory of gravity was applied to human interaction. At that time, H. C. Carey (6) theorized "Gravitation is here, as everywhere, in the direct ratio of the mass and the inverse of distance." Work by E. G. Ravenstein (7) in 1885 and later by E. C. Young (8) confirmed the belief that gravitational function does apply to the migration of people from one area to another.

A key effort in this field is associated with W. J. Reilly (9) in his study of the retail trade areas of moderately sized American towns. Reilly came to the conclusion that:

> "Under normal conditions two cities draw retail trade from a smaller intermediate city or town in direct proportion to some power of the population of these two large cities and in an inverse proportion to some power of the distance of each of the cities from the smaller intermediate city."

This is an analogue of Newton's Law of Gravity. Further examples of the use of the gravity function are available in the works of Zipf (10), Cavanaugh (11), and Dodd (12).

B. Adaptation of the Gravity Model Theory to Travel

The early users of the gravity model in transportation planning applied it to studies of intercity travel. In the 1920's for example, the Swedish investigator Pallin used the gravity model with a distance exponent of 2 to determine intercity traffic flows. In 1954, J. D. Carroll (13) used the gravity formula to help determine the area over which urban centers have influence. Using intercity telephone messages and intercity travel for some 21 cities in Michigan, Carroll concluded that the exponent of distance should be about 2.8 instead of Pallin's 2.0.

Since that time, the distance factor in the gravity model formula has been the subject of much debate. The work by both Pallin and Carroll suggested that the effect of distance is not really uniform and its relationship is not a simple inverse one, but one in which distance is raised to some power other than unity. One of the underlying problems in determining values for the exponent is the variation in the measure used to express distance. If airline distance is used, one exponent will result; if over-the-road distance or time is used, others will result; and so on.

At about the same time, research by Alan Voorhees (5) (14) endeavored to further quantify this exponential value. Based on origin-destination survey data collected in Fort Wayne, Indiana, Voorhees found that the exponential value of spatial separation varied by trip purpose.

Comparing the exponent for total travel between cities (about 2.5) with that for intracity travel (about 1.5) reflects, to some extent, the effect of using different measures to express the spatial separation between the areas under consideration. Airline distance has generally been used for intercity travel, while over-the-road driving time has been used for intracity travel. The variation between these two exponents, however, may be explained in part by the fact that neither of the traveltimes used took into account terminal time.[1] In intercity travel where most of the trips are relatively long, the effect of omitting 5 or 6 minutes of terminal time is probably negligible. In intracity travel, however, when the median traveltime is generally less than 20 minutes, a 5-to 6-minute terminal time will have a considerable effect.

In order to determine the effect of terminal time on the exponent of distance, Hansen (15) studied the results of an analysis of travel patterns in Baltimore, Maryland. His study showed that by adding 5 to 6 minutes of terminal time to interzonal driving time the exponent for total trips came to about 2.5, the same as for intercity travel. Further analysis of the Baltimore data by Hansen (15) also substantiated the previous research concerning the variation of exponents by trip purpose.

Hansen (16), in research using Washington, D.C., data, has also shown that the exponent is not constant for all time increments. Figure 1 shows the variation he found. If the exponents had been constant, all the curves would have been linear.

Besides these and other empirical studies (17 (18) (19) which have shown the need for a variable exponent in the gravity model, there is also a theoretical rationale behind this notion. This was demonstrated mathematically by Tanner (20) in Great Britain. He showed that a constant exponent cannot yield reasonable results for both short trips and long trips unless the range between the longest and the shortest trip in the area is small.

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[1] Terminal time is the time which is added to the driving time to account for the congestion in the zone at each end of a trip.

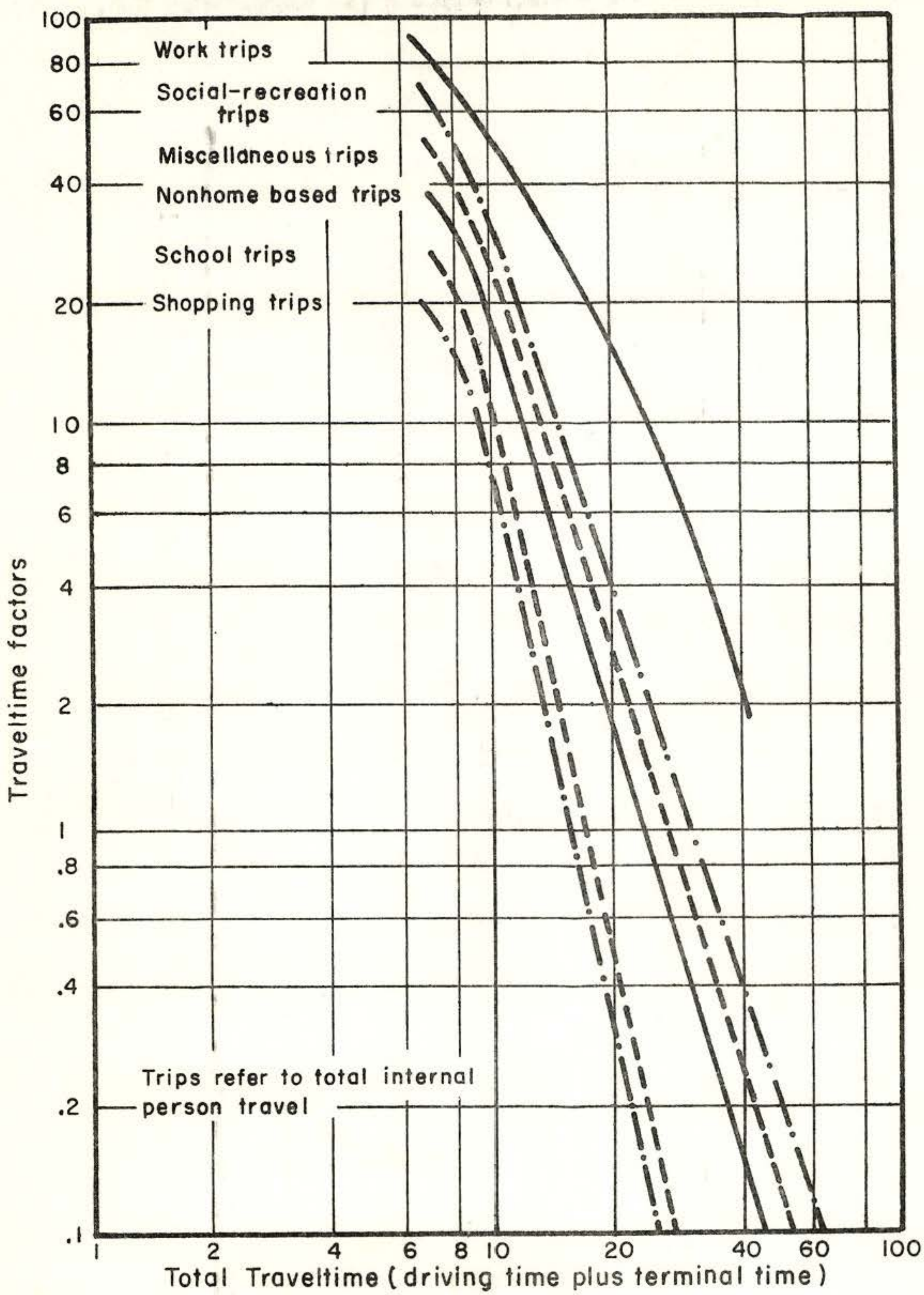

Figure 1.--Traveltime factors for Washington, D. C., 1955.

Whitmore (21), in a rather detailed study of traveltime factors, indicated that variation in traveltime exponents between cities is due to factors other than the measure of spatial separation. He found that city size, population, and car ownership help to explain the variation.

C. Analysis of Early Gravity Model Travel Studies

The work of the above researchers in applying the gravity model theory to travel, particularly urban travel, has been substantial. This is not to say that all the problems have been solved, nor that there exists a perfect tool for estimating trip distribution patterns. This certainly is not the case. However, this work was an excellent beginning of an analytical approach that has become an invaluable tool for the transportation planner.

An analysis of the results of this early research work indicates four significant findings.

1. Spatial separation between zones appears to be best measured by "over the road" driving time between zones, plus some measure of terminal times in the zones at each end of the trip.

2. The exponent of traveltime differs by trip purpose. It appears to vary roughly with the importance of the trip, generally decreasing as the trip becomes more important. For example, work trips which appear to be the most important, have a lower exponent than social-recreation trips.

3. The exponent of traveltime is not constant for all intervals of time within each trip purpose. This variation is most pronounced for work trips. For most trip purposes the exponent generally increases as the time interval increases.

4. The exponent of traveltime alone does not, when considered in relationship to the use of land, completely explain the propensity for travel between two points. Travel patterns can also be affected by various social and economic linkages which to date have not been completely identified or quantified. Hence, factors other than traveltime factors must be taken into account. These secondary adjustments are called "K" factors and will be discussed in detail in chapter III.

Chapter III

PRESENT USE OF THE GRAVITY MODEL

A. Definition of Parameters

1. Trip production and trip attraction.--From the gravity model formulation shown in chapter I, it can be seen that four separate parameters are required before the trip interchanges (T_{ij}) can be computed. Two of the basic parameters, the number of trips "produced" (P_i) and the number of trips "attracted" (A_j) by each traffic zone in the study area, are related to the use of the land and to the socio-economic characteristics of the people who make trips.

The gravity model distributes trips from production zone to attraction zone, while the other travel models in use distribute trips from origin zone to destination zone. To demonstrate the production and attraction definition, it is first necessary to class all trips as home based or nonhome based. Home based trips always have one end at the residence of the trip maker. Nonhome based trips have neither end at the residence of the trip maker.

Home based trips are always produced by the zone of residence of the trip maker whether the trip begins or ends in that zone. Home based trips are always attracted at the nonresidential end of the trip.

Nonhome based trips are always produced by the zone of origin and attracted by the zone of destination.

2. Spatial separation between zones.--As previously discussed, the spatial separation between zones can be measured by one of several parameters. To date, the most effective measure seems to be traveltime.

The total traveltime between zones is the sum of the minimum path driving time between zones plus the terminal times at both ends of the trip. Terminal times are added in order to allow for differences in parking and walking times in these zones, as caused by differences in congestion and parking facilities. This provides a more realistic measure of the actual spatial separation (in time) between zones as it is likely to influence automobile drivers in their decisions as to places to work, shop, etc.

The minimum path driving time between each pair of zones is obtained by the traffic assignment process. The traffic assignment process works with data showing the distance and travel speed over major routes of the transportation system. These data are used in preference to the trip times reported in the O-D home interview survey because people tend to report traveltime to the nearest 15 minutes even when asked to specify time to the nearest minute.

Terminal times on the other hand, can be obtained from data on average walking distances, which are generally available from parking surveys. They can also be estimated by personal judgment. A reasonable estimate of the terminal time is better than omitting it completely.

Intrazonal driving times, the average driving times of those trips that start and end within the same zone, must also be estimated. Terminal times are added to intrazonal driving time to arrive at intrazonal traveltime.

3. Traveltime factors.--Traveltime factors[1] (F_{ij}) express the effect that spatial separation exerts on trip interchange. They indicate the impedance to interzonal travel due to spatial separation between zones. In effect, these factors measure the probability of tripmaking at each one-minute increment of traveltime.

To obtain traveltime factors for the present period, it is currently necessary to go through a process of trial and adjustment. Today's traveltime factors are usually assumed to remain the same into the future. The validity of this assumption has never been definitely proven, but evidence from studies of work trip travel patterns in Baltimore (14) for the time period between 1926, 1946, and 1958, indicates that there is some basis for making this assumption. In addition, Pyers and Bouchard (22) have shown that the traveltime factors for Washington, D.C., remained constant from 1948 to 1955.

Whitmore (21), however, in his analysis of traveltime factors from many cities suggests that traveltime factors may vary over time. This research only utilized data for single points in time and this premise must be verified. Whitmore suggests that the introduction of an expressway system could have an effect on traveltime factors.

The Puget Sound Transportation Study has varied their base year traveltime factors when making forecasts.[2] This application had certain unique aspects. For example, the level of service offered by the transportation

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[1] Traveltime factors are sometimes referred to as "Friction Factors" or as "propensity factors." Figure 1 illustrates a set of traveltime factors for six trip purposes utilized in Washington, D.C. (22).

[2] A report is being prepared by the Puget Sound Transportation Study staff to document the conditions and assumptions regarding their forecast of traveltime factors.

system varied significantly from the base year to the forecast conditions. CBD speeds reflecting heavy congestion on the arterial streets in the base year plan were drastically improved with the addition of a freeway with an assumed minimum speed of 45 miles per hour. This large increase in system speeds allows trips to go much farther in a fixed time. For example, at a speed of 15 miles per hour a 10-minute trip is a 2.5-mile trip. At 45 miles per hour a 10-minute trip is a 7.5-mile trip. In such situations it may be desirable to develop travel cost factors (i.e., weigh in distance on the minimum time path) rather than traveltime factors.

4. Zone-to-zone adjustment factors.--The remaining input to the gravity model formula reflects the effect on travel patterns of social and economic characteristics of particular zones or portions of the study area. These are represented by the zone-to-zone adjustment factor (K_{ij}). These factors reflect the effects on travel patterns of social and economic characteristics which are not otherwise accounted for in the use of the model. If found to be necessary, they must be quantitatively related to socio-economic characteristics of the particular zones to which they apply. It is necessary to relate the adjustment factors to characteristics of the zones so that they may be forecast as a function of the socio-economic conditions estimated for the future land use plan. Although the gravity model provides for these adjustments very few cities have found it necessary to use them.

B. Sample Problem

The application of the gravity model formula can be illustrated by the following example. Work trips produced by the residents of one zone are distributed within a simple four-zone study area. The problem can be stated as follows:

One thousand work trips are produced by the residents of zone 1 each day. It is desired to distribute these trips to zones 1, 2, 3, and 4. The four possible attraction zones have the following characteristics:

Zone 1 has an intrazonal time of 1 minute and has 1,000 work trips attracted to it from all zones in the study area.

Zone 2 is 14 minutes from zone 1 and has a total of 700 work trips attracted to it from all zones in the study area.

Zone 3 is 16 minutes from zone 1 and has a total of 6,000 work trips attracted to it from all zones in the study area.

Zone 4 is 20 minutes from zone 1 and has a total of 500 work trips attracted to it from all zones in the study area.

Figure 2 illustrates this problem graphically.

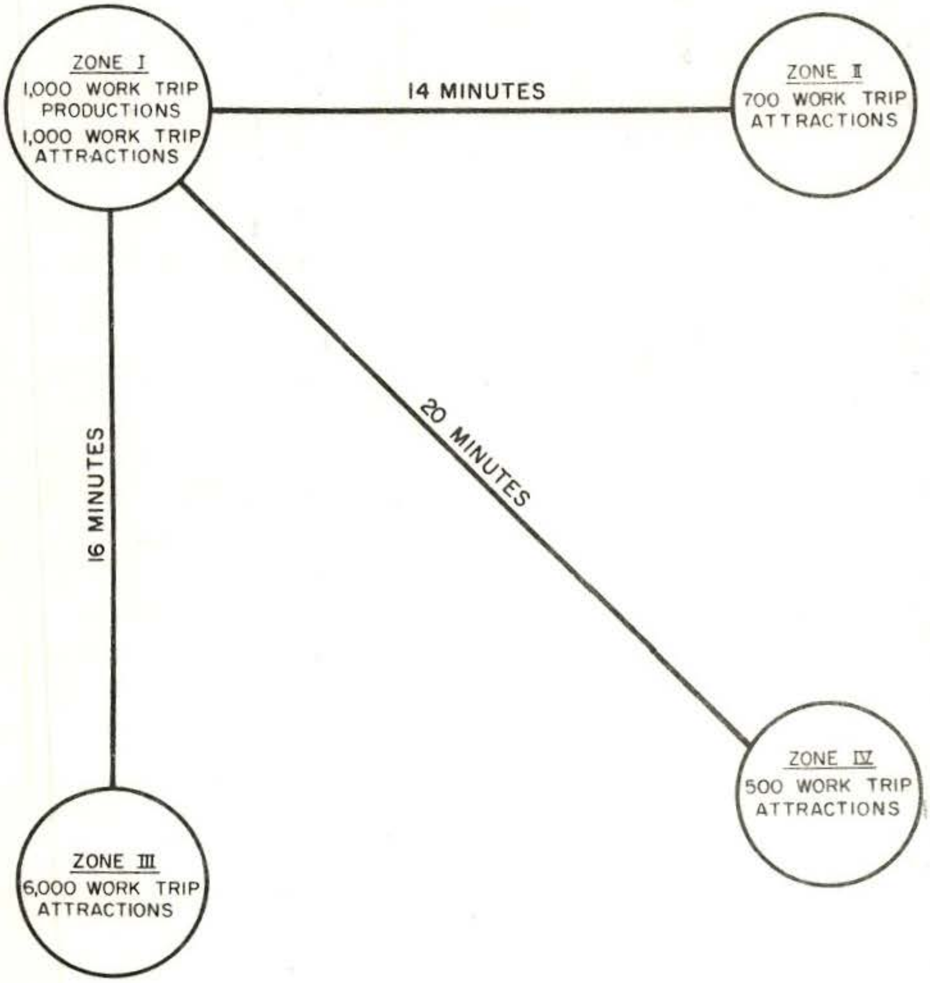

Figure 2.--Hypothetical four-zone problem.

Using the gravity model formula and the traveltime factors from table 2, the work trip distribution pattern for zone 1 is determined as shown in table 1.

Table 1 shows that the 1,000 work trips produced by the residents of zone 1 would be distributed as follows: 186 trips remaining in zone 1, 88 trips to zone 2, 680 trips to zone 3, and 46 trips to zone 4.

Table 1.--Tabulation for sample problem.

					Friction factor		
Zone	A_j	Terminal time	Driving time	t_{ij}	F_{ij}	A_jF_{ij}	T_{ij}
1	1,000	2	3	7	1.00	1,000	186
2	700	2	10	14	.68	476	88
3	6,000	4	10	16	.61	3,660	680
4	500	3	15	20	.49	245	46

Note: Adjustment factors (K_{ij}) were not used in this sample problem.

$$\sum_{i=1}^{4} A_jF_{ij} = 5,381$$

Table 2.--Traveltime factors for sample problem

Traveltime minutes	Traveltime factor F_{ij}
1.0	200
7.0	100
11.0	80
14.0	68
16.0	61
17.0	58
20.0	49
21.0	47
25.0	39

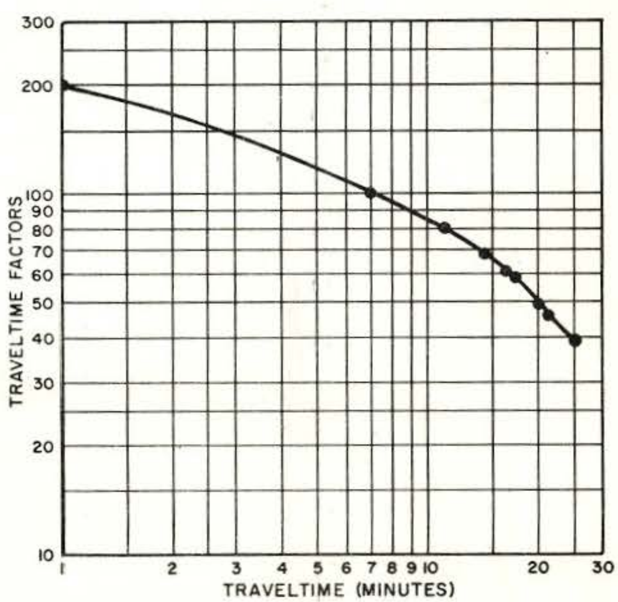

Figure 3.--Plot of traveltime factors for sample problem.

C. Data Needed to Determine Parameters

1. Origin-destination survey.--There should be available factual data in sufficient detail and of the proper statistical stability to provide reliable estimates of the gravity model parameters. In this respect, the home interview survey yields the most complete and accurate data for computing these parameters for use in the gravity model.

The desired data can best be collected through a comprehensive home interview survey using direct person-to-person interviews. Under certain circumstances, however, satisfactory data might be obtained through telephone interviews, pick up cards, or mailed questionnaires. In all cases, sufficient controls must be exercised to assure that the resulting travel data are complete and statistically unbiased. It is also important that information pertaining to the following items be obtained from each dwelling unit contacted:

a. Address of dwelling unit
b. Number of persons residing in dwelling unit
c. Number of cars owned by residents of dwelling unit
d. Occupation of household head
e. For each trip taken by each resident of the dwelling unit:

    (1) Identification of person making trip
    (2) Identification of trip
    (3) Address of origin of trip
    (4) Address of destination of trip
    (5) Start time
    (6) End time
    (7) Purpose at origin end
    (8) Purpose at destination end
    (9) Mode of travel

Small O-D sample sizes ranging from 0.1 to 1 percent have been used in several transportation studies. Those using such small samples for calibrating the gravity model feel that they are adequate to develop a total study area universe of trips. Others question such claims and argue that this procedure should be used only to update the original survey. Research has shown, however, that a small sample yields very little information on trip making by zone (23). Trip production and trip attraction rates cannot be obtained on a zonal basis from this type of survey. Consequently, some assumption has to be made as to how the total universe of trip productions and attractions will distribute themselves on a zonal basis. Procedures and assumptions which have been used in various studies to synthesize zonal production and attraction rates without a comprehensive O-D home interview survey have been documented. However, at the present time, the small random sample technique is considered useful only for broad and general studies or for updates of comprehensive studies.

Another type of home interview survey sometimes recommended is a form of "clustered" survey where a rather small percentage of the total dwelling units are interviewed. The dwelling units to be interviewed are "clustered" into a few pre-selected zones which reflect ranges in the factors which affect travel. Several zones are selected to reflect ranges in such factors as residential density, car ownership rates, income, family size, distance from the central business district, and distance from the nearest large employment or commercial center. Subsequently, a standard size sample (based on population) is interviewed in the selected zones.

One of the principal reasons for conducting a "clustered" type sample is to obtain data on trip generation rates at the home. Since the selected zones exhibit a range in the factors which affect travel, relating these characteristics to the trips generated by the residents of each zone is claimed to yield relationships useful for estimating future trip generation rates from the home. Research conducted using a special "clustered" sample collection in Pittsburgh, Pennsylvania, found that a significant drawback of conducting a "clustered" type home interview survey was that zonal trip attraction rates in each zone could not be established since a total universe of trips was not obtained (24). So, from the standpoint of developing a gravity model even for broad planning purposes, this type of survey has disadvantages. Consequently, a home interview of a sample size as recommended in the Bureau of Public Roads Manual of Procedures for Home Interview Traffic Studies (25) is preferable.

In addition to a home interview survey of internal travel, an external cordon survey (26) and a truck and taxi survey (27) should also be included to complete the picture of travel in the urban area under study.

2. Travel facilities inventory.--Besides sufficient reliable data on travel patterns, information must also be available on the major travel facilities in the area. The following data are usually tabulated for major sections of the highway and transit facilities in the area:

a. Location
b. Physical dimensions

(1) Length
(2) Width
(3) Number of lanes

c. Average speed of travel in both peak and off-peak hours
d. Signalization, parking requirements, direction of travel and other data for capacity calculations
e. Existing traffic volumes

The information is used in calculating the driving time between zones.

3. Other inventories.--Since this manual is concerned mainly with the trip distribution aspects of the gravity model, data concerning travel patterns and spatial separation between zones are all that are generally required. However, since it is possible that zone-to-zone adjustment factors may be required, information relative to socio-economic indicators may also be necessary. Data sufficient for the trip generation analysis will generally be adequate for developing socio-economic adjustment factors.

In the remaining discussions it will be assumed that all the required inventories have been taken and the data are available for use.

D. Initial Decisions to be Made

1. Vehicle trip or person trip model.--Once a transportation study has decided on the basic type of trip distribution model to be used, in this case the gravity model, there remain a great many choices as to the manner in which this model is to be utilized to provide reasonable estimates of travel patterns.

Perhaps the first question is whether the model should distribute vehicle trips or total person trips. The answer is directly related to both the objectives and needs of the study and to the size of the area involved. The type of modal split analysis is usually the prime determinant. In most studies a vehicle trip model is utilized. The modal split is determined at the trip generation phase of the analysis and the auto driver and transit passenger trips are distributed separately via each mode.

In other studies, where a more extensive modal split analysis is being made, total person trip distributions are necessary. The modal split is then made separately for each zone-to-zone person trip movement.

The complexity of the latter analysis can be demonstrated by considering that the number of modal split determinations necessary is equal to the square of the number of zones. In the former type of modal split analysis, only one modal split determination is made for each zone.

2. Trip purpose classification.--A decision must also be made as to how many and what trip purpose categories will be used in the study. Gravity model trip distribution formulas have been developed using as few as one trip purpose and as many as nine or more. There is no clear agreement on this point and it is at least partially a function of the scope and objectives of the study, as well as the size of the urban area involved. As a general rule, it is desirable to take into consideration the number of trips in each category, and the trip length characteristics for each of the trip purpose categories and the ability to forecast the categories separately. The amount of data preparation time, computer time, and analysis time must also be considered.

Several studies in large urban areas have used the following trip purpose categories in their gravity model with satisfactory results:

a. Home based work.--those trips between a person's place of residence and his place of employment for the purpose of work.

b. Home based shop.--those trips between a person's place of residence and a commercial establishment for the purpose of shopping.

c. Home based social-recreation.--those trips between a person's place of residence and places of cultural, social, and recreational purposes.

d. Home based school.--those trips by students between the place of residence and school for the purpose of attending classes.

e. Home based miscellaneous.--all other trips between a person's place of residence and some form of land use for any other trip purpose.

f. Nonhome based.--any trip which has neither origin nor destination at home regardless of its purpose.

g. Truck trips

h. Taxi trips

In some large areas where these eight purposes have been used, it has been observed that the results could have been improved with further stratification without causing additional difficulty in forecasting. For example, in a study of travel patterns in Washington, D.C., it was observed that the gravity model results could probably have been improved if work trips had been further stratified to distinguish between government and nongovernment workers. Some studies also reported the need for further stratification of shopping trips to distinguish between convenience shopping trips (trips to grocery stores, etc.) and other shopping trips.

Most of the recent gravity model studies in small urban areas have been using three trip purpose categories, home based work, home based nonwork and nonhome based trips. Home based work trips are those defined previously in category "a." Other home based trips are those defined in categories "b" through "e" above. Categories defined as "f" through "h" composed the nonhome based trip group. A study of travel patterns in Sioux Falls, South Dakota (23), showed that the differences in the accuracy obtained when using eight trip purposes, as compared with three purposes are insignificant in small areas.

Consequently, it appears that in large urban areas an eight purpose model is desirable but in small urban areas (less than 100,000 population), a three purpose model may be sufficient.

3. Treatment of external trips.--The treatment accorded to external trips, that is, trips with one or both ends outside the cordon line, presents the transportation planner with a choice. In some studies, the external cordon stations have been considered as fictitious zones and have been assumed to produce and attract trips in a manner similar to the internal zones. Generally, it is undesirable to do this for the following reasons:

a. Trips made by those persons living inside the cordon may exhibit different trip length characteristics than those made by persons who live outside the area.

b. External-to-external trips are associated with the study area in question for only a small portion of their total journey and, therefore, exhibit distribution characteristics which have nothing at all to do with the study area.

Consequently, it is generally desirable to treat the total universe of trips as three distinct types:

a. Internal trips, those with both ends of trip within the cordon area.

b. External trips, those with one end inside the cordon and one external end.

c. Through trips, those with both ends outside the cordon.

For the first group of trips the gravity model can be used directly. For the second group of trips the gravity model can also be used. However, since the trip length characteristics of these trips are generally different from those in the first group, a separate gravity model analysis should be made. The external trips are normally considered as being produced at the external stations and attracted at the internal zones. For the third group of trips (through trips) a growth factor technique such as the Fratar (28) procedure is recommended.

Chapter IV
CALIBRATING THE GRAVITY MODEL

A. General

After all of the basic decisions have been made about the specific form which the gravity model will take, it is necessary to develop each of the parameters of the gravity model formula and to calculate the estimated trip interchanges. The phases involved in calibrating a gravity model trip distribution formula for an urban area, as well as those concerned with testing the calibrated model, are shown in figure 4 on the next page.

Very briefly, these steps can be described as follows:

1. Phase one, depicted by the unshaded blocks, is concerned with processing basic data on the area's travel patterns and transportation facilities into a more usable form for analysis purposes.

a. For the travel pattern inventory, this involves editing, sorting, and linking of the basic trip records. This can be done on an IBM 1401 (16K) electronic computer.

b. For the transportation facility inventory, this involves building a network description on the IBM 7090 from records containing information on the location and characteristics of major segments of the network. Next, the minimum time paths between all zone pairs are calculated.

2. Phase two, which is shown in the lightly shaded blocks, utilizes the previously processed survey trip records to obtain complete tables of trip movements for any desired combinations of trip purpose and travel mode. From this, a record is also made of the number of trips produced (P_i) and attracted (A_j) by each zone. The resulting trip tables are then related to the minimum path traveltimes for all zones (obtained in phase one) to obtain trip length frequency distributions.

3. Phase three is shown in the heavily shaded blocks. This phase is concerned with the development of traveltime factors for each of the gravity models to be calibrated. Trip productions (P_i) and attractions (A_j) by zone, together with the minimum path traveltimes between zones and an assumed set of traveltime factors (F_{ij}) are inserted into the gravity model formula

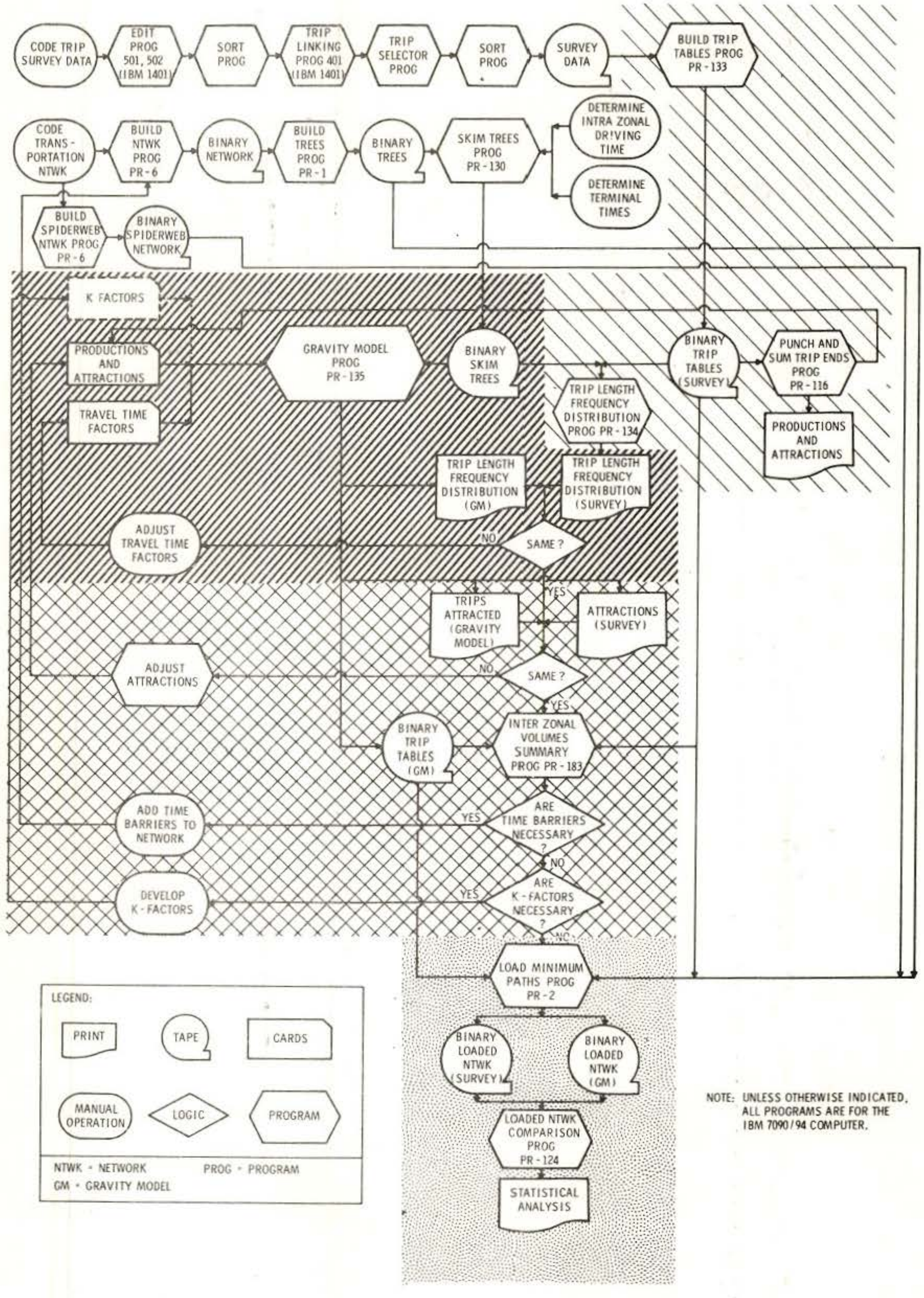

Figure 4.--Gravity model calibration and testing process.

and the trip interchanges (T_{ij}) are calculated. The estimated trip length frequency distributions are then manually compared with the appropriate frequency distributions from the surveyed trips, and the assumed traveltime factors are revised accordingly. A new set of trip interchanges is calculated and the process of trial and adjustment is continued until the two trip length distributions are in approximate agreement.

4. Phase four, shown by the crosshatched blocks, is concerned with the development of adjustment factors which may be required to properly calibrate the models to accurately simulate existing travel patterns. Estimated interchanges are compared with surveyed interchanges, and revisions are made, if required, as follows:

a. Geographical bias, as caused by topographical barriers such as rivers, is eliminated by adjustments to the minimum path traveltimes.

b. Geographical bias, as caused by defined social or economic linkages, is eliminated by zone-to-zone adjustment factors (K_{ij}).

5. Phase five, which is indicated by the dotted blocks, is concerned with the testing of the calibrated gravity models to be certain that they accurately simulate existing travel patterns.

B. Phase One--Preparing Basic Data

1. Editing trip records.--In any analysis that uses the survey data, it is always necessary to edit the information to insure that the items of data have been correctly coded and punched. This is particularly important where a great deal of time and money is to be expended in the processing and analysis of these data. If the source data are not rigidly controlled and edited, it is possible that much useless analysis will result. This is particularly true when using the system of programs described in this volume as some of the IBM 7090 programs have internal controls which reject trip records when they contain certain unacceptable information. To avoid these costly problems and to permit smooth processing in later phases of model development, all trip records should be edited using an appropriate edit program. An IBM 1401 edit program is described in detail in the appendix. This program will edit up to 50 data fields for characters which may be unacceptable to the program user. It can also transfer these fields into any format desired for use in later programs. (The program which "links" trip records requires these records to be in a specified format.)

Input to the IBM 1401 edit routine consists of the home interview trip records (cards) in any format. Output consists of the edited and reformatted records on tape, an on-line printout of records which contain unacceptable characters with an error message indicating the position of the unacceptable characters. Each of the trip records that contained unacceptable characters is punched on a new card. These unacceptable records are then corrected manually and resubmitted to the edit routine. When the corrected cards have successfully passed the edit routine, they go directly on tape and may be merged with the previously edited and reformatted records. These records are now acceptable and are in the proper format for the subsequent computer programs discussed below.

2. Sorting trip records.--It is necessary for the linking program to have the trip records in a sample number, person number, and trip number sort. The sample number is the primary sort, person number is the secondary sort, and trip number the tertiary sort. This sort is necessary to sequence the trip pattern of each trip maker in the order in which the trips were made on a particular day. This is required to "link" trip records if linking is necessary. Sort programs are available in most program libraries. Output from the sort program consists of the edited trip records on tape and in low to high sort by sample number, person number, and trip number.

3. Linking trip records.--Figure 4 shows that the next step is to "link" the internal survey trip records. Because of the standard origin-destination survey definition of a trip many journeys made by a trip maker have to be represented by two or more trip records even though only one journey is involved. In an origin-destination survey, one trip ends and another begins every time a person changes his mode of travel, or an auto-driver stops to serve a passenger, or when the trip maker reaches his ultimate destination. There are two types of trips which require linking, change mode and serve passenger trips. If each of these trips are analyzed separately, the relationships between the actual starting point, the ultimate destination, and the purpose of trip would be lost. It also would be difficult to relate the type and intensity of trip making to the type and intensity of the land use. Consequently, it is usually desirable to combine or "link" those trips with a "purpose to" or "purpose from" of either "change mode of travel" or "serve passenger" so that the relationship between the purpose and the ultimate destination of the trip is preserved.

Some examples of those trips which might be combined or "linked" are shown in figures 5 and 6.

Figure 5 illustrates an auto driver driving his car from home to a fringe area parking lot, where he boards a bus and rides to work. In an origin-destination survey this journey would be recorded as two separate trips. The first trip would be recorded as an "auto driver" trip from "home" to "change mode of travel." The second trip would be recorded as a "transit passenger" trip from "change mode of travel" to "work."

Since the ultimate purpose of this journey was to get from home to work, it is desirable, for analytical purposes, to "link" these two trip records into one which covers the entire journey. In this particular case the "linked" trip would become a home-to-work trip since this was the ultimate purpose of the trip. The mode of travel would be bus, the assumption being that if satisfactory bus service had been available at the trip makers home, he would have used it. Mode of travel is assigned according to a priority listing which normally ranks transit over the automobile. Regardless of the phase of the journey, that mode used which is of highest priority on the list is assigned to the "linked" trip.

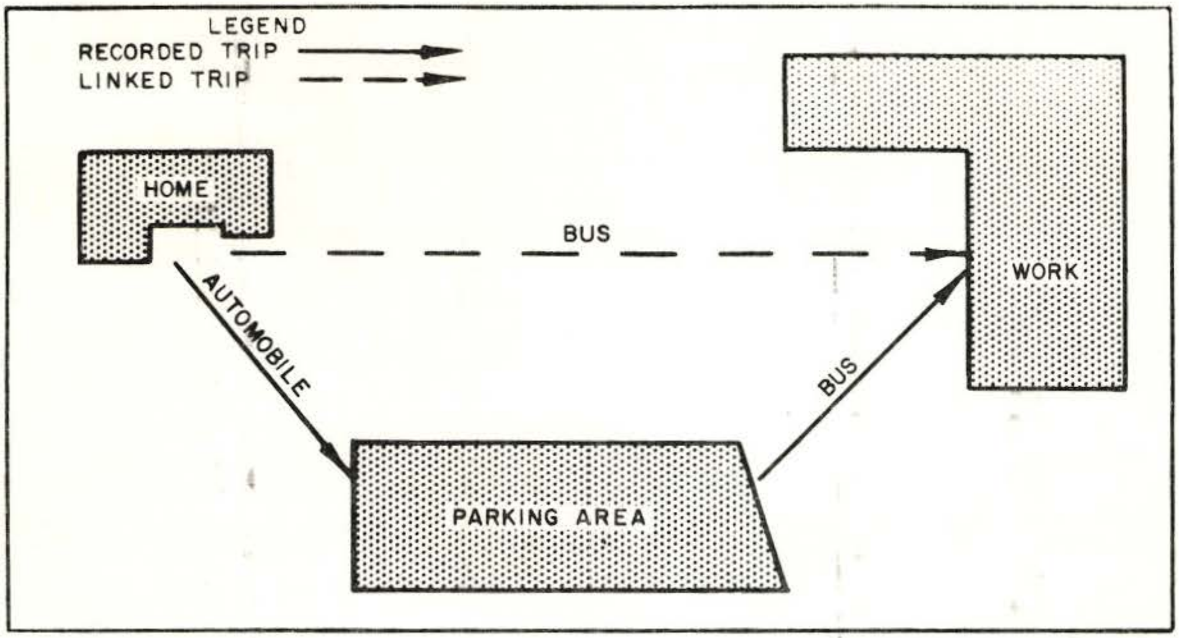

Figure 5.--Example of trip linking.

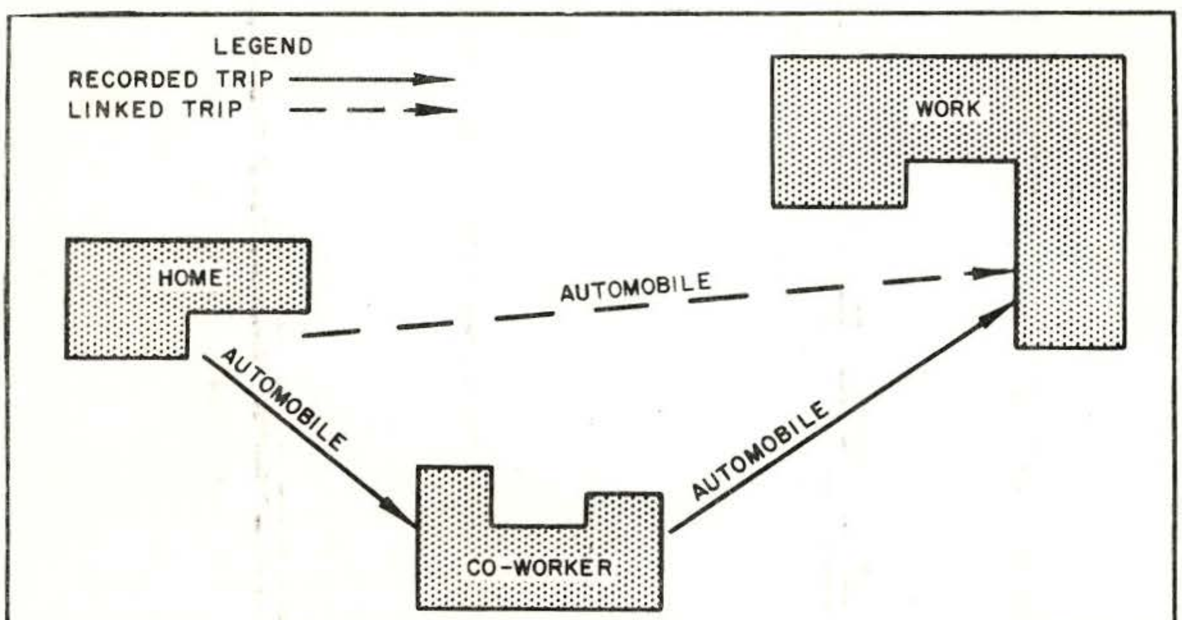

Figure 6.--Example of trip linking.

Figure 6 illustrates a similar situation. A person drives his car from home to the home of a co-worker and they both proceed to work. In this case, the auto driver's journey would be recorded as two separate auto-driver trips, the first one from "home" to "serve passenger" and the second one from "serve passenger" to "work." Since the auto driver's ultimate purpose was to get to work, it is again desirable for analysis purposes to "link" these two trip records into one which covers the entire journey. In this case, the auto driver's "linked" trip would become a home-to-work trip by automobile based on the same reasoning as for the previous example.

There are two additional cases in the recording of trips which are handled by utilizing the program options. The first of these types occurs when a wife drives her husband to work and then returns home. These two trips would be coded as home to serve passenger and serve passenger to home. The "linked" card for these trips would show an invalid home-to-home trip for the wife, provided the normal logic was followed. Instead, the serve passenger code for each trip is changed to personal business. This procedure is outlined in the program description. The normal process is then followed.

The second type concerns those trips which have only one trip record in the journey. For example, a trip by a person who changes mode of travel at an airport or railroad station and leaves the city and does not return that day, would be recorded in an origin-destination survey as only one trip with a purpose to of "change mode of travel." The one trip record is used as the "linked" trip record after changing "change mode of travel" code to "personal business" code.

Trip linking is not necessary in all studies. For example, in urban areas where "change mode" trips may be small in number because of the lack of transit facilities and where "serve passenger" trips may also be small in number because of the absence of car pooling, trip linking may not be necessary. For analysis purposes trips of this type can often be combined with the other trip purposes with no significant loss in accuracy. However, in larger urban areas, it is generally desirable to link trips.

The trip linking process may be accomplished on the IBM 1401 computer using the trip linking program described in the appendix. Some typical information taken from each record to be linked is shown in table 3. The final "linked" trip record is written on tape with those records that did not require linking.

The trip linking process causes a decrease in both the absolute number of "trips" taking place and in the total vehicle (or person) miles of travel in the urban area. The loss in vehicle miles results from the more direct routing of some linked trips. The exact amount of the decrease in the number of trips can be determined by simple subtraction of the number of trips in the "linked" records from those in the "unlinked" records. The slight decrease in vehicle-miles of travel can be obtained by assigning both the "linked" and the "unlinked" trip records to a comprehensive highway network and subtracting the two resulting vehicle-miles of travel. From analysis of past studies, it appears that the decrease in trips and in vehicle-miles of travel is of little consequence.

Table 3.--Location of information for linked trip record

Column	Information	Instructions
1	Card number	(1/)
2	County	(1/)
3- 4	Tract	(1/)
5- 7	Sample number	(1/)
8-11	Subzone of residence	(1/)
12-14	Blank	(1/)
15	Ring	(1/)
16-17	Month	(1/)
18	Week in the month	(1/)
19	Day in the week	(1/)
20	Length of residence	(1/)
21	Previous address	(1/)
22	Reason for move	(1/)
23-24	Occupation and industry	(1/)
25	Interviewed	(1/)
26-27	Person number	(1/)
28-29	Trip number	Last card
30	Race and sex	(1/)
31-34	Origin subzone	First card
35	Blank	(1/)
36-39	Destination subzone	Last card
40	Mode of travel	Mode priority, 3-1-2-4-5 2/
41-43	Starting time	First card
44-46	Arrival time	Last card
47	Purpose "From"	First card
48	Purpose "To"	Last card
49	Persons in car	If mode 1 in col. 40, use last card, if not leave blank.
50	Parking	If mode 1 in col.40, use last card, if not leave blank.
52-62	Route of travel	Leave blank
63	Cars owned	(1/)
64-65	Total persons	(1/)
66-67	Total trips	(1/)
68-77	Blank	(1/)
78-80	Factor (tenths)	(1/)

1/ Information is the same in both cards, and can be taken from either first or last card.

2/ Use the highest priority mode code appearing in any of the trips in linking sequence.

4. Selecting trip records.--As shown in figure 4, the next step in the calibration of the gravity model is to select the basic trip records for model calibration.

All the information collected in the travel pattern inventory is assumed to have been processed through the editing and, in the case of the internal survey, the linking phase.

The information in the detail trip cards, from each of the inventories (i.e., home interview, external cordon, and truck and taxi), should be compatible. Depending on the decisions reached on the items discussed in the previous chapter, certain of these detail trip records must now be selected for further processing, as it is these records which will be used in calibrating the gravity models.

For example, if it has been decided to calibrate a gravity model for vehicle trips during the average 24-hour day, then the following trip types would be used:

a. Internal vehicle trips, those with both ends of trip within the cordon area;

b. External vehicle trips, those with one end inside the cordon and one end external;

c. Through trips, those with both ends outside the cordon.

The type (a) trips would be selected from the home interview survey and truck and taxi survey detail trip cards. The type (b) trips would be selected from the external survey records. The remaining external survey trips would constitute the type (c) trips.

The type (a) and (b) trips are normally utilized to calibrate internal and external gravity models. A single purpose external model should be sufficient for most urban areas; however, if there is one type of dominant external movement such as travel to a military installation just outside the cordon, it may be desirable to isolate these trips into a separate trip category and to calibrate a separate model.

The type (c) trips are typically expanded using the Fratar growth factor technique. An IBM 7090 program is available for this purpose in the Bureau of Public Roads computer program battery.

5. Determining spatial separation between zones.--This subject, which will be discussed only briefly in this volume, is treated fully in the Traffic Assignment Manual (1).

a. Preparing the network.--A map is prepared which describes the components of the transportation system. The beginning and ending of each of the significant elements of the system is defined, along with the type of facility, its length, and its operating characteristics.

To uniquely define each section of the transportation system, a numbering system is used that also designates type of facility.

Figure 7 shows a small urban area which can be used to illustrate the mechanics of this process. The study area has been zoned and the street classification is shown. The numbering system to be used to code the network for assignment must be within the size limitations imposed by the computer programs. For purposes of this discussion the limitations imposed by the traffic assignment programs (1), currently being used by the Bureau of Public Roads, will be followed. These programs will handle a maximum of 3,999 nodes and centroids, and approximately 750 of these can be zone centroids when using the gravity model. More centroids can be accommodated if fewer than six trip purposes are specified for a given computer run.

Figure 8 shows a more schematic illustration of the area involved including the allocation of node numbers. The following numbering system has been used:

(1)	Zone centroids and external stations	001 to 50
(2)	Arterial street nodes	70 to 400

This numbering system allows for the incorporation of additional nodes which may be needed in defining the future transportation system for the area.

In the traffic assignment programs the zone centroids and external stations must be numbered in an unbroken sequence beginning with 001. In most cases the numbers used during the field surveys are not in sequence and must be converted. External stations must be placed at the end of the sequence. Since the urban area under consideration has 50 zones and stations, only the numbers between 1 and 50 have been used. These have been indicated in figure 8 by dots.

With the zone centroids and external stations identified, it is necessary to number each highway intersection to identify the sections between them. The numbers used in this identification should be within the indicated ranges, depending on whether freeways or arterial streets are involved.

Once all intersections in the urban area that are on the coded system have been identified, it is necessary to code the distance and speed of each section. The distances and the travel speeds are determined from an analysis of data collected in the travel facility inventory to provide the operating characteristics of each section. All the data necessary for the computer to calculate zone-to-zone driving times are now available.

b. Determining interzonal driving time.--The build and update network description program examines the transportation network data for several standard errors [1]. In addition, this program processes the transportation network data for use in later programs. The print link data program prints out a description of the network for use by the analyst in correcting any errors in the network.

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[1] See Traffic Assignment Manual (1) for detailed descriptions of these programs.

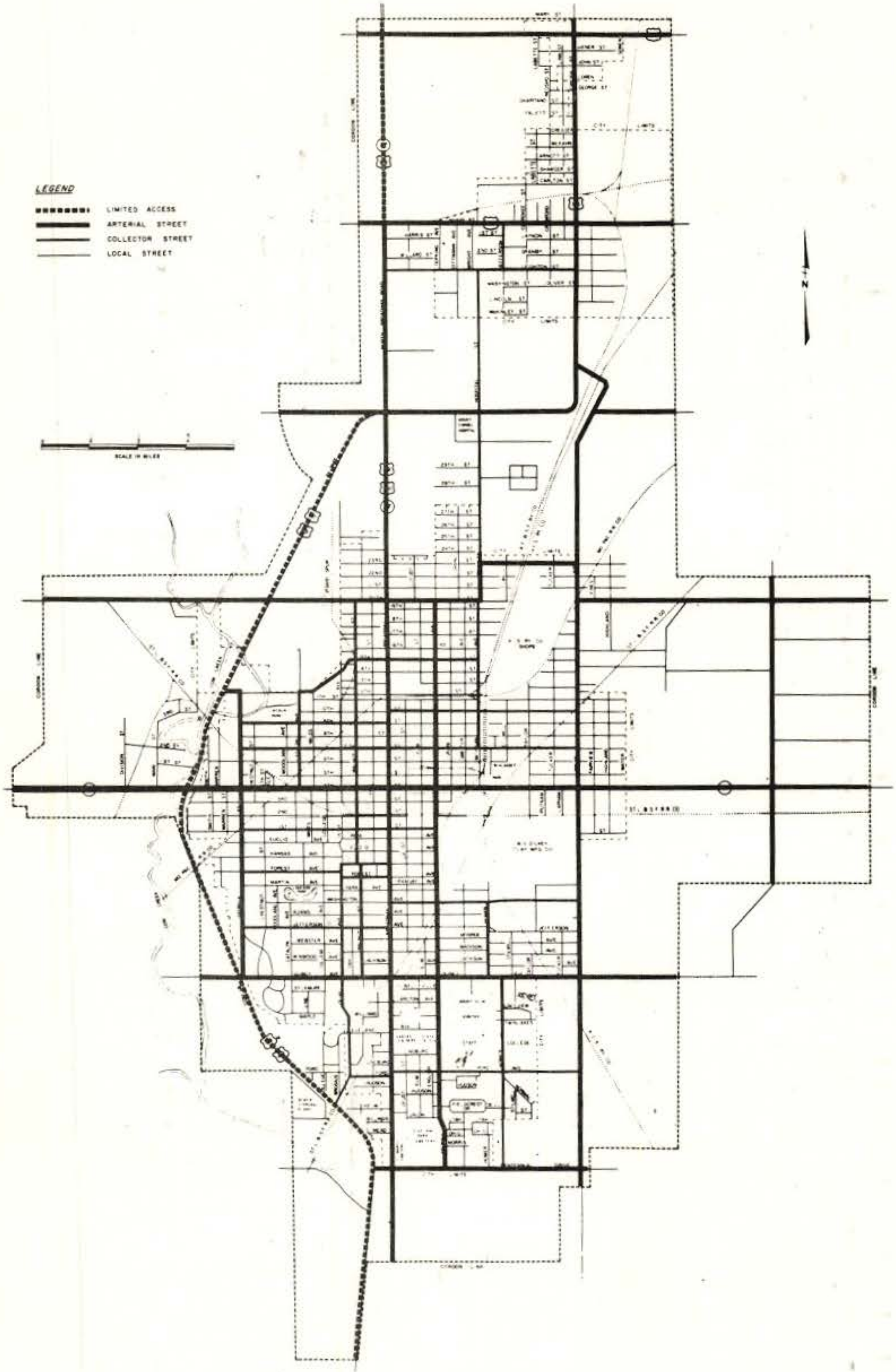

Figure 7.--Sample street classification and base map.

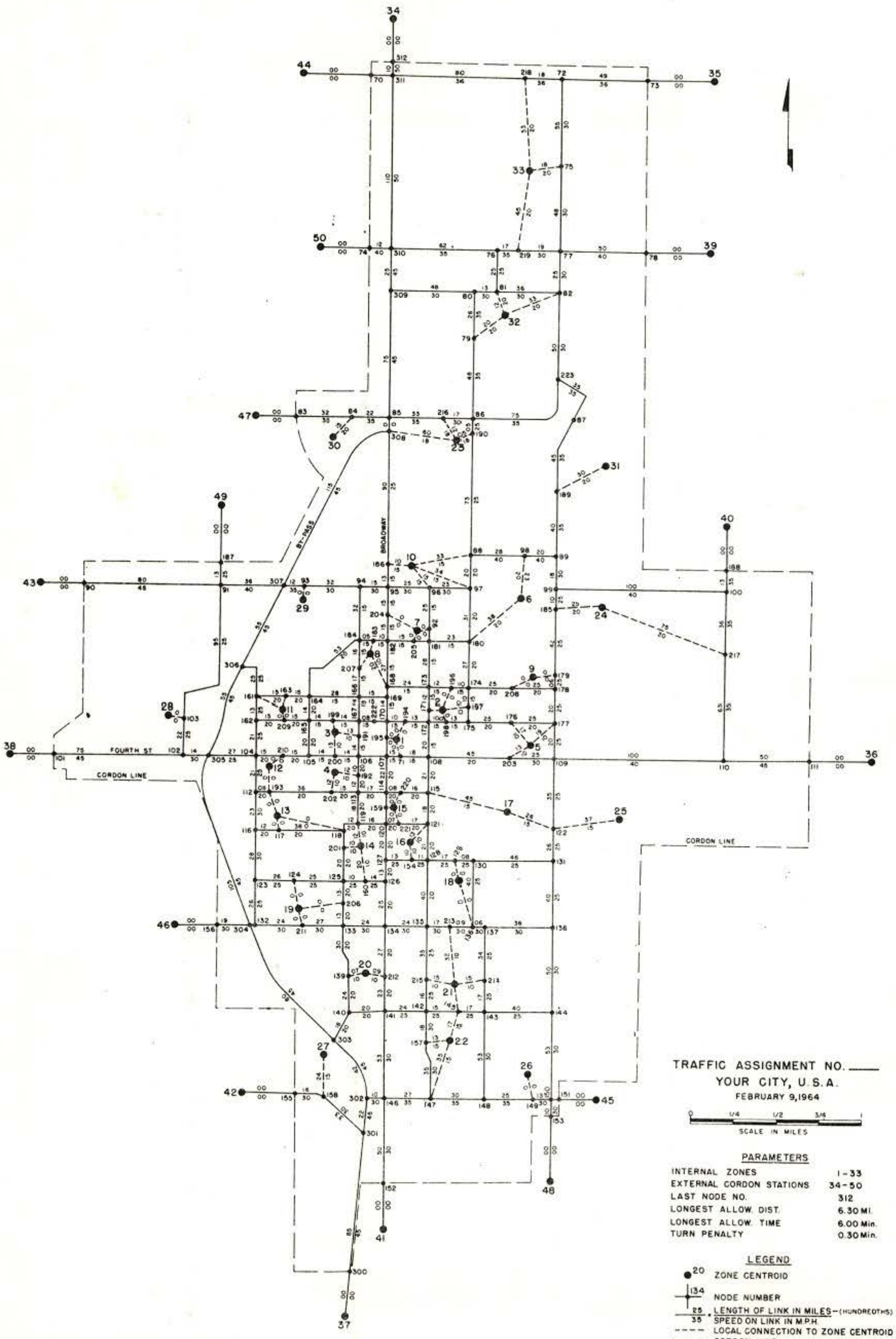

Figure 8.--Sample network map.

After the network has been corrected, minimum time paths (driving times) from selected centroids to all other nodes are determined. The build trees and format trees programs compute and print trees as aids to checking the reasonableness of the network description. The "trees" show minimum time paths and times of travel from a given zone to all nodes in the highway network. The results can be plotted directly on a map, as illustrated in figure 9, for checking.

Once the network is verified as adequately simulating the existing system, all minimum path driving times are computed using the build trees program. For use with the gravity model the trees are reduced, ("skimmed") to show only the driving times between zone centroids. Table 4 is a printout from a formatted skim tree.

c. <u>Determining the traveltimes.</u>--Spatial separation between zones appears to be more realistically approximated by traveltimes than by driving times. The zone-to-zone traveltime is the sum of the over-the-road driving time between zones and the terminal times within the origin and destination zones. Consequently, it is necessary to develop a measure of terminal time for each zone in the study area to be combined with the information on driving time in determining spatial separation between zones.

Terminal times may result from the following conditions:

(1) The time spent in looking for a parking place at the nonhome end of a trip.

(2) The time spent in walking from a parking place to the actual destination of a trip, be it an office, store, recreation facility, or home.

(3) The time spent in walking from a trip origin, be it the home, an office or other such origin, to the parking place.

(4) The time spent in getting from the parking place to the street system at the origin end of the trip.

There are no absolute rules for estimating terminal times. Several methods have been employed in various transportation studies, including (1) the subjective allocation of a terminal time to each zone based on a knowledge of the study area or upon data derived from studies such as a parking survey, (2) relating the values of terminal time to the distance from the CBD, (3) the use of an index that is a relative measure of congestion conditions in a zone.

One recent study employed a so-called subjective method in allocating terminal times to each zone for a small urban area (23). From the results of a central business district parking survey, it was observed that in the downtown area, an average of two minutes was spent in walking from

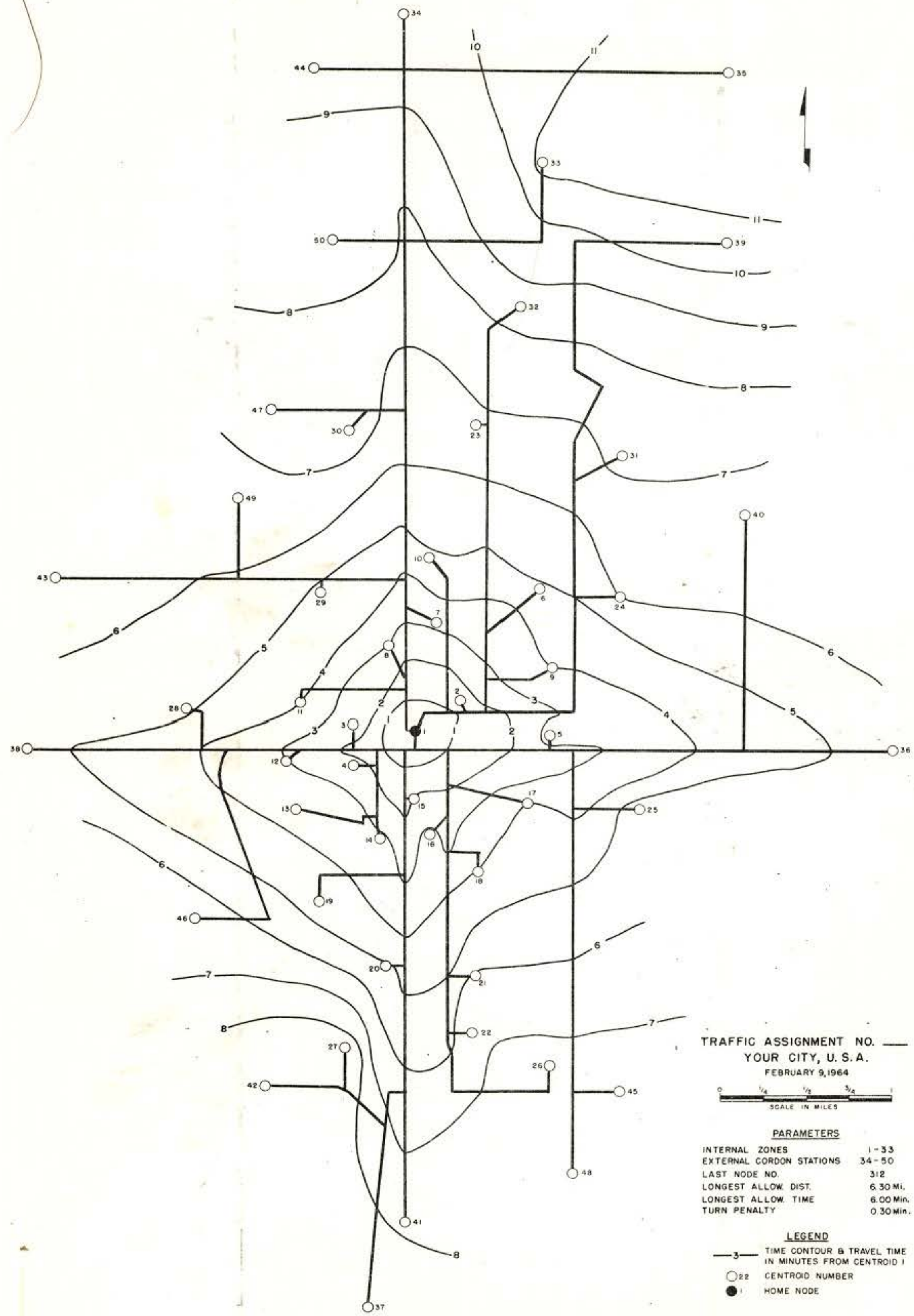

Figure 9.--Minimum path tree with isochronal contours.

Table 4.--Output of IBM 7090 Skim Trees Format Program
Sample output Sioux Falls, South Dakota System 56-1

Zone-to-Zone Driving time -- In minutes

Zone 1 to all other zones

Zone	0	1	2	3	4	5	6	7	8	9
00		//////	3	1	3	2	1	2	1	4
10	4	5	8	7	6	7	9	10	9	4
20	5	5	7	8	8	11	9	11	12	4
30	5	7	7	8	9	8	9	9	12	3
40	2	3	4	5	6	7	8	8	6	4
50	4	4	7	7	8	4	5	6	9	7
60	9	11	5	6	8	9	3	5	7	5
70	7	8	9	7	8	8	8	9	9	11
80	7	6	6	8	9					

parking space to the store or office of ultimate destination. Furthermore, it was estimated that an average of three minutes was spent in cruising for a parking space. Consequently, for all zones in the central business district, a terminal time of five minutes was used; for residential zones, a terminal time of one minute was used; for zones with moderate amounts of commercial activity, intermediate values of terminal time were used.

It is next necessary to incorporate the calculated terminal times into the trees to change the driving time to traveltime. This is accomplished by using the skim and update trees program (see the program description in the appendix). The terminal times are specified through the use of terminal time cards. This program adds the terminal time for the respective zones to the skim trees, thereby producing a series of binary records containing the traveltimes between each pair of zone centroids. Table 4 illustrates the type of output which is obtained by formatting the skim trees (PR-113).

Another method that has been utilized to incorporate the terminal times into the analysis is to modify the coded highway network. Using this procedure terminal times are added to "dummy" links which connect the centroid to the highway network. (See page III-27 of the Traffic Assignment Manual.)(1)

d. Determining intrazonal driving times.--It is noted by the lightly shaded block in table 4 that the procedures do not yield any measure of time for trips that do not leave a particular zone. This time is called intrazonal driving time and must be derived separately. One method of arriving at an estimate of intrazonal driving time is to analyze the driving times to adjacent zones. Figure 10 illustrates this procedure. The average of the driving times from the centroid of zone 15 to the adjoining zone centroids is 3.6 minutes.

The intrazonal driving time is taken as one-half of this average driving time, or 1.8 minutes. The rounded values would then be incorporated into the skim trees by using the update skim trees program described in the appendix.

C. Phase Two.--Analysis of Basic Data

1. Building a table of zone-to-zone movements.--Figure 4 shows that a key step in the analysis of the basic trip data is the determination of zone-to-zone movements for each of the several trip purposes. The trip table builder program performs this function through the following four operations:

a. Converts survey zone numbers to zone centroid numbers.

b. Determination of the zone of production and the zone of attraction for each trip record.

c. Classification of each trip record into one of several trip purposes.

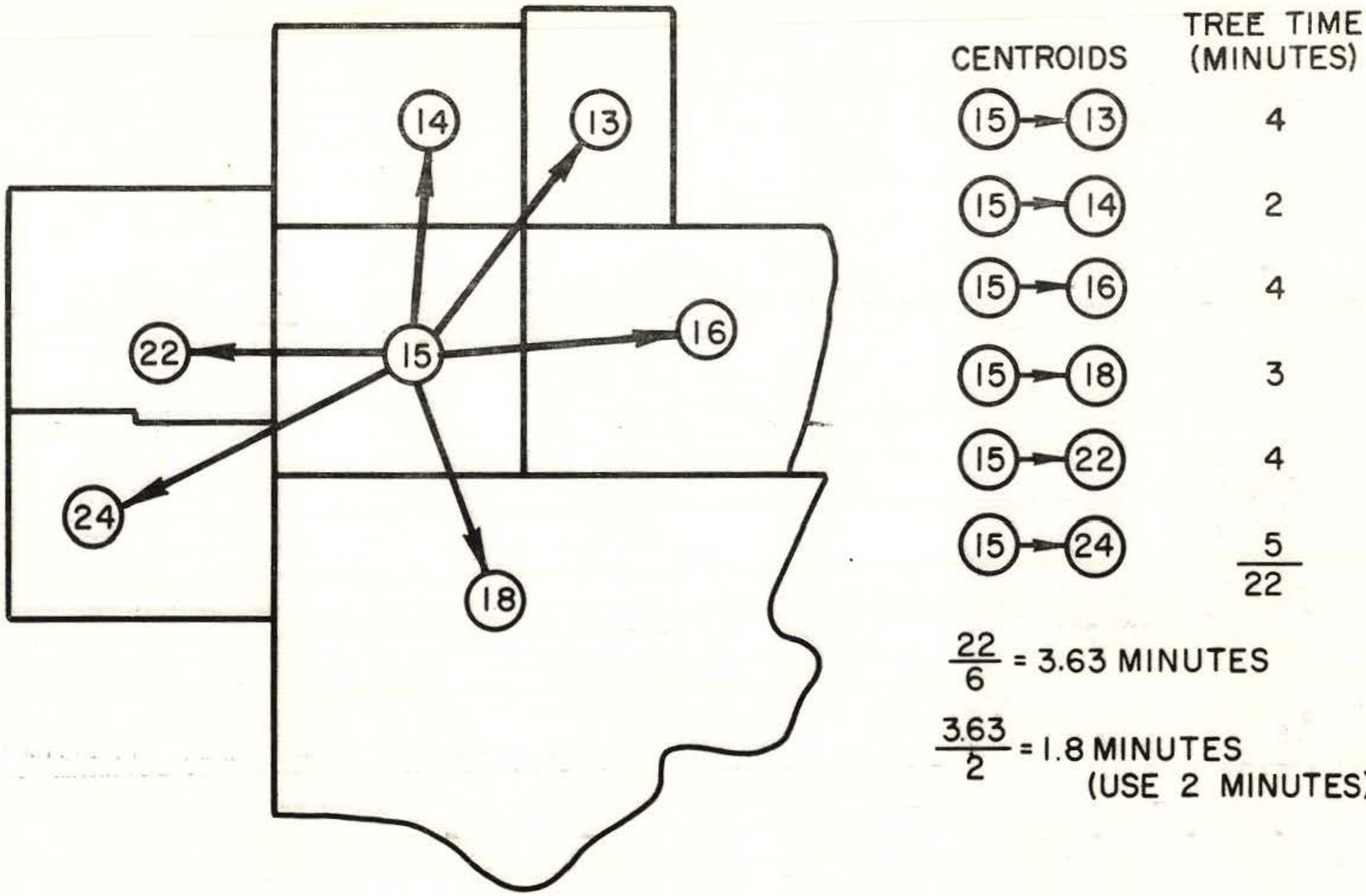

Figure 10.--Determination of intrazonal driving time.

d. Determination of the number of trips between each zone of production and every zone of attraction for the several trip purposes.

e. Accumulation of the number of trips produced and attracted by each zone in the study area for each trip purpose.

The first two operations process and identify data for further analysis in the remaining operations. The second two operations provide the necessary information for many of the subsequent analyses in the gravity model calibration and testing process. The trip interchanges, for example, will eventually be combined with the minimum path traveltimes to obtain a one-minute frequency distribution of trip occurrence for each trip category as shown in figure 11.

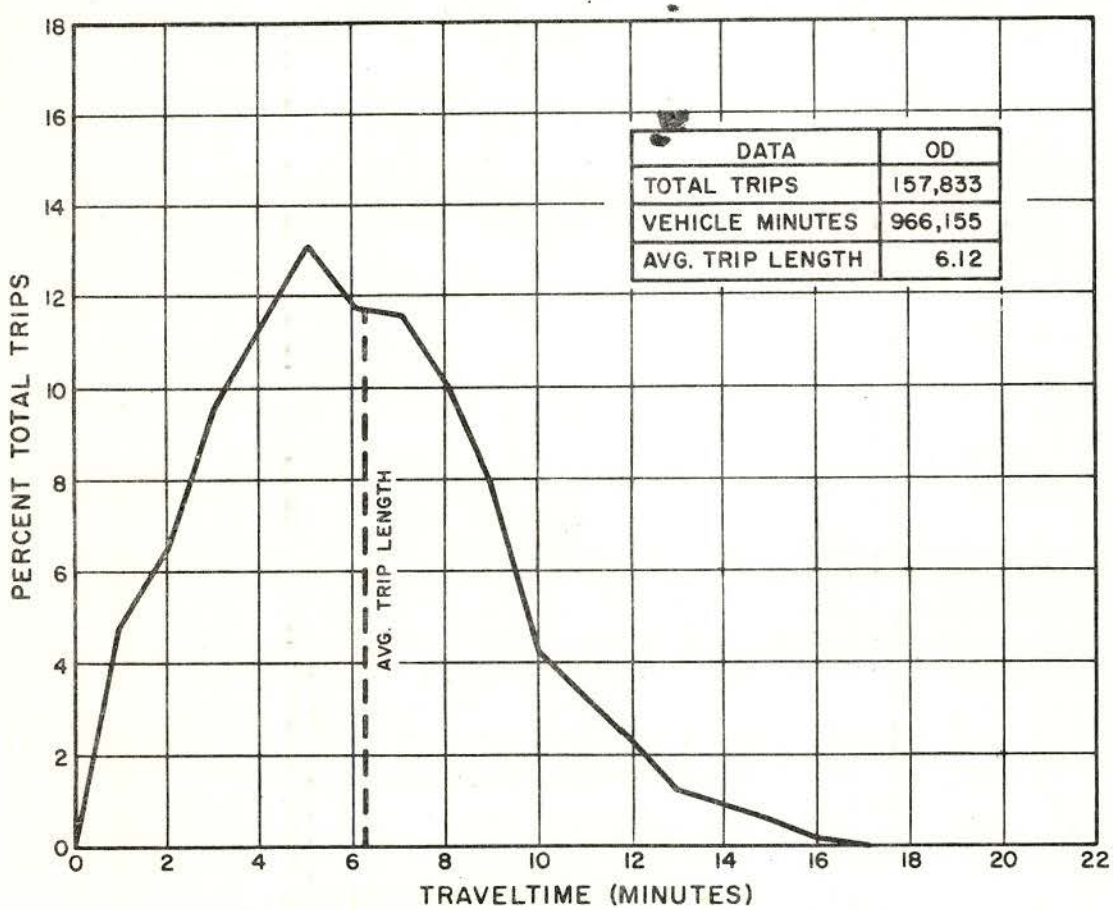

Figure 11.--Trip length frequency distribution for total trips, Sioux Falls, S.D.

The number of trips produced and the number of trips attracted by each zone in the study area are two of the necessary inputs to the gravity model formula. These values are used throughout the entire calibration process. In addition, these data are used with land use and socio-economic data to develop a basis for determining future zonal trip production and trip attraction values.

Regression analysis can be employed to determine a mathematical equation which expresses the relationship between a dependent variable (zonal trip production or trip attraction by any desired trip purpose or travel model category) and one or more independent variables such as car ownership, residential density, employment, or the type and intensity of specific kinds of land uses.

The trip table builder examines each trip record to determine the zone of production and a zone of attraction for each trip. All urban trips can be divided into two broad basic categories, home based and nonhome based. Home based trips must have either their origin or their destination at the residence. All those trips which have neither their origin nor their destination at the home are designated as nonhome based trips.

For home based trips, the zone of production is always the zone of residence. Since either the origin or the destination of the trip can be at the home, each record is examined to determine whether the zone of residence is the same as the zone of origin or the zone of destination. Whichever one of these two zones is the same as the zone of residence, it becomes the zone of production. The remaining zone is designated as the zone of attraction.

All nonhome based trips are considered as being produced by the zone of origin of the trip. Consequently, for nonhome based trips the zone of production is always the zone of origin and zone of attraction is always the zone of destination.

At the same time the trip table builder program determines the zone of production and the zone of attraction, it also classifies each trip record into specified categories of trip purpose or travel model classifications. A general trip purpose code is assigned to each trip record. Essentially, the program examines each trip record for the "purpose to" and the "purpose from" and assigns the appropriate general purpose code. Home based trips are assigned a purpose on the basis of the purpose at the nonhome end. Trips with neither a "purpose to" nor "purpose from" of "home" are assigned the general purpose nonhome based. For example, a trip record with the code for home in the "purpose to" column and work in the "purpose from" column would be assigned the general purpose code for home based work trips. If a trip record has the code for work in the "purpose from" column and the code for shop in the "purpose to" column, it would be assigned the general purpose code for nonhome based trips because neither end of the trip was at home. In a similar manner, trip records can be classified by travel mode or other desired categories.

When these two preliminary steps have been completed, the program accumulates the movements between each zone of production and every zone of attraction according to the desired trip purpose. This program also accumulates all the trips produced and trips attracted by each traffic zone according to these same purposes.

Input to the trip table builder program consists of the edited and linked trip records. Specified details of input sorts for home based and nonhome based trips are contained in the program writeup.

The output from the trip table builder is in two parts. First, a printed summary of zonal trip production and trip attraction values for each desired trip purpose and travel model category is obtained. An illustration of this output is shown in table 5. Trip productions in each zone can be obtained by adding the "OUTS" to the "INTRAS." Trip attractions in each zone can be obtained by adding the "INS" to the "INTRAS." This information will then be used as an input to gravity model calculations.

Second, a binary table of zonal trip interchange (production and attraction) is obtained for each trip purpose. If desired, a printed format (similar to table 4) of these binary trip interchanges can be printed out for visual inspection. This operation is accomplished by the format trip tables or skim trees program.

A new program (punch and sum trip ends) has recently been written to eliminate the computations required in using the BCD output of the trip table builder program. This new program prepares printed tables of trip productions and trip attractions and also zonal parameter cards for input to the gravity model program.

2. Obtaining a trip length frequency distribution.--The next step in the gravity model calibration process is to obtain a trip length frequency distribution by one-minute traveltime increments, for each trip purpose being analyzed. The table of zone-to-zone movements for each trip purpose and the updated skim trees are used as input to the trip length frequency distribution program.

This program works as follows: By accumulating the number of trips between each pair of zones according to the traveltime between the zones, and repeating this process for all possible zone pairs, the number and percentage of total trips in each traveltime increment is obtained.

The input data for each run of the program are the updated skim trees and the trip table for the desired trip purpose or travel mode category. The output is a listing of the number and percent of trips for each trip purpose occurring at each one minute increment of traveltime. The use of this program is described in the appendix.

D. Phase Three.--Developing Traveltime Factors

1. Selecting initial traveltime factors.--At the present time, a specific mathematical equation or function which can adequately express the effect of spatial separation on zonal trip interchange is not available. A single exponential function of traveltime is known (see chapter II) to be inadequate. Consequently, it is necessary to go through a trial and adjustment (calibration) procedure, to fit the model to a particular urban travel situation. The traveltime factors developed in this manner are an empirical measure of the relationship of spatial separation and travel.

Table 5.--Summary of trip ends, sample printout from the trip table builder program

TRIP END SUMMARY G M WORK TRIPS — - SUMMARY OF TRIP ENDS - — PAGE

(1) ZONE	(2) INS	(3) OUTS	(4) INTRAS	(5) TOTAL INS & OUTS (2) & (3)	(6) TOTAL TRIPS (4)&(5)	(7) TOTAL TRIP ENDS (4) & (6)
1	2,033	17	2	2,050	2,052	2,054
2	680	0	0	680	680	680
3	1,792	0	0	1,792	1,792	1,792
4	916	113	7	1,029	1,036	1,043
5	1,124	85	6	1,209	1,215	1,221
6	1,097	19	1	1,116	1,117	1,118
7	882	18	1	900	901	902
8	16	0	0	16	16	16
9	290	303	7	593	600	607
10	61	666	3	727	730	733
11	486	438	22	924	946	968
12	262	707	22	969	991	1,013
13	307	370	12	677	689	701
14	156	576	9	732	741	750
15	45	717	4	762	766	770
16	47	353	2	400	402	404
17	47	0	0	47	47	47
18	76	209	2	285	287	289
19	138	407	4	545	549	553
20	64	659	3	723	726	729
81	0	0	0	0	0	0
82	0	0	0	0	0	0
83	0	0	0	0	0	0
84	0	0	0	0	0	0
TOTAL	24,631	24,631	530	49,262	49,792	50,322

The initial set of traveltime factors for each trip purpose can be determined in at least two ways. First, one can assume that each traveltime factor has a value of one, or, in other words, that traveltime has no effect on trip interchange. It is known that this is not the case, but this method allows you to initiate the calibration procedures. The second and most expedient method of beginning the calibration process is to use a set of traveltime factors taken from a city of comparable size and use these to calculate a gravity model distribution of trip interchanges.

The most preferable method for determining traveltime factors is the second method as it usually requires fewer calibrations.

See tables 6 and 7 for examples of traveltime factors used in actual gravity model calibrations.

2. Calibration procedures to obtain final traveltime factors.--With the initial set of traveltime factors developed for each trip purpose, it is now possible to calculate trip interchanges using the gravity model program. Input to the gravity model program consists of the following items:

a. Zonal trip production and trip attraction values by purpose as obtained from the trip table builder program.

b. Minimum path traveltimes for all zones (including intrazonal traveltimes) as obtained from the skim trees program. These data generally remain the same for all trip purposes but may change for different travel models.

c. Initial traveltime factors for each one-minute increment of traveltime.

The output from this program consists of the following items for each trip purpose:

a. A table of zone-to-zone movements as estimated by the gravity model formula. This table is in binary form in a format that is identical to the binary trip table obtained from the survey data using the trip table builder program.

b. A trip length frequency distribution, by one-minute traveltime increments, of trip interchanges estimated by the gravity model formula. These distributions contain intrazonal trips. A sample of this output is shown in table 8.

c. A table of accessibility indexes (which is the denominator of the gravity model formula) for each zone. This accessibility value, a by-product of the calibration, is often used in connection with land use fore-casting techniques and in certain modal split procedures. This output is a program option and may be suppressed if desired.

Table 6.--Sioux Falls traveltime factors

Traveltime	Home based Work	Home based Nonwork	Nonhome based
1	275	335	390
2	255	325	380
3	240	305	350
4	220	280	310
5	205	245	250
6	180	205	205
7	160	170	165
8	138	140	130
9	120	115	105
10	102	94	84
11	88	76	69
12	75	62	57
13	64	50	47
14	55	40	38
15	45	32	31
16	36	26	25
17	28	22	20
18	18	18	13
19	9	15	8
20	2	13	3

Table 7.--Traveltime factors used for New Orleans, Louisiana

Minutes	Purposes					
Traveltime	Home to Work	Home to Shop	Home to Soc.-Rec.	Home to School	Home to Other	NHB
1	1,450	7,200	7,800	4,300	6,800	5,100
2	1,150	7,000	1,150	5,600	5,100	3,400
3	740	4,600	2,500	1,500	3,400	1,700
4	540	2,800	1,390	840	1,700	950
5	430	1,300	840	550	880	530
6	345	700	650	390	530	330
7	285	420	400	290	340	220
8	240	250	305	230	237	150
9	198	170	240	190	168	110
10	170	120	190	155	123	81
11	149	82	159	130	92	63
12	126	61	130	110	72	51
13	110	46	110	94	58	40
14	97	36	91	80	48	33
15	86	27	80	74	38	27
16	77	23	70	64	32	23
17	69	18	60	57	27	20
18	62	15	54	50	23	17
19	56	12	48	46	20	15
20	50	10	42	43	18	13
21	45	9	39	39	15	11
22	42	8	35	35	13	10
23	38	7	32	33	12	9
24	35	6	29	30	10	8
25	32	5	26	28	9	7
26	29	4	24	25	8	6
27	27	4	23	24	7	6
28	25	3	21	22	7	6
29	23	3	20	21	6	5
30	21	3	18	20	6	5
31	19	3	17	19	5	4
32	18	2	16	17	5	4
33	17	1	15	17	4	4
34	16		14	16	4	3
35	15		13	15	4	3
36	14		13	14	4	3
37	13		12	13	3	3
38	12		12	12	3	2
39	11		11	11	3	2
40	10		10	10	3	2
42	9		9	9	2	2
43	8		8	7	2	1
45	7		8	5	1	1
47	6		7	3		
50	5		6	2		
52	4		6	1		
56	3		5			
62	2		4			
71	1		3			
73			2			
78			1			

Table 8.--Output of gravity model program, trip length distribution, work trips

SIOUX FALLS NO 2 CARD INT-INT TRIP LENGTH FREQUENCY W/INTRA AND TERMS 1

TRIP LENGTH DISTRIBUTION - PURPOSE NO. 1 PAGE 1

TRIP LENGTH MINUTES	TRIPS	PERCENT OF TOTAL	ACCUMULATED PERCENTAGE
0	0	0.000	0.000
1	0	0.000	0.000
2	0	0.000	0.000
3	380	1.508	1.508
4	372	1.477	2.985
5	889	3.529	6.514
6	1,752	6.954	13.468
7	2,295	9.110	22.578
8	3,728	14.798	37.376
9	3,371	13.381	50.757
10	3,334	13.234	63.991
11	3,225	12.801	76.792
12	1,944	7.716	84.508
13	1,771	7.030	91.538
14	1,022	4.057	95.595
15	412	1.635	97.230
16	256	1.016	98.246
17	442	1.754	100.000

TOTAL TRIPS FOR THIS PURPOSE 25,193

TOTAL PERSON HOURS OF TRAVEL 4,017

AVERAGE TRIP LENGTH, THIS PURPOSE 9.569 MINUTES

d. A table of comparisons between the trips attracted ($\sum_{i=1} T_{ij}$) to each zone by the gravity model and the trips attracted (A_j) to each zone as input on the zonal parameter cards. This table shows the numerical differences and the percentage differences between the two values for each zone, a sample of this format is shown in table 9.

The operation of the gravity model program is as follows: Zonal trip interchanges are first calculated using the previously described input data. Trips attracted to each zone in the study area are then compared with those trips attracted to each zone as given by the trip table builder program. After making this comparison, the program, at the option of the user, will automatically adjust (iterate) each zonal trip attraction factor by the ratio of the O-D trip attraction factor to the gravity model results. (A review of the gravity model formula will show that there is no assurance inherent in the formula that these two attraction figures will be equal on a zonal basis.) The program will then calculate an entirely new set of trip interchanges based on the adjusted attractions.

During the initial calibration runs or until the trip length frequency curves are in fairly close agreement it is not necessary to specify more than one iteration. Some analysts prefer to specify two iterations throughout the calibration process so that the effect, if any, of the adjusted attractions on the trip length frequency can be ascertained. In either instance, the traveltime factor calibration should utilize the trip length frequency from the first iteration.

The gravity model program also has an option which allows the binary output (trip tables) to be suppressed. This reduces the running time on the computer by about 30 percent. It is recommended that this option be employed until the gravity model trip distributions approach the O-D trip distributions.

The trip length frequency distributions are the outputs most directly used at this point. Table 8 illustrates the format of this output. In addition to these data, the person hours of travel are also calculated. The percentages of total trips, for each trip purpose are plotted on rectangular coordinate paper along with the O-D trip length frequency for each trip purpose. Figure 12 shows the estimated and the survey trip length frequency curves for one purpose. Also shown in figure 12 are the person hours of travel and the average trip length. This information is sufficient to begin the trial and adjustment procedure to determine the "best" set of traveltime factors for each trip purpose.

Since the gravity model uses data directly from the field surveys to express all parameters except the traveltime factors, any difference between the two trip length frequency curves are due principally to the initial values of the traveltime factors. Comparisons between the actual and the estimated trip length frequency curves indicate the degree to which the traveltime factors were correctly chosen.

Table 9 -- Output of gravity model program, comparison of trips attracted to each zone by the gravity model with trip attraction values used in calculation

SIOUX FALLS INTERNAL TRIP GRAVITY MODEL DISTRIBUTION CALIB. NO. 1 1 ITERATION NO. 2

COMPARISON OF TRIP ATTRACTION TO TRIPS ATTRACTED - PURPOSE NO. 1 PAGE 1 OF 03

DISTRICT	TRIP ATTRACTION	TRIPS ATTRACTED	DIFFERENCE	PERCENT DIFFERENCE	RATIO
1	2,031	2,033	2	.09	.999
2	687	683	-4	-.58	1.006
3	1,784	1,785	1	.05	.999
4	919	923	4	.43	.996
5	1,118	1,119	1	.08	.999
6	1,111	1,108	-3	-.27	1.003
7	881	880	-1	-.11	1.001
8	19	20	1	5.26	.950
9	292	287	-5	-1.71	1.017
10	67	75	8	11.94	.893
11	504	502	-2	-.39	1.004
12	282	285	3	1.06	.989
13	322	326	4	1.24	.988
14	156	145	-11	-7.05	1.076
15	48	59	11	22.91	.814
16	57	52	-5	-8.77	1.096
17	38	39	1	2.63	.974
18	78	81	3	3.84	.963
19	145	145	0	.00	1.000
20	67	63	-4	-5.97	1.063
81	0	0	0	--	
82	0	0	0	--	
83	0	0	0	--	
84	0	0	0	--	
TOTALS	25,150	25,161	11		

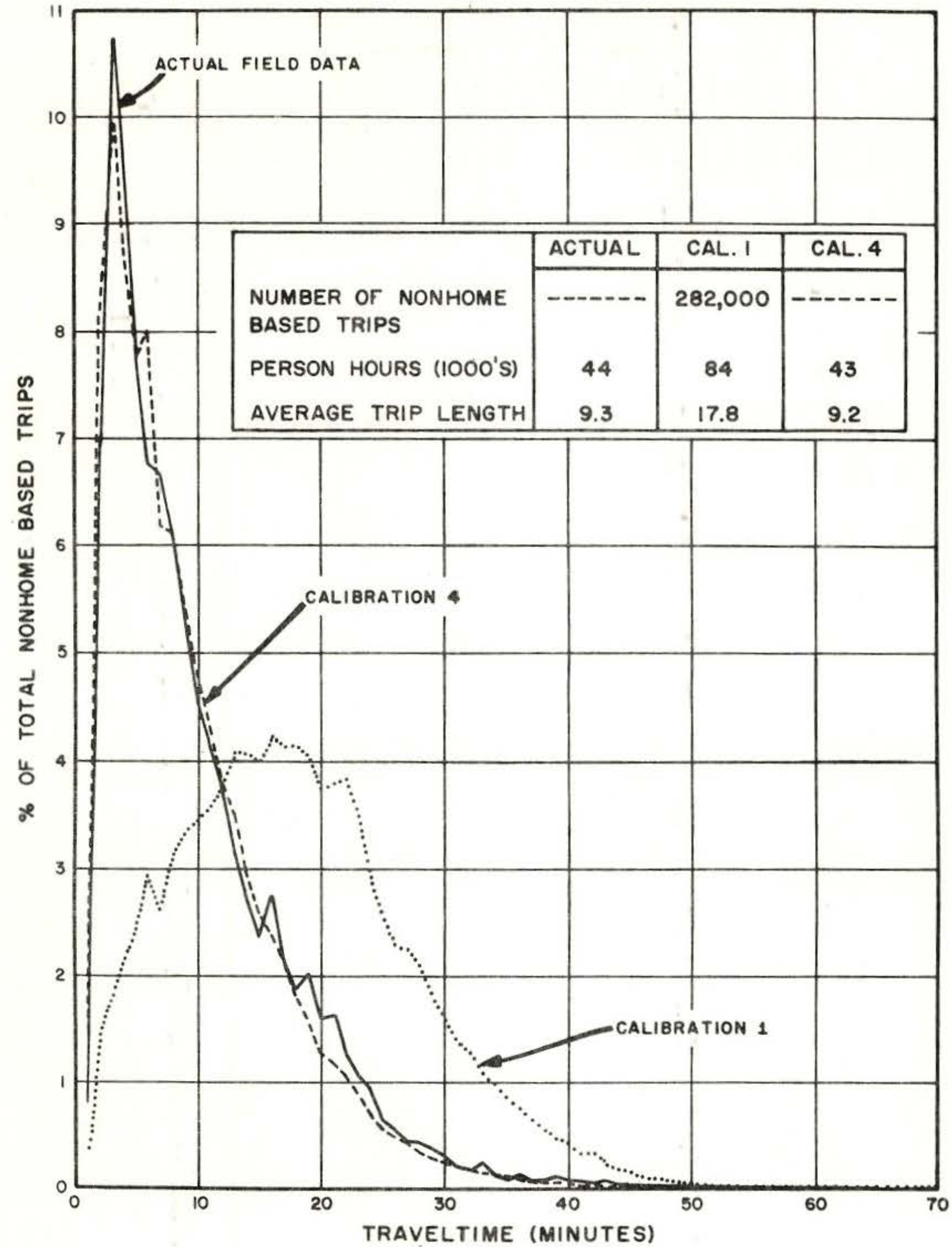

Figure 12.--Trip length frequency for nonhome based trips, Washington, D. C., 1955.

The comparison is made between the O-D and the gravity model curves based on the following criteria:

a. Both curves should be relatively close to one another when compared visually.

b. The difference between average trip lengths should be within ± 3 percent.

If the comparisons do not meet these criteria, then the adjustments should be made to the initial set of traveltime factors.

The traveltime factors are adjusted by an iterative procedure. To make this adjustment, the standard form shown in table 10 is used for recording the information. The actual adjustment is made for each traveltime increment by multiplying the traveltime factor used by the ratio of the percentage of surveyed trips to the percentage of gravity model trips.

Mathematically for each time increment:

$$F_{adj.} = F_{used} \times \frac{OD\%}{GM\%}$$

where:

$F_{adj.}$ = Traveltime factor to be used in next calibration

F_{used} = Traveltime factor used in the gravity model run being analyzed

$OD\%$ = Percentage of origin-destination survey trips

$GM\%$ = Percentage of gravity model trips from the run being analyzed

This calculation results in the adjusted traveltime factor for each one-minute increment of traveltime.

The adjusted traveltime factors are then plotted against their respective traveltime increments on log-log graph paper as shown in figure 13. This is done for each trip purpose. An analysis of those plots will generally indicate that for certain points the adjusted traveltime factors do not reflect the gravity model theory. In essence this theory says that the greater the spatial separation between two zones, the less the probability for trip making. Examining table 10 for trips which are 7 minutes long the traveltime factor is 119, while the traveltime factor for zones which are 8 minutes long is 126, which is somewhat greater and consequently is contrary to the gravity model theory. To adjust for this illogical situation, a "line of best fit" is fitted to the distribution of points. This fitted line should be as smooth and as straight as possible, keeping in mind that it should also approximate the distribution of points. The line shown in figure 13 meets these criteria satisfactorily.

Table 10.--Traveltime factor adjustment

(1) Traveltime	(2) % Trips (Actual)	(3) Traveltime factor # 1	(4) % Trips (Est. #1)	$\frac{(2)}{(4)} \times (3)$ (5) Adjusted traveltime factor	(From figure 13) (6) Traveltime factor #2
1	0	0	0	0	0
2	0	0	0	0	0
3	1.508	172	1.165	223	300
4	1.477	162	0.970	247	247
5	3.529	152	2.607	206	206
6	6.954	142	5.616	176	176
7	9.110	132	10.135	119	145
8	14.798	122	14.379	126	126
9	13.381	112	14.725	102	110
10	13.234	102	13.410	101	101
11	12.801	92	13.032	90	90
12	7.716	82	8.342	76	76
13	7.030	72	7.496	68	65
14	4.057	62	4.479	56	56
15	1.635	52	1.840	46	46
16	1.016	42	0.934	46	40
17	1.754	32	0.791	71	32
18	0	0	0.060	0	0
19	0	0	0.020	0	0
20	0	0	0	0	0

Note: This table represents a fictitious problem

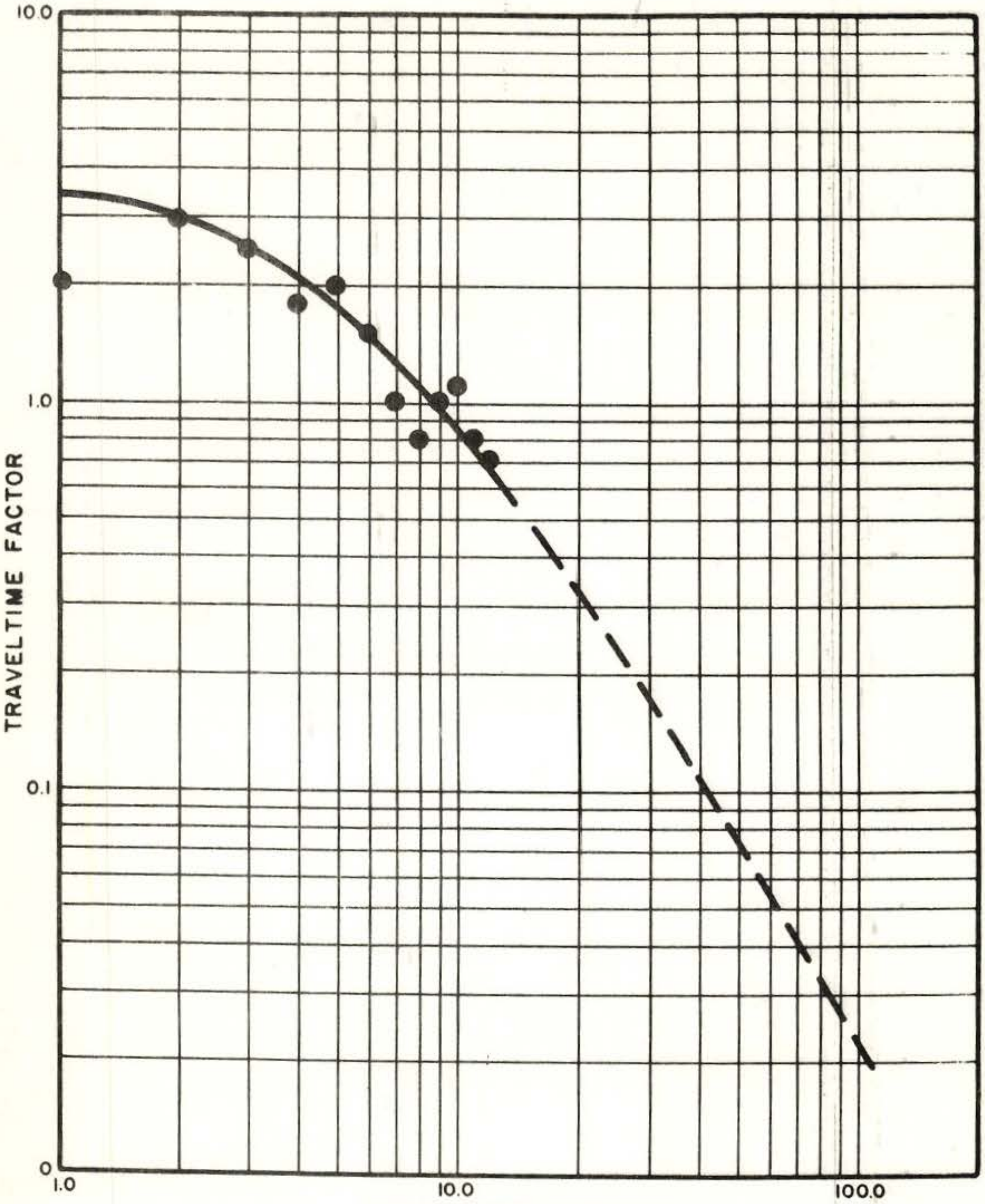

Figure 13.--Traveltime factor vs. traveltime.

It is important to keep the "line of best fit" smooth and as straight as possible for the following reasons:

a. Smooth curves can be approximately defined in a mathematical expression; possibly, one that is not complex.

b. If these curves can be approximated by a mathematical expression, meaningful comparisons can be made between these expressions for different urban areas with various population and density characteristics.

c. These comparisons would eventually help quantify, with a mathematical function, the effect of spatial separation between zones on trip interchange.

Once the line of best fit has been drawn, a new set of traveltime factors is selected from it. For example, the new traveltime factor for 7 minutes would be 145; for 8 minutes it would be 126; for 15 minutes it would be 46 and so forth.

The new sets of traveltime factors are then used in the next calibration of the gravity model program. Zonal trip production (P_i) and trip attraction (A_j) values and the minimum path traveltimes (t_{ij}) between all zones remain as previously described for use in the first calibration. This second calibration results in another estimate of trip interchanges, and a new trip length frequency distribution. As in the previous calibration, the gravity model trips attracted to each zone in the study area ($\sum_{i=1}^{n} T_{ij}$) are automatically compared.

The trip length frequency curves for the second calibration are then plotted and compared with those resulting from the origin-destination survey. If this comparison does not meet the criteria outlined previously, another new set of traveltime factors is developed. The gravity model program is then rerun and the calibration process repeated until these criteria are met. Operationally, this trial and adjustment procedure for determining traveltime factors should take approximately three calibrations, assuming that reasonable first approximations of the traveltime factors were used.

When the traveltime factors are reasonably close, the optional second iteration to balance attractions should be specified. The gravity model program will then automatically calculate a second set of trip interchanges using the same input data except that in place of the original trips attracted (A_j), the adjusted trips attracted (adjusted A_j) are used.

The entire process may be repeated for a third iteration if necessary. Actually this third iteration is usually only on the final calibration, if at all. Experience has shown that the second iteration gravity model attractions ($\sum_{i=1}^{n} T_{ij}$) are approximately equal to the trip attraction factors (A_j) for each zone. On this last iteration, second or third, whichever the case may be, all four items of output data are obtained for analyzing the model results.

E. Phase Four.--Topographical Barriers

Many of the gravity model studies conducted to date have shown that topographical barriers, such as mountains, rivers, and large open spaces, may cause some bias in the gravity model trip interchange estimates. For example, a recent study in Washington, D.C., (29) indicated that the Potomac River had some influence on trip distribution patterns. A study in New Orleans, Louisiana, (30) indicated similar findings. A study in Hartford, Connecticut, (31), indicated that the toll bridges crossing the Connecticut River also affected travel patterns.

The nature of the influence of such topographical barriers is not known. All of the above-mentioned studies have analyzed the apparent reasons why these barriers have influenced travel patterns in their own unique situation. In Washington, D.C., (29) it was attributed to the fact that off-peak hour traveltimes did not correctly indicate the amount of congestion which was present on bridges crossing the Potomac River. An analysis of congestion patterns in the region showed that there was greater congestion in the area of the Potomac River than elsewhere in the region. From this analysis, it was reasoned that a more realistic measure of the traveltime on these bridges was required. In the Hartford study (31), it was attributed to the fact that tolls are collected on several bridges crossing the Connecticut River. Since travel costs can also influence travel patterns, it was concluded that this cost barrier should be reflected by increased traveltimes on those bridges where tolls were collected. In New Orleans (30), the Mississippi River separates portions of the study area. Many persons cross this river by ferry boat, as well as over the bridge. It was concluded that traveltimes on these bridges should be increased to allow for the effect of the long traveltimes necessary in crossing the river by ferry boat.

In each of the above cases, the effects of topographical barriers were accounted for in the gravity model by inserting time penalties on portions of the transportation network. The need for these penalties is a result of the present lack of knowledge of a precise measure of spatial separation between zones.

The examination of the traveltime patterns for bias caused by topography involves an analysis of the differences between the estimated and the surveyed trips crossing the various topographical barriers in the study area. Essentially, it is a screenline analysis. The trip interchanges developed from the travel pattern survey are compared directly with those of the final gravity model calibration. These comparisons are made by using the results of the accumulate selected interzonal volumes program (PR-183). This program will accumulate trip movements between any desired portions of the urban area. The results are compared and, if a bias exists in the gravity model estimates, the necessary steps can be taken to correct the situation in subsequent gravity model calibrations.

This analysis should generally be made for the principal trip purpose. It can be made either on the zonal interchanges or it could also be made using district-to-district movements. In either case, the binary tables of both actual and estimated interchanges are supplied to program (PR-183) and any desired movements can be obtained for analysis.

This program has been used in connection with research work by the Bureau of Public Roads using data for Washington, D.C. Using both the actual and the estimated trip interchanges, for each of five major trip purposes, the trips crossing the Potomac River, from each direction were extracted and tabulated as shown in table 11.

Inspection of the volumes in table 11 shows that the gravity model overestimated trips crossing the Potomac River in both directions and for all trip purposes. This indicates that the river definitely acts as an impedance to travel. The largest over-estimate, in terms of volumes of trips, is for work trips. This indicated that the over-estimate had some connection with peak period congestion. As was indicated earlier, this was found to be the case.

To correct for the effect of such barriers in subsequent gravity model calibrations, traveltime impedances are inserted in these portions of the transportation network which traverse the barrier being analyzed. This is done directly on the affected links (usually bridges) by updating the network description or in certain instances by using the skim and update trees program.

The amount of time barrier to impose is determined by a trial and error procedure. In New Orleans, La., for example, a time barrier of 7 minutes was first imposed on all those portions of the transportation network crossing the Mississippi River. Subsequent analysis of the revised gravity model estimate of trips crossing this river showed that the time barrier was too high. By adjusting it, the correct time barrier was finally set at 6 minutes. A similar procedure was used in Hartford, Connecticut, and Washington, D.C.

An investigation of traffic using the Potomac River crossings (22) substantiated the fact that these barriers depend on the relative congestion on the bridges. The congestion was found to be directly related to a "volume to capacity" ratio of the traffic on the bridges. This ratio is then used to forecast the barriers for the future year.

It is important to point out that when time penalties are imposed on portions of the transportation network, these penalties must be brought to bear on the trip length frequency distribution of the survey trips. This can be done by updating the network description and rebuilding the trees. The trip interchanges for each trip purpose are then rerun through the trip length frequency program.

The revised trip length frequency distributions are then used as a base against which any subsequent gravity model estimates are compared.

Table 11.--Comparison of trips, by trip purpose, crossing the Potomac River - Gravity model versus 1955 O-D interview survey

Trip Purpose	Person trips by residents of Maryland and D. C.			Person trips by residents of Virginia		
	Model	Survey	% Diff.	Model	Survey	% Diff.
Home based work	83,000	72,000	+15%	120,000	97,000	+23%
Home based shop	3,500	2,000	+75%	7,000	6,500	+ 7%
Home based social-recreation	13,000	12,500	+ 4%	21,500	19,000	+13%
Home based school-miscellaneous	9,000	9,000	-	15,500	12,000	+29%
Nonhome based	14,000	13,500	+ 3%	13,500	12,000	+12%
TOTAL	122,500	109,000	+12%	177,500	146,500	+20%

F. Developing Zone-to-Zone Adjustment Factors

There may be factors, other than those related to traveltime, which could affect patterns of urban travel. Travel patterns may also be influenced by various social and economic conditions. The effect of these factors can be accounted for in the gravity model formula by the use of zone-to-zone adjustment factors (K_{ij}).

Due to the limited research on this particular point, the underlying reasons behind the need for K_{ij} factors are not well understood. However, several studies (29) (30) (31) have indicated that the following may influence our ability to identify the real causes for the need to incorporate zone-to-zone adjustment factors into the gravity model formula.

1. The trip purpose stratifications used today may not be precise enough to account for all of the basic differences in travel patterns. For example, it is possible that all the work trips produced by a particular zone are those trips made by industrial workers. When distributing these trips by the gravity model, or any other traffic model for that matter, the largest proportion of these trips would be sent to the closest zones with large employment centers, regardless of the type of employment which is available. This means that many of these industrial workers may be sent to large offices and

commercial establishments, mainly because of their proximity to the residences of these workers. However, if total work trips were to be further stratified according to white collar and blue collar workers, for example, this deficiency might be corrected. However, such a stratification may create problems in forecasting trips, since it would be more difficult to forecast the place of residence and the employment opportunities for blue collar and white collar workers than it would be for all workers.

2. It is customary to develop a set of traveltime factors for each trip purpose category. Since trips between all zones are used in developing these factors, they represent the average areawide effect of traveltime on trip interchange. However, there is some evidence which tends to show that traveltime factors vary by zone depending on the characteristics of the people who live in each zone. These factors may also depend upon the distribution of land uses immediately adjacent to these zones.

3. There is some evidence that factors such as income and residential density may influence the need for zone-to-zone adjustment. It is not yet clear whether these two factors may actually be a reflection of items 1 and 2 or whether they are independent factors in themselves. In Washington, D.C., for example, it was observed that low income families were not as likely to work in the central business district as were higher income families. This observation was made by direct comparison of zonal interchanges estimated by the gravity model formula and those from the origin-destination survey. However, since average areawide traveltime factors and only a six-purpose trip stratification were used, this conclusion may be somewhat weak.

Regardless of the reason for zone-to-zone adjustment factors, the need may exist for incorporating them into the gravity model formula. In some cases these adjustments (K_{ij}) may be significant and in others they may not be necessary at all. Generally, in the large urban areas where there are many types of employment, shopping, and recreation, these adjustments may be necessary. However, in the smaller urban areas, the need for K_{ij} factors is small and in most cases the factors are not necessary at all.

Even with many limitations on the understanding of the K_{ij} factor, tests to determine the extent of required adjustments and procedures for incorporating them into the model have been devised and used in several studies. The procedures require an analysis of the differences between the trip interchanges calculated in the final calibration of the gravity model and those measured in the O-D survey. This analysis is performed on data for the trip purposes where problems are suspected using procedures described below.

Limited experience has shown that it is the large traffic generators for which the gravity model trip interchanges must be adjusted. Trips between all zones and the central business district of an urban area, for example, may require adjustment. Occasionally, trips between one city of an urban complex and another city within the same complex must be adjusted. The procedure used in developing adjustment factors is to compare the trip interchanges between large traffic generators as estimated by the gravity model with those developed from the origin-destination survey. These comparisons are usually done graphically.

The first step is to combine the trip purpose categories into major groups. For example, if trips between all zones and the central business district were to be examined, it would be desirable to look at home based work trips and home based shopping trips separately, while the remainder of the trips may be combined into one major group. Work trips and shopping trips should be analyzed separately because of the importance of the central business district as a generator of these two types of trips. All remaining trip purpose categories could then be combined by using the general purpose program. This combining is done for both the gravity model interchanges and those from the origin-destination survey.

The specific movements to be examined in the "K" factor analysis may be isolated through the use of the interzonal volumes summary program.

Figure 14 illustrates this analysis for the central business district trips.

A district map is used in this examination, one for each major trip purpose category examined. Sector lines are drawn to denote major traffic drainage corridors. One fictitious radial transportation route is assumed to be centered in each of these sectors. The movements between each district and the central business district are then manually "assigned" to the fictitious facility within the sector in which the district is located. These volumes are then accumulated as the fictitious route approaches the central business district. Generally, three values are shown for each corridor-- the total origin-destination survey movements, the total gravity model movements, and the difference between the two. Using this procedure, any systematic errors which reflect the need for zone-to-zone adjustment factors can be easily located.

The same procedure could be repeated for any desired traffic movement. Once the analyses are completed, the need for adjustments must be determined. Generally the amount of adjustment would be dependent on the ratio of the origin-destination survey results to the gravity model results for a particular movement. But, it is also dependent to a more limited extent on the proportion of trips produced in any zone which are to be adjusted. A recent study in Washington, D.C., (29), concluded that the following formula expressed the relationship between the adjustment factor required for any zonal movement and these two factors:

$$K_{ij} = R_{ij} \frac{1 - X_i}{1 - X_i R_{ij}}$$

where: K_{ij} = adjustment factor to be applied to movements between zone i and zone j (or district i and district j)

R_{ij} = ratio of origin-destination survey results to the gravity model results for the movement between zone i and zone j

X_i = ratio of OD trips from zone i to zone j to total OD trips leaving zone i

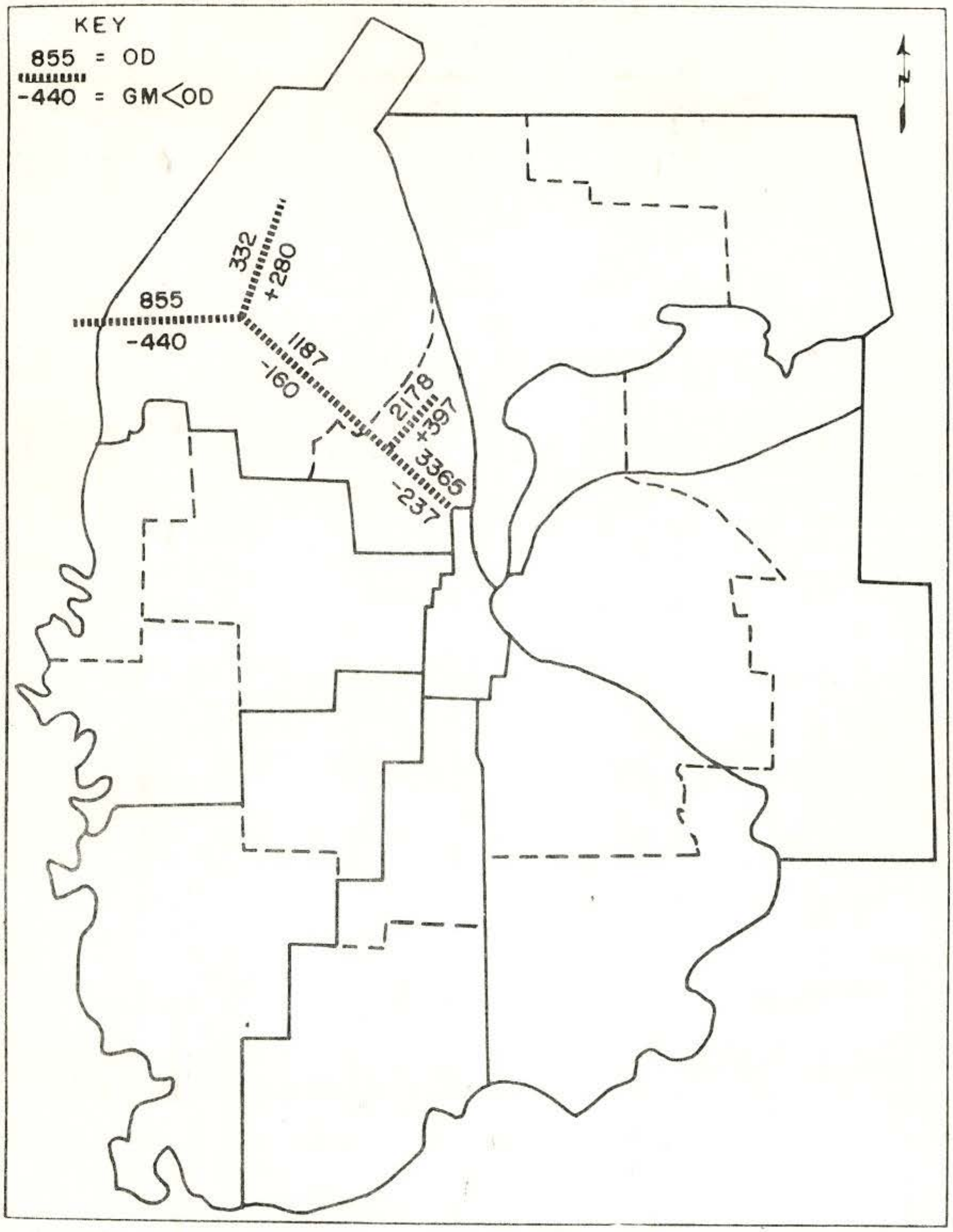

Figure 14.--Graphical analysis to determine the need for zone-to-zone adjustment.

This formula modifies the initial adjustment factor (R_{ij}) to account for the fact that the final factor (K_{ij}) appears in both the numerator and the denominator of the gravity model equation, and thus its effect in the numerator is buffered. This buffering is critical if from 10-40 percent of the trips out of a zone have factors applied all in the same direction (i.e., all positive or all factional). In this situation it is necessary to apply this formula to maintain the proper adjustments.

If over 40 or under 10 percent of the trips leaving a zone are to be adjusted, R_{ij} should be used as the K_{ij} factor.

The distribution utilizing the adjustment factor should be checked to determine if the proper adjustment has been attained. In some instances it may be necessary to modify certain of the initial K_{ij} factors and to calculate a new trip distribution in order to attain the desired accuracy.

The following example will illustrate the use of this formula. It has been determined that work trips between all districts and the central business district must be adjusted. District 100 produces 5,000 total work trips daily. The origin-destination survey reported that 1,000 of these trips went to the central business district. The gravity model however, estimated that only 500 of these trips went to the central business district. The adjustment factor to correct the gravity model results for this condition would be calculated as follows:

$$K_{100\text{-}CBD} = \frac{1{,}000}{500} \left[\frac{1 - \frac{1{,}000}{5{,}000}}{1 - \left(\frac{1{,}000}{5{,}000}\right)\left(\frac{1{,}000}{500}\right)} \right] = 2.67$$

This factor would then be inserted into the gravity model formula with other calculated adjustment factors and a revised trip distribution pattern obtained.

The trip length frequency of this revised trip distribution pattern must be checked against the origin-destination survey distribution to verify its correctness.

Chapter V
TESTING THE GRAVITY MODEL

A. General

The gravity model program produces a synthetic trip distribution pattern which is an approximation of existing conditions. It must be realized that variations between the existing and the estimated conditions are inherent in any approximation process. Tests can be made to determine the accuracy of the procedure used in forecasting future travel patterns. Several types of tests are available to aid the transportation analyst in evaluating the procedure.

The analytical tests which were described in chapter IV, are designed to assist in analyzing and adjusting the model for bias in movements crossing topographical features or for bias associated with income or other socio-economic characteristics. Upon completion of the analytical tests, statistical tests may be undertaken to provide an overall measure of quality of the final calibrated model.

B. Statistical Tests

The statistical tests are generally applied only to a calibrated gravity model. The total trips from the calibrated gravity model are compared to the origin-destination survey trip interchanges after both are assigned to the same spider network. Urban areas with a population less than 100,000 may find it feasible to assign their trips to the actual network rather than to a spider network. The trip comparison program is used in making the comparisons and the details concerning this program are found in the appendix.

This comparison program accepts as input two binary loaded networks, one containing the surveyed information and the other the corresponding gravity model estimates.

The program operates as follows: It first produces a table of differences between the gravity model and origin-destination survey movements as illustrated in table 12. Next, the program separates the link volumes into 16 groups depending on the survey volume. For each of these 16 volume groups the differences between the origin-destination survey and the gravity model movements are tabulated according to magnitude into 32 difference groups.

Table 12.--Output of trip comparison program - link volumes

A Node	B Node	O-D Volume	G-M Volume	Difference
1	9	38,680	43,412	4,732
1	500	16,452	16,428	-24
1	509	36,412	36,180	-232
2	3	5,812	5,692	-120
2	7	3,552	3,704	152
2	500	1,704	2,040	336
2	509	10,796	11,460	664
3	2	11,428	12,440	1,012
3	4	2,820	2,180	-640
3	6	5,944	6,724	780
3	280	3,492	4,036	544
4	3	10,404	11,900	1,496
4	5	31,940	30,340	-1,600
4	284	11,664	10,556	-1,108
4	285	4,872	3,676	-1,196
5	4	8,832	7,736	-1,096
5	6	18,600	23,628	5,028
5	19	16,708	12,392	-4,316
6	3	5,352	6,012	660
6	5	3,704	4,628	924
6	7	9,128	10,416	1,288
6	22	9,944	10,756	812
7	2	2,932	2,748	-184
7	6	2,936	1,920	-1,016
7	8	8,476	8,348	-128

Table 13 shows the frequency of occurrence of various differences between the gravity model and the origin-destination survey movements within the 8000-9999 volume group. It also shows the sum of these differences, the sum of their squares, the mean difference, the standard deviation, the root-mean-square error, the percent root-mean-square error, and the total trips from both sources, within this volume group. It can be seen that a total of 102 movements fall into this category.

The same procedure is used on all volume groups. If the relative error for each group is within the limits of accuracy the transportation planner is willing to accept, then the model is deemed statistically satisfactory. If it is not within acceptable limits, the source of the error must be located using the analytical tests outlined in chapter IV and the model revised.

The trip comparison program may also be used to compare compressed binary trip tables. This test is somewhat more stringent than the spider network comparison as there is no chance for geographic or socio-economic bias to be averaged out in the assignment.

When evaluating the accuracy of travel models the accuracy of the origin-destination survey data should also be considered. Figure 15 developed by A. Sosslau and G. Brokke can be used to estimate the accuracy of survey volumes given the home interview sampling rate. For example, given a sampling rate of 5 percent, a volume of 10,000 trips estimated from the home interview survey can be expected to be accurate within ±8 percent at the two-thirds level of confidence.

It follows that if a model demonstrates an accuracy at each volume level equivalent to the accuracy of the survey data, the calibration can be considered complete. To achieve any further accuracy other sources of data would have to be used.

Table 13.--Output of trip comparison program - frequency distribution and analysis of differences, volume group - 8,000 to 9,999

Difference	Frequency	Sum of Differences
-99,999 AND OVER	0	0
-75,000 TO -99,998	0	0
-50,000 TO -74,999	0	0
-25,000 TO -49,999	0	0
-20,000 TO -24,999	0	0
-15,000 TO -19,999	0	0
-10,000 TO -14,999	0	0
-8,000 TO -9,999	0	0
-6,000 TO -7,999	0	0
-5,000 TO -5,999	0	0
-4,000 TO -4,999	0	0
-3,000 TO -3,999	0	0
-2,000 TO -2,999	5	-12,612
-1,000 TO -1,999	18	-27,616
-500 TO -999	11	-8,332
0 TO -499	16	-3,260
0 TO 499	15	4,020
500 TO 999	14	11,024
1,000 TO 1,999	15	21,428
2,000 TO 2,999	5	11,824
3,000 TO 3,999	3	10,908
4,000 TO 4,999	0	0
5,000 TO 5,999	0	0
6,000 TO 7,999	0	0
8,000 TO 9,999	0	0
10,000 TO 14,999	0	0
15,000 TO 19,999	0	0
20,000 TO 24,999	0	0
25,000 TO 49,999	0	0
50,000 TO 74,999	0	0
75,000 TO 99,998	0	0
99,999 AND OVER		
TOTALS	102	7,384

SUM OF SQUARES	=	192,891,392
MEAN DIFFERENCE	=	72
RMS ERROR	=	1,375
STANDARD DEVIATION	=	1,373
TOTAL O-D TRIPS	=	909,180
TOTAL G.M. TRIPS	=	916,564
PERCENT RMS ERROR	=	15.43

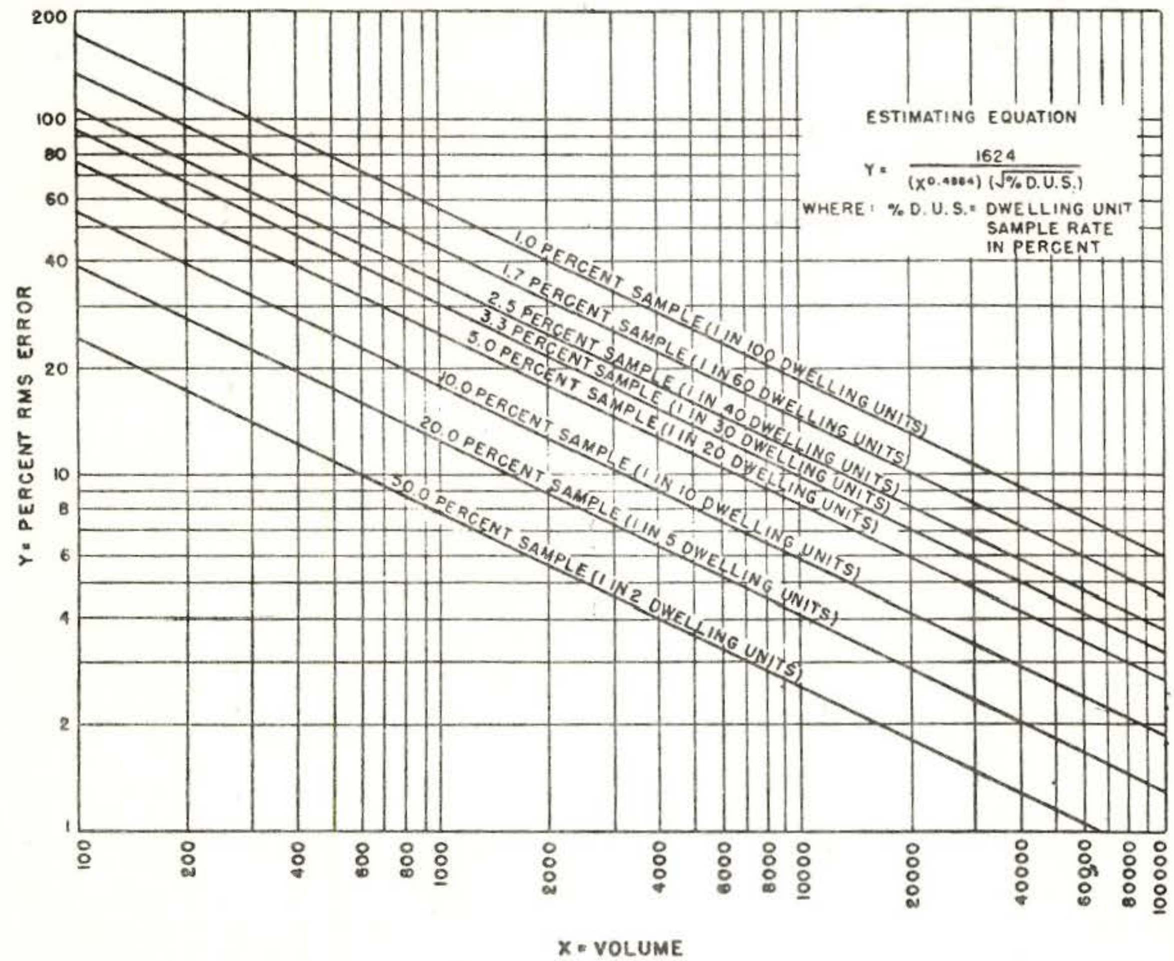

Figure 15.--Relation of percent root-mean-square error and volume for various dwelling unit sample rates.

Chapter VI
OTHER CONSIDERATIONS

A. Converting the Gravity Model Results to Directional Movements

Once the gravity model trip interchanges have been shown to reproduce the travel patterns surveyed by the field inventories, it is desirable to convert the gravity model results to directional movements between origin and destination zones. The gravity model results yield movements from zones of production to zones of attraction. The converted movements may be used for directional assignment to the transportation network. Provision has been made to convert the gravity model results using the trip conversion program.

Consider the following examples of the conversion to directional volumes. Zone 1 produces 100 work trips which are attracted to zone 2. This is shown schematically in figure 16. Each of these trips is produced in the home zone and attracted by the zone at the nonhome end of the trip.

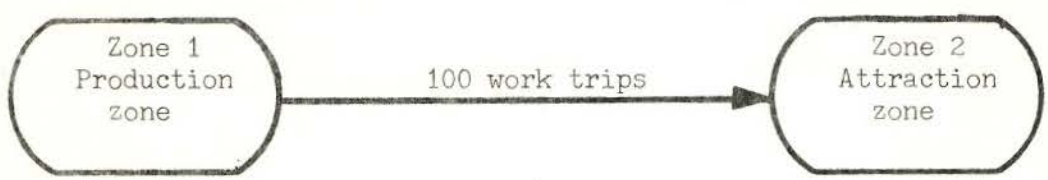

Figure 16.--Case I - Schematic gravity model trip interchange.

These gravity model trip interchanges converted to directional origin-destination movements are illustrated in figure 17.

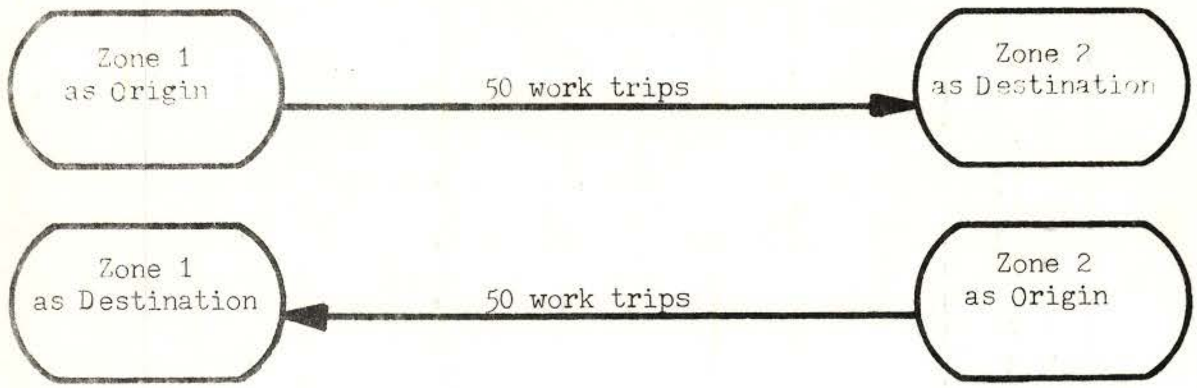

Figure 17.--Case I - Schematic origin to destination interchange.

In current practice a 50-50 split is usually assumed for all home based trips. Since for nonhome based trips, the zones of production and attraction remain the same as the zones of origin and destination, respectively, no splitting of these trips is required. The output from this program is a binary trip table of directional movements between all origin and destination zones. This output can then be assigned to the transportation network to obtain directional volumes.

In certain areas unique situations may exist where it might be desirable to convert on other than a 50-50 basis. The trip conversion program provides the user with this option. This same option may also be used to factor an ADT trip table (by purpose) to a directional peak hour trip table.

Specific details on the trip conversion program can be found in the appendix.

B. Forecasting Future Travel Patterns Using the Gravity Model

The calibrated gravity models developed from present data are used to estimate future travel patterns for any desired year or land use pattern. Many of the phases related to the process of estimating future travel patterns are outside the scope of this manual. Figure 18 illustrates the complete urban travel forecasting process. Inspection of this figure shows that future trip distribution is influenced by many other elements in the forecasting process. The primary elements are the traveltime factors developed in the calibration of the model, the future network, and the future land use. Each of these elements is in turn conditioned by the basic travel characteristics, the existing network, the forecast of economic activity and population, and the community goals and policies.

URBAN TRAVEL FORECASTING PROCESS

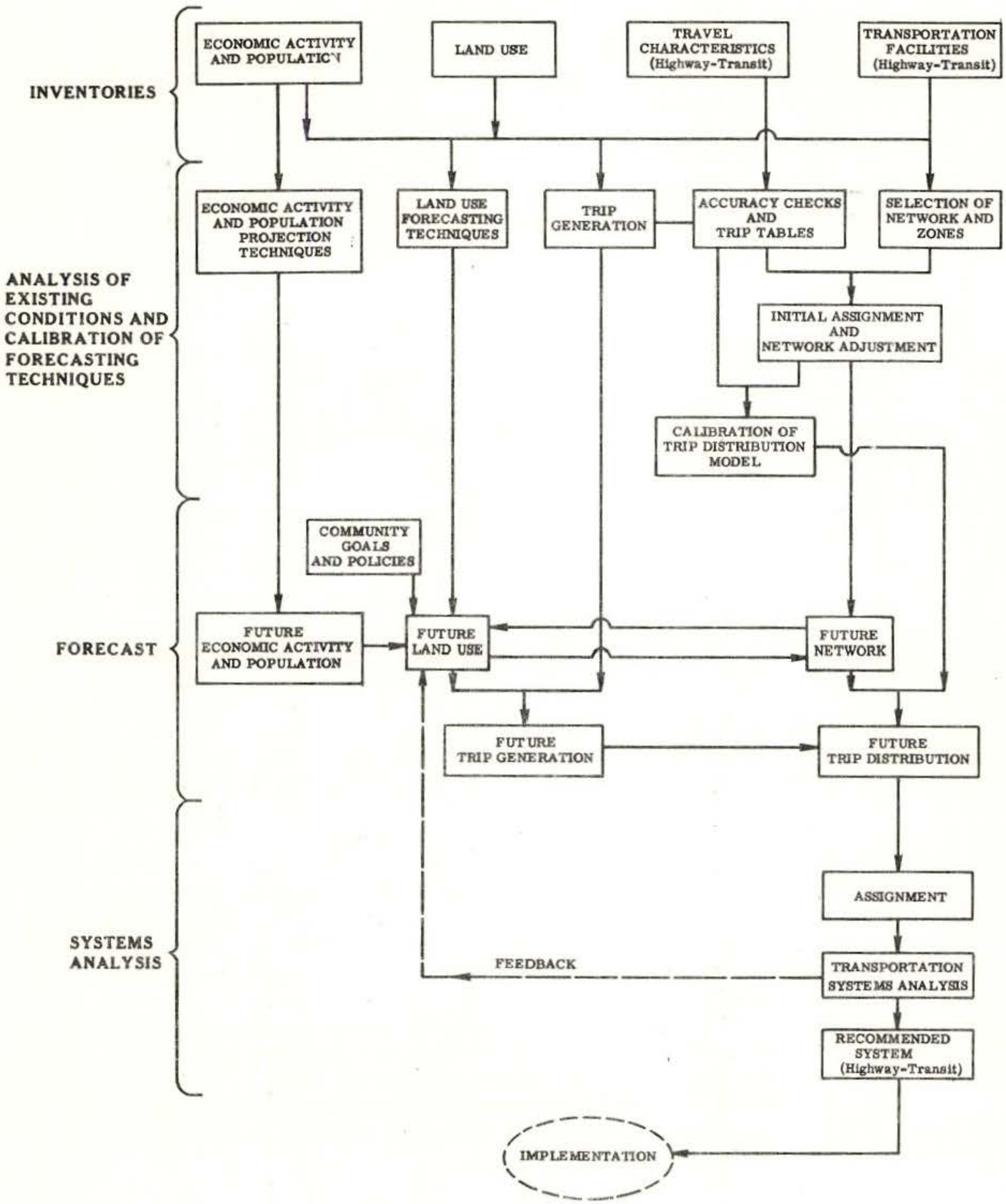

Figure 18.--Urban travel forecasting process.

Briefly the process may be described as follows:

The entire forecast is based upon the estimate of future economic activity and population. Once this estimate is available, the economic activity and population must be translated into land requirements and distributed among the various zones. The trip generation is then a direct function of land use.

Trip generation relationships are developed using the base year data. These mathematical expressions, which relate trip production and attraction to various land use and socio-economic indicators, are applied to the future land use to arrive at future generation.

A proposed transportation system is determined for the future time period. The location and extent of this system can be influenced by present points of congestion and probable changes in land development patterns. The proposed system is then coded and described to the computer in the same manner as described in chapter IV for the present system. The minimum path traveltimes between all zone pairs for the proposed system are then calculated.

Traveltime factors, as developed from present data, are used for the future time period. Very limited evidence leads to the conclusion that this is a reasonable assumption to make.[1] However, much research work is required on this point before the assumption can be accepted without reservation.

In addition, if zone-to-zone adjustment factors (K_{ij}) were found necessary for the present time period, they may also be necessary in the future. These are developed for the future based on their relationship to the same specific socio-economic characteristics. For example, a recent study in Washington, D.C., (22) developed zone-to-zone adjustment factors for all home based work trips to the central business district. The factors were then related to the income level of the persons living in each zone. The socio-economic adjustment factors for the forecast period were determined by analyzing the forecast estimates of zonal income.

The essential techniques have thus been described for the calibration of a gravity model for base year data and for the application of this technique to a forecast year.

The gravity model provides the transportation planner with an effective tool to relate the characteristics of land use (as represented by generated trip ends) to the characteristics of the transportation system in order to simulate the distribution of trips. The feedback from the transportation system to the land use and vice versa is the key to the transportation system analysis.

The transportation planner has many alternate approaches to systems analysis available to him. Alternate land use configurations can be studied with respect to a single transportation plan or more likely alternate transportation systems can be studied with respect to a given land use plan. The number of combinations of land use and transportation systems requires a systematic approach to the problem.

---

[1] For further discussion see page III-2.

It is generally agreed that a first step in the process should be the assignment of future trips to the present plus committed system. The specific additional steps in the systems analysis will be conditioned by the land use and transportation systems to be evaluated. The reader is referred to the Traffic Assignment Manual (1) for a more detailed discussion of the programs and procedures to be used in systems analysis.

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Appendix I
COMPUTATIONAL METHODS

A. Introduction

This appendix presents a detailed description of a battery of computer programs to automate the operations described in the text. These programs are designed for production-oriented batch processing. Most of the programs operate on the IBM 7090 computer. Data formats for the 7090 computer are entirely compatible between programs and all operate under the supervision of the BELMN submonitor. Data reduction and editing are performed using programs written for the smaller IBM 1401 computer. There is no monitor system for this smaller computer.

The remainder of information on computer operation includes: (1) A description of the operating system; (2) the program descriptions; and (3) a description of standard data formats.

The operating system hardware and software will be described in only as much detail as is necessary to operate the programs in production. A more extensive discussion, including the information necessary to program for the system, is available in an earlier publication, Traffic Assignment Manual (1), published by the Bureau of Public Roads. To alleviate repetitive items in the program descriptions, common items will be discussed in a separate section and referenced in the program descriptions as required. The descriptions will be in an abbreviated format, suitable for production operation of the programs. There is a description for each program discussed in the text, with the exception of a sort program. The sorting operations may be performed using any standard library sort program available at most computer installations.

There are some differences in the operation of the submonitor (BELMN) as described in the Traffic Assignment Manual (1) and as described here. The information contained in this volume is the most current and refers to the latest version of BELMN as available from the Urban Planning Division, Bureau of Public Roads. It should be noted that any previously described operations may still be performed and have not been eliminated.

B. Equipment

Two different types of computing equipment are used in the application of the following programs: (1) A BCD IBM 1401/1410 and (2) a binary IBM 7090/7094. The programs for the latter machine operate on a 32K IBM 7090/7094 computer with an on-line printer, two data channels, and an optional on-line card reader. The editing programs require a 16K IBM 1401 with two tape units. The linking program requires an 8K IBM 1401 with two tape units.

All the IBM 1401 programs require three index registers, sense switches, high-low-equal compare, the advanced programing package, a 1402 card-read-punch, and a 1403 printer.

C. Operating System

The IBM 7090 programs operate under the supervision of the BELMN submonitor. The submonitor is designed to be initiated by a senior monitor, which is the integral part of a computer installation's operating system. The senior monitor will not be described here. It is intended that the user will adapt the BELMN submonitor to operate under the control of his particular senior monitor. The primary function of the senior monitor is to schedule the processing for many different types of jobs and to reduce the idle time between jobs. A series of BELMN programs is operated as a unit job under a senior monitor, or if desired the series may be run independently.

Thus, BELMN allows the user the flexibility of either remote operation of these programs under his installation's particular batch-processing monitor, or direct processing without any monitor system. In either case, the BELMN submonitor has complete control of operations during the processing of the gravity model programs, and at completion either halts (with no senior monitor) or returns to the senior monitor.

Each of the BELMN programs that are to be used is "stacked" on a magnetic tape which will be referred to as the "program library tape." The BELMN submonitor controls the initialization of a specific program from this tape by means of various control cards. It also handles the transition from program to program, the various housekeeping operations, and the return to the senior monitor system in use.

In order to initialize the BELMN submonitor, a small program, referred to as the "BELMN loader," is loaded into storage by the senior monitor and executed. These instructions must also be available in storage to refresh the BELMN monitor and to allow return to the installation's senior monitor. It is also possible to start operations by mounting the library tape on tape unit A1 and pressing "LOAD TAPE" on the console. This is possible because the BELMN submonitor programs contain the BELL (BESYS3, distributed by the Bell Telephone Laboratories) senior monitor. In the latter case, more tape units will be available to the user, though the computer will halt at the completion of operations and must be restarted.

Thus the BELMN submonitor allows ready reference to, and use of, a senior monitor as desired, but it can also operate independently of it.

Appendix II
PROGRAM DESCRIPTIONS

This appendix presents, in an abbreviated form, descriptions of the programs required to calibrate and test a gravity model trip distribution. These descriptions will reference material in appendices III and IV. This is done to prevent the repetition of items which will remain the same in each program description. The user should refer to appendix III for the standard formats of BELMN control cards, subject program control cards, and for standard input data and output data formats. Appendix IV contains the details of the operation of the BELMN submonitor. The user should refer to appendix IV for the information necessary to operate BELMN with his specific senior monitor system. This appendix also describes the uses and results of the various BELMN control cards. It is preferable that someone with computer programing experience read appendix IV and develop the method to initiate the BELMN submonitor.

1. PR-113, TRIP TABLE OR SKIMMED TREE FORMAT PROGRAM IBM 7090/7094

A. Identification

Deck No.: BS0113

Written by: P. Jennings, G.E. Computer Division, February 1960 for IBM 704. Revisions for IBM 7090 by W. Hansen, Vogt-Ivers and Associates, and L. Seiders, BPR.

Assembly Date: July 27, 1964.

B. Purpose

PR-113 converts binary trip tables or skim trees into a BCD format suitable for off-line printing.

C. Data Requirements [1]

1. Tape inputs

   a. Binary trip table or skimmed trees

2. Card inputs (in order required)

   a. Call card
   b. Identification card
   c. Parameter card

      (1) Options

Card columns	Contents	Result
1	"1"	Skimmed tree input
1	blank	Trip table input

---

[1] See section "E" of the appendix for standard data formats.

(2) Parameters

Card columns	Contents
37-39	Number of zones

d. Selected zones card
e. Tape assignment card (Optional)

Field	Tape	Normal tape assignments
1	Trip table or skimmed trees	B5

D. Program Operation

The program reads the cards in the above order, checks them for correctness, stores them in memory, and prints them on the system output tape.

The first record specified on the control card is selected and read by the program. It then is processed and written in BCD form on the off-line print tape. The program proceeds to the next designated record and repeats the operation. This continues until all selected records have been processed. At the end of the job, the input tape is rewound and control is returned to BELMN.

This program has been designed to print the trip tables on 72 column paper with from one to four tables to a page depending upon the maximum size of the table.

Number of zones	Tables per page
210 or more	1
140-209	2
70-139	3
69 or less	4

At the end of each table, the total trips for that table are printed.

E. Timing

Processing requires 2-10 seconds for each record (origin zone) depending upon the number of zones in the trip table, and the number of nonzero trip transfers.

F. Error Conditions

1. "NO ONE PUNCH IN COL. 72"

2. "NO TWO PUNCH IN COL. 72"

3. "NO THREE PUNCH IN COL. 72"

All of the above are printed under the card in error and are caused by improper identification.

4. "LAST ZONE NO. OMITTED"
Number of zones missing from parameter card.

5. "A3 END OF TAPE. DIAL NEW A3" (On-line)
Self explanatory.

6. "TOO MANY TAPES---"
More tapes on assignment card than are required.

7. "BAD CHANNEL ASSIGNMENT."
Improper channel, must be "A" or "B"

8. "BAD TAPE NUMBER"
Improper unit number, must be zero or one to nine.

NOTE: All of the above conditions, except "5," result in a return of control to the senior monitor system.

2. PR-116, PUNCH AND SUM TRIP ENDS PROGRAM IBM 7090/7094

A. Identification

Deck No.: BS0116

Written by: L. Seiders, BPR, February 1965.

Assembly Date: March 26, 1965

B. Purpose

PR-116 prepares printed tables of summary of trip ends and/or prepares zonal parameter cards for input to the travel model programs.

C. Data Requirements [1]

1. Tape inputs

   a. Binary trip tables

2. Card inputs (in order required)

   a. Call card

   b. Identification card

   c. Parameter card

      (1) Options

Card columns	Contents	Results
1	"1"	Card images will be written on punch tape
1	blank	Do not punch cards
2	"1"	Set districts equal to zones on punch cards

[1] See section "E" of the appendix for standard data formats.

Card columns	Contents	Results
2	blank	Zones on the punch cards will be either the ones read from the "3" cards or blank.
3	"1"	Special. Only cols. 7-66 on the punch cards can be used. Cols. 67-72 will be labeled with cols. 49-54 of the parameter card, cols. 73-80 will be blank and cols. 1-6 will contain the zone number.
3	blank	No effect
4	"1"	Do not print the trip end summaries
4	blank	No effect

(2) Parameters

Card columns	Contents
37-39	Number of zones
42	Number of tapes
49-54	Label for option 3

d. Zone district equivalent ("3") cards

These cards are utilized by options 1 and 2 only. The program will place the district in cols. 4-6 of the punch card output. If no "3" card is read for a zone the district is left blank.

Card columns	Contents
4- 6	District
10-12	First zone of district
16-18	Last zone of district; this field may be left blank if there is only a single zone in this district.
72	"3" (necessary for identification)

e. Punch field selection ("4") card

This card can be used to designate the format of the punch cards. If this card is not used the following card is simulated:

12,48,18,54,24,60,30,66,36,72,42,78.......4

Card columns	Contents
1- 2	Column on punch card in which total trips sent for tape 1 are placed
3	Comma
4- 5	Column on punch card in which total trips received for tape 1 are placed
6	Comma
7-12	Same as cols. 1-6, but for tape 2
13-18	Ditto, tape 3
19-24	Ditto, tape 4
25-30	Ditto, tape 5
31-35	Ditto, tape 6
72	"4" (necessary for identification)

The punch card location of trips sent and received for each tape must compose 6 card columns. The right most column must be a multiple of 6; greater than 11 and less than 79. The same columns may be specified for different tapes, in which case an accumulation is obtained. Null fields are allowed; i.e., if n commas appear in a row, n-1 tape fields are skipped, keeping the normal fields in effect. Example: everything is normal except it is desired to also include the trips sent from tape 3 in column 12 with tape 1, and the trips received from tape 4 in column 54 with tape 2. The card would be punched as:

Card columns	Contents
1-11	,,,,12,,,54

The first blank terminates the redesignations; zero also acts as a blank field.

f. Tape assignment ("0") card

This card must be present, and must be the last card in the input data deck. If normal tape assignments are to be used, the card may be left blank, with the exception of column 72.

Field	Contents
1	Binary trip table, purpose 1
2	" " " " 2
3	" " " " 3
4	" " " " 4
Etc.	

Only those fields that are needed should be used.

D. Program Operation

The input cards are read in any order so long as the "0" card is last. After 6 "1" cards are read, additional "1" cards are merely listed off-line to document the run; therefore, as many "1" cards as desired may be used, but only the first P 1/ will be used with the trip end summaries. "1," "3," and "4" cards are all optional. The tapes are placed on any units, so long as the "0" card specifies the units, if they are not on the expected ones. Tape units should be alternated in pairs; tapes 1 and 2 should be on opposite channels, etc. The program always exits to BELMN. Data cards are not edited.

E. Timing

If both trip end summaries and punch cards are specified, the program will run at P times tape speed, with the time closely divided between read tape time and output print time. Three tapes of 419 zones each, with all output specified have been run in 1.1 minutes. If option 4 is specified, run time would be less than half.

F. Error Conditions

1. INVALID CARD
   Col. 72 is mispunched on preceding data card. Two such are overlooked.

1/ "P" refers to number of trip tables employed.

2. NO PARAMETER CARD
   Self-explanatory; run ended.

3. TAPE ON UNIT_______HAS (Octal) FOR ID WORD FOR ZONE___________,
   IT SHOULD HAVE (Octal)
   Self-explanatory, program proceeds to message 6.

4. (Unit) - UNREADABLE RECORD (on-line)
   Self-explanatory, program proceeds to message 5.

5. TAPE ERROR-SEE ONLINE COMMENTS
   ZONE_____________________
   Self-explanatory, program proceeds to message 6.

6. DUE TO TAPE ERROR, THE FOLLOWING TAPES ARE NOT USED
   (Tape Unit), (Tape Unit)

Note: All of the above return control to the senior monitor system.

3. PR-120, GENERAL PURPOSE PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0120

Written by: L. Seiders, BPR

Assembly date: April 21, 1965

B. Purpose

1. To accept a varied number of binary trip tables (or skim trees) and perform one of the following operations on them and produce a new binary trip table.

a. Add up to 12 tables at a time
b. Interpolate between two tapes
c. Sort a table to produce a table of special format
d. Determine vehicle-minute deficiency
e. Determine vehicle-minute deficiency delay
f. Subtract one table from another
g. Multiply one tape by another
h. Save trips of selected times
i. Divide tape 1 by tape 2

2. Factor the output of (1) if desired.

3. Obtain a summary of trip ends on the output tables.

C. Data Requirements [1]

1. Tape inputs

a. Binary trip tables or skim trees

---

[1] See section "E" of the Appendix for standard data formats.

2. Card inputs (in order required)

a. Call card

b. Tape assignment card

Field	Tape	Normal Assignments
1	Output tape	A5
2	Input tape 1	B5
3	Input tape 2	A6
4	Input tape 3	B6
5	Input tape 4	A7
6	Input tape 5	B7
7	Input tape 6	A4
8	Input tape 7	B8
9	Input tape 8	A9
10	Input tape 9	B9
11	Input tape 10	A0
12	Input tape 11	B1
13	Input tape 12	B2

c. Identification cards

Any number of "1" cards may be read and printed off-line at the beginning of the run. If option 36 (for purpose 3) is specified the first "1" card read will head each page of trip end summaries.

d. Selected times ("3") card

This card is needed with Option 8 only. Desired whole minute times, or ranges of times may be specified on this card. Single times are separated by commas; ranges of times are designated by placing a dash between the specified limits. For example: it is desired to specify times 3,17-19, 21-24,39,40,60,90-95. The card would be punched as follows:

3,17-19,21-24,39,40,60,90-95.....3

The first number may begin anywhere on the card and the first blank to appear thereafter terminates the selections. Any number exceeding 6 characters (most unlikely) will be limited to the right-most 6 characters.

e. Parameter card

This card must be present and is the last card read by the program. When a "2" card is read, the program begins processing the tapes.

(1) Options

Card columns	Contents	Results
1	"1"	Add trip tables.
2	"1"	Interpolate on a straight line basis between the years specified for tapes 1 and 2 on the "2" card. Interpolation may extend beyond or before the years of the two tapes, or it may fall between. Assume input tape 1 is for 1960 and input tape 2 is for 1985. Output tape may be for year 2000, 1953, or 1974.
3	"1"	Sort and sequence a skim tree. Input is a normal skim tree; output is a skim tree in sort by time sequence with the corresponding zone number located in the decrement portion of the word.
4	"1"	Vehicle-minute deficiency is obtained by subtracting airline skim trees (tape 1) from minimum ground-path skim trees (tape 2) and multiplying the difference by interzonal trips (tape 3).

Card columns	Contents	Results
5	"1"	Vehicle-minute deficiency delay is obtained the same as Option 4, but the answer is divided by interzonal distance (tape 4).
6	"1"	Subtract tape 2 from tape 1.
7	"1"	Multiply tape 2 by tape 1.
8	"1"	Save trips of selected times is accomplished by scanning the skim tree (tape 1) and zeroing out the trips on (tape 2) whose inter-zonal trip time does not fall within one of the specified ranges.
32	"1"	Print trip end summaries.
33	"1"	Negative difference in options, 2,4,5,6, are NOT set to zero, but are left as minus numbers.
34	"1"	List negative entries.
35	"1"	If this option is specified, any messages after tape processing is begun are printed on-line only. This is useful if tape drives are limited, particularly if Option 1 is specified. Warning: not recommended for use with Option 32.

If any negative answers occur in Option 2 or 4-6, they are set to zero. Option 33 can be used to bypass the zero portion.

(2) Parameters

Card columns	Contents
37-39	Number of zones (N)
42[2]	Number of tapes (P)
45-48[3]	Year of output tape (EG. 1975)
51-54[3]	Year of input tape 1 (EG. 1964)
57-60[3]	Year of input tape 2 (EG. 1983)
61-66	Multiplication constant (XXX.XXX). All entries in all output tables are multiplied by this constant. Each table is then prorated to assure that the new total for the table is equal to the old total before factoring. It is possible that the total could be in error by 1; the total is rounded to the nearest number. The decimal point is assumed between columns 63 and 64. If no factoring is desired leave these columns blank.

D. Program Operation

PR-120 reads, writes off-line, and edits the data cards. When the 2 card is reached, it unpacks the options and parameters, checks for a factor and then makes any tape reassignments altering any so designated on the previously read "0" card (if used). If any tape reassignments are improper, a message is written and the job ended. If everything is in proper order, all tapes are rewound and processing begins. The "0," "1," and "3" cards are all optional.

If any tape transmission errors occur during the run, an explanatory message is written, all tapes are unloaded, and the job ended.

---

[2] Needed for option 1 only.

[3] Needed for option 2 only.

E. Timing

PR-120 for all practical purposes, runs at tape speed. Six tapes of 419 zones have been added in less than 2 minutes, and 10 tapes of 650 zones have been added in 5 minutes. Timing normally depends on the number of input tapes.

F. Error Messages

1. IMPROPER TAPE ASSIGNMENT, CHECK ("0") CARD
   Written on and off-line

2. IMPROPER IDWORD ON TAPE (Unit), HAS (Octal), SHOULD BE (Octal)
   ZONE____________________.

3. INVALID CARD TYPE
   Column 72 of the previously listed card is mispunched.

4. TOO MANY TAPES
   Error in col. 41-42 of "2" card.

5. (Unit) - UNREADABLE RECORD (On-line)
   TAPE ERROR-SEE ON-LINE COMMENTS

Note: All the above return control to the senior monitor.

4. PR-124, COMPARISON PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0124

Written by: Original IBM 704 program by G. Brown (WMATS) and J. Manning (BPR) in 1961. Converted to BELMN by Vogt-Ivers and Associates in 1964. Modifications by L. Seiders (BPR) in 1964.

Assembly Date: May 16, 1965

B. Purpose

1. To compare binary trip tables: (1) Model versus origin-destination survey or (2) model versus model.

2. To compare binary loaded networks: (1) Model versus origin-destination survey or (2) model versus model.

3. To compare slightly dissimilar binary loaded networks: (1) Model versus origin-destination survey or (2) model versus model.

4. To prepare BCD tabular results of these comparisons showing:

a. Volume differences by zone or link
b. The frequency distribution of volume differences by specified volume groups
c. Certain statistics for each volume group

C. Data Requirements[1]

1. Tape inputs

a. Binary trip tables or loaded networks

2. Card inputs (in order required)

a. Call card
b. Identification card
c. Parameter card

---

[1] See section "E" of the Appendix for standard data formats.

(1) Options

Card columns	Contents	Results
1	blank	Compare binary trip tables
1	"1"	Compare binary loaded networks
2	blank	The loaded networks are compatible
2	"1"	The loaded networks are not compatible, compare only equivalent links
3	blank	Do not include differences in frequency tables when tape "1" volumes are zero
3	"1"	Include differences in frequency tables when tape "1" volumes are zero
4	blank	Print tables of link-by-link or zone-by-zone comparisons ("table 1")
4	"1"	Do not print "table 1"
5	"1"	Do not read any volume group ("3") cards. The program will supply group limits [3]
6	"1"	Do not read any difference group ("4") cards. The program will supply group limits [4]

[3] Lower limits of volume groups as supplied by program are: 500, 1000, 2000, 3000, 4000, 5000, 6000, 8000, 10,000, 15,000, 20,000, 25,000, 50,000, 75,000 and 99,999.

[4] Lower limits of difference groups as supplied by program are: 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1,000, 1,250, 2,000, and 2,500.

(2) Parameters

Card columns	Contents
37-39	Number of zones
41-44	Last node number

d. Volume group "3" cards

The program requires that 15 volume groups be specified, 11 on the first card and 4 on the second card. The numbers specified on the card are expected to be the lower limit of the volume group and these numbers must be increasing across the card. Each number occupies one 6 column field. The lower limit of the first group is assumed to be zero and this should not be entered. For example, the following 4 volume groups:

0 to 499
500 to 999
1,000 to 2,499
2,500 and over

would be coded as follows:

Card columns	Contents
1- 6	"500"
7-12	"1000"
13-18	"2500"
72	"3" (necessary)

e. Difference group ("4") cards

The program requires that 15 groups be specified, 11 on the first card and 4 on the second card. The format is entirely similar to that for the volume group cards, except that the lower limit of a difference group is coded in each 6 column field. Again the program assumes the lower limit of difference group one to be zero. A positive group and an equivalent negative group will be automatically created for each coded difference group. Negative groups should not be coded into the cards. Thus, 16 difference groups above zero and 16 difference groups below zero will be created. For example, the following 8 difference groups:

-2,500 and less
-1,000 to -2,499
-500 to -999
0 to -499
0 to 499
500 to 999
1,000 to 2,4999
2,500 and over

would be coded as follows:

Card columns	Contents
1- 6	"500"
7-12	"1000"
13-18	"2500"
72	"4" (necessary)

f. Tape assignment card[2]

Field	Contents	Normal tape assignments
1	Tape "1"	B5
2	Tape "2"	A7

D. Program Operation

BS0124 is called from the library tape by means of the program call card, and control is transferred to it. A sign-on message is writtem off-line indicating the date of the program assembly. The program then reads and prints off-line the first card, assuming that it is the identification card and saving it for use in the printed page headings. The parameter card is then read, printed off-line, checked, and unpacked to determine the options and program parameters. Volume and difference group cards are then read, printed off-line, checked, and stored for future reference. If a tape assignment card is present, reassignments are made as required.

If loaded networks are to be compared, 8,000 links are read in from tape "1," followed by 8,000 links from tape "2." When the network system has less than 8,000 links, the entire loaded network is read into storage. A node by node comparison is performed and the differences computed. The volumes and differences, by link, are written (optionally) as "table 1" on the BCD print tape. If the options indicate that the networks are dissimilar, only those links which are compatible are compared and all others are ignored. If this option is not expressed, the networks are assumed equivalent and incompatible links are listed out. If more links remain to be processed, these are read in and the above operations are repeated.

As each link is processed it is placed in one of 16 volume groups, based on the link volume from tape "1." Each link is further sorted by difference, again using tape "1" as a base, into 32 difference groups per volume group. If option 3 is not specified, differences with zero tape "1" volumes are not entered in the frequency table.

---

[2] The reader should note that throughout this description, the inputs shall be referenced as tape "1" and tape "2," where "1" will be used as the base for comparison and statistical calculation.

For each volume group the program calculates: sum of the squares of the differences, the mean difference, the standard deviation about the mean, the "root-mean-square error" and the percent RMS error, and the total trips for tapes "1" and "2."

Alternatively, if trip tables are to be compared, the procedure is the same except that trips between zone pairs are compared rather than link loads. A table of differences is again calculated with tape "1" as the base and the above mentioned statistics are calculated. There is no provision to compare dissimilar trip tables.

E. Timing

Trip tables can be compared at nearly tape speed. If option 4 is not specified considerable time can be spent printing "table 1." Two 500 node binary loaded networks can be compared (printing both table 1 and table 2) in approximately 1 minute on the IBM 7094.

F. Error Messages

1. "IMPROPER CARD"
   Written after a card which is improperly identified in column 72.

2. "AN EOF HAS BEEN ENCOUNTERED"
   An unexpected tape mark has been encountered during tape transmission. Check input tapes.

3. "REDUNDANCY - SEE ON-LINE COMMENTS"
   A redundancy error has occurred during tape transmission. Check tape indicated by on-line comments.

4. "SCALE PARAMETERS OVERLAP, CHECK CARD NO.__________"
   There is an overlap in the limit specifications for the volume or difference groups. Check the card indicated.

5. "ZONE__________, IMPROPER ID WORD (Tape Unit)"
   The first word of the record for this zone is not in the proper format.

6. "MISMATCHED LINKS, A NODE__________B NODE, NO. 1__________B NODE, NO. 2__________"
   Self-explanatory. The input files should be checked.

Note: All errors return control to the senior monitor.

5. PR-126, ZONE-DISTRICT COMPRESSOR PROGRAM IBM 7090/7094

A. Identification

Deck No.: BS0126

Written by: R. Bunyan, Alan Voorhees and Associates, September 1963

Assembly Date: September 28, 1964

B. Purpose

1. To prepare a binary tape of district-to-district trip volumes from a binary tape of zone-to-zone trip volumes, according to certain district-zone equivalents.

2. BS0126 can also be used to expand a trip volume tape by filling with zeros.

C. Data Requirements [1]

1. Tape inputs

   a. Binary trip tables

2. Card inputs

   a. Call card
   b. Identification card
   c. Parameter card

      (1) Parameters

Card columns	Contents
37-39	Number of zones on input tape

---

[1] See section "E" of the Appendix for standard data formats.

3. Control card (District equivalents card)

There must be only one card per district and all districts must be present in sequential order. All zones of input must also be accounted for, though a zone may be placed in more than one district. If the user wishes to change the zone numbering, each district may be set equal to a single zone, with districts required in sequential order while zones can be in any order. The zones in a district are specified in columns 1 to 66, in a format of 6 column fields. In preparing the card, place the first zone right-justified in column 6. If it is to be a single zone follow with a comma (,) in column 7. If it is to be the first zone of a consecutive series, punch the last zone of the series in column 12 (right-justified) followed by a comma, if more zones are to follow. Additional series or single zones may be selected by using the successive 6-column fields through card column 66. Any combination of grouped and single zone selections may be made as long as column 66 is not exceeded. The district number to correspond to the selected zones is punched right-justified in columns 68-70. A "3" punch in column 72 is required to identify the district equivalents card.

For example, assume zones 6, 9-15, 18-20, and 27 to be compressed into district 5. The control card would be punched as follows:

Card columns	Contents
6	6
7	"," (comma necessary)
12	"9"
17-18	"15"
19	"," (comma optional)
23-24	"18"
29-30	"20"
31	"," (comma optional)
35-36	"27"
70	"5"
72	"3" (necessary)

4. Tape assignment card

Field	Contents	Normal tape assignments
1	Input (zonal) tape	B5
2	Output (district) tape	B6
3	First intermediate storage tape	A5
4	Second intermediate storage tape	B2

D. Program Operation

BS0126 is called from the binary tape by means of the program call card, and control is transferred to it. The program reads the "1" and "2" cards, prints them off-line, and stores the information. The "3" cards are read into the equivalents table and checked. When the tape assignment card is read the program performs the necessary tape assignments and begins processing.

It then searches the input zonal volume tape for the zones specified for the first district and accumulates them. This results in a table of district to zone interchanges. The destination zones for this accumulated district are them combined to give district-to-district trip interchanges. This table is then written as a single binary record of the output tape and this procedure continues with the next sequential district. Processing continues until all the districts are completed in this manner.

The user should note that BS0126 can also be used to expand or square the table of a binary trip volume tape:

The program will write a record of n (number of districts) with zeros (with the exception of the identification word) for a district with no specified zonal equivalency.

E. Timing

Timing will vary greatly depending on the grouping of zones into districts and the sequence of zones within the district sequence.

F. Error Conditions

1. "ERROR IN PARAMETER CARD, JOB TERMINATED"
   The parameter card does not have a "2" punch in column 72 or columns 37-39 do not contain the number of zones on the input tape.

2. "ERROR IN CONTROL CARD, JOB TERMINATED"
The district equivalents cards are not in an ascending order by district number, or a zone selection series is improperly specified.

3. "NO EQUIVALENT FOR ZONE ________________ RUN TERMINATED"
The zone number indicated has not been placed within a district.

4. "ZONE ________________ NOT ON INPUT OR PARAMETER ERROR"
The zone number indicated is not on the input tape. Check the input tape or the number of zones specified on the parameter card.

5. "END OF FILE, BCD INPUT. JOB TERMINATED.
Necessary input cards are not all present.

6. "READ ERROR ON INPUT. RUN TERMINATED."

7. "OUTPUT WRITE ERROR. RUN TERMINATED."
Both of these messages are self-explanatory I/O errors. These tapes should be checked.

8. "BAD CHANNEL ASSIGNMENT"

9. "BAD TAPE NUMBER"
Tape assignment card has an improper tape number.

10. "TOO MANY TAPES---"
More tapes are assigned than are specified on the parameter card.
Note: All above conditions return control to the senior monitor.

G. Other Messages

1. "________________ DISTRICTS"
Number of districts on output tape.

2. "JOB COMPLETED"
Execution has been completed and control is returned to the BELMN control program.

6. PR-127, TRIP TABLE CONVERSION PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0127

Written by: Brown, WMATS, June 1961 for IBM 704; revised for IBM 7090 BELMN by F. Hood, WMATS, and Manning, BPR, May 1962.

Assembly date: October 7, 1963

B. Purpose

PR-127 takes a file of trip volumes in which values represent trips produced at the origin zone, and converts it into a file of origin-destination movements. At the same time, these volumes may be factored so that the output values represent a specific percentage of input values. The percentage (factors) may be varied in order to build tables for a.m. peak and p.m. peak travel, etc.

C. Data Requirements[1]

1. Tape inputs

   a. Binary trip tables

2. Card inputs

   a. Call card
   b. Identification card
   c. Parameter card

      (1) Parameters

Card columns	Contents
37-39	Number of zones

[1] See section "E" of the Appendix for standard data formats.

Card columns	Contents
47-48	Percent origins (percent of trips produced by a zone to be converted into "trips originated by" that zone) e.g., "39" for 39% origin factor.
65-66	Percent destinations, e.g., "69" for 69% destination factor.

d. Tape assignment card

Field	Contents	Normal tape assignments
1	Input-binary trip table	B9
2	Intermediate storage tape	B2
3	Output-binary trip table	A5

D. Program Operation

The trip volume tape is read one record at a time. As each of these records is placed in memory, its duplicate is written out on the intermediate tape. On completion of this phase, both tapes are rewound and the first group of converted trip records is written on the output tape. The intermediate tape is then read completely, rewound, and the second group of trip records written on tape A5. The original input tape is then read completely, rewound, and the third group of trip records is written. This process continues until the output tape is completed. An end of file is written on the output and the tapes are then rewound.

E. Timing is related to the square of the number of zones. For 419 zones, processing required 5 minutes of IBM 7094 time.

F. Error Conditions

"NO ONE PUNCH IN COLUMN 72 - Card which has error"
Identification card error.

"NUMBER OF ZONES NOT GIVEN"
Parameter card does not have last zone number.

"NO PERCENTAGE GIVEN"
Neither origin nor destination factor has been punched in the parameter card.

"NO TWO PUNCH IN COLUMN 72 - Card which has error"
Parameter card error.

Note: All of the above conditions result in control returning to the senior monitor.

7. PR-130, SKIM TREES PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0130

Written by: Original IBM 704 Program by A. Sosslau, BPR in 1961. Revised for IBM 7090 by Brown, Voorhees in 1962. Converted to BELMN by Bunyan, Voorhees, in 1963.

Assembly Date: February 17, 1964

B. Purpose

1. To prepare an interzonal traveltime binary file, for input to the gravity model distribution program, from a file of binary trees produced by the build trees program.

2. To update a file of interzonal traveltimes or trip volumes.

C. Data Requirements [1]

1. Tape inputs

a. Binary trip tables or trees

2. Card inputs

a. Call card
b. Identification card
c. Parameter card

(1) Options

Card columns	Contents	Results
1	blank	All BCD input cards will be written on A3
1	"1"	Only the "1" and "2" cards will be written on A3

---

[1] See section "E" of the Appendix for standard data formats.

Card columns	Contents	Results
3	blank	Tree times scaled according to the longest link time (assumes binary trees as input)
3	"1"	No scaling will be done (assumes binary skimmed trees as input)
4	blank	Input on B5, output on A4
4	"1"	Input on B2, output on B6
5	blank	Updating will be done
5	"1"	No update cards will be read

(2) Parameters

Card columns	Contents
37-39	Last zone number
46-48	Scale factor (longest link time) if option 3 not specified. Same units (X.XX minutes) as used when the trees were built.

d. Tape assignment card (must be present)

Field	Contents	Normal tape assignments
1	Input tape	B5
2	Output tape	A4

e. TERM card (used only if terminal times are to be added)

Card columns	Contents
1- 4	"TERM"

f. Terminal time ("T") cards

Terminal times for consecutive zones are punched, right-justified, in successive three column fields, with the beginning zone number in cols. 4-6.

Card columns	Contents
4- 6	First zone of the group on this card (Z_i)
7- 9	Terminal time for Z_i
10-12	" " " $Z_i + 1$
13-15	" " " $Z_i + 2$
	. . . .
64-66	" " " $Z_i + 19$
72	"T" (optional)

A "T" card need not have times for 20 zones. There may be any number of "T" cards.

g. UPDT card (<u>must</u> be used if option 5 not specified)

Card columns	Contents
1- 4	"UPDT"

h. Update ("U") cards

Card columns	Contents
4- 6	Origin zone (OZ)
10-12	First destination zone of range (D_1)
16-18	Last destination zone of range begun by D_1. May be blank if D_2=D_1.
19	Blank, if UT (cols. 20-24) is to <u>replace</u> the amount in the input record; "+," if UT is to be added to the record; or "-," if UT is to be subtracted from the record.
20-24	Amount of update in whole minutes or trips (UT)
72	"U" (optional)

A "U" card is required for each range of zones.

i. Last card (<u>must</u> be used if option 5 not specified)

Card columns	Contents
1- 4	"LAST"

D. <u>Program Operation</u>

BS0130 is called from the library tape by means of the program call card, and control is transferred to it. It first reads and prints off-line the "1" and "2" cards, and then unpacks the parameter ("2") card and determines the options and parameters. The tape assignment card is then read and any necessary changes made.

If the user has specified that updating will be done a card is read from the BCD input. If it is a TERM card, the terminal time cards are read until a UPDT card is encountered. When no updating is to be done, these operations will not be performed.

The program then reads N+1 words from the binary input (N=number of zones). The identification word is converted so that it contains the origin zone in the decrement and the number of zones in the address. The remaining N words are converted to whole minutes in accordance with the scale factor and the sign and backnode are set to zero. If scaling is not specified the program assumes a skimmed tree input and the above operations are not performed.

If no updating is to be done, the skimmed tree is written on the binary output tape. If updating is to be done, the skimmed tree is retained in storage and update cards are read and entered (added, subtracted, or inserted) until all updates are completed for this origin zone. The program then adds the terminal times into the record. The skimmed and updated tree is then written on the binary output tape. The program repeats the above operations for each record until all zones have been processed. If a LAST card is encountered in reading cards, no further update cards are read and the records are processed without entering further updates.

Upon reaching the last zone, the binary output is end filed and it and the binary input tape are rewound.

The cards must be used in the order as shown in card inputs. Cards e through i are optional. If card e is used, cards f, g, and i must be used also. If "U" cards (h) are used, cards g and i must also be used. A complete run (skim, add terminal times and apply updates) would involve all the cards a-i.

E. <u>Timing</u>

A 300 zone tree can be skimmed and updated in about 1-2 minutes.

F. Error Messages

1. "READ ERROR, BCD INPUT"
   Ten unsuccessful attempts have been made to read the BCD input.

2. "ERROR IN ID CARD"
   The first card read did not have a "1" in column 72. It was accepted as the "1" card anyway. Run continues.

3. "ERROR IN PARAMETER CARD. JOB TERMINATED"
   The second card read does not have a "2" in col. 72, the number of zones (cols. 37-39) is missing, or the longest time factor (cols. 46-48) is missing.

4. "END OF FILE, BCD INPUT. JOB TERMINATED."
   An end of file has been encountered on A2 (or the card reader) before all the input cards have been read.

5. "WRONG IDENT. ON UPDATE FILE"
   The card following the "2" card was neither a TERM nor a UPDT card. (Option 5 not specified.) Run continues as though option 5 were specified.

6. "NO ZONE IN TERMINAL TIME CARD."
   A card(s) between the TERM card and the UPDT card had nothing in cols. 1-6. The offending card is printed following the message, and is not used. The next card is read. When 5 such cards are found, the run is terminated.

7. "2ND DEST. ZONE IS LESS THAN FIRST."

8. "NO ORIGIN ZONE IN UPDATE CARD."

9. "NO DEST. ZONE IN UPDATE CARD."

10. "UPDATE CARD OUT OF SORT."
    The above 3 messages are self-explanatory and all refer to the cards read between the UPDT and the LAST cards. The offending card is printed after the message and is not used. Five bad update cards are allowed before the run is terminated.

11. "READ ERROR, BINARY INPUT. JOB TERMINATED."
    Ten unsuccessful attempts have been made to read the binary input tape.

12. "PREMATURE END OF FILE ON BINARY INPUT, RUN TERMINATED."
    An end of file has been encountered before the specified number of zones has been read.

13. "UNABLE TO WRITE BINARY OUTPUT. JOB TERMINATED."
Several unsuccessful attempts have been made to write the output tape.

Unless noted, all the above errors return control to the senior monitor.

G. Other Messages

1. "END OF BCD OUTPUT TAPE."

2. "END OF BINARY OUTPUT TAPE."
Above messages written on-line and the program halts to allow the operator to mount new tapes. Pressing start continues run.

3. "END OF JOB."
Written when program has completed successfully. Control returns to BELMN control program.

8. PR-133, BUILD TRIP TABLES PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0133

Written by: Brown, May 1962, revised for BELMN by Bunyan

Assembly date: February 28, 1964

B. Purpose

PR-133 prepares binary files of trip volumes from O-D survey cards. For home-based trips, the zone of residence (production zone) is regarded as the "origin" zone and the zone of attraction as the "destination" zone. Nonhome based trips, which must be processed separately, are built-in true origin-destination form. Up to six files of trips may be built during a single run of the program (except that home based and nonhome based must be built in separate runs). Files may be built for specified purposes of travel, modes of travel, land uses, occupations, etc., or for any combination of these.

C. Data Requirements[1]

1. Tape inputs — Tape unit
   a. O-D survey cards — A4 (or A2)

2. Tape outputs — Tape unit

a.	Trip table 1	B2
b.	" " 2	B3
c.	" " 3	B4
d.	" " 4	B5
e.	" " 5	B6
f.	" " 6	B7

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[1] See section "E" of the Appendix for standard data formats.

3. Card inputs (in order required)

   a. Call card
   b. Identification card
   c. Parameter card

      (1) Options

Card columns	Contents	Results
27	"1"	No header or trailer cards
28	"1"	Second reel of trip cards on A5 following end of tape one.
29	"1"	Trip cards are on A4 rather than A2
30	"1"	No equivalent cards

      (2) Parameters

Card columns	Contents
6	Number of purposes - also number of output tapes (1 to 6)
9-12	Blank if trip purpose is reported by means of purpose "from" and purpose "to." "1" if trips are home based and a blank or zero if trips are nonhome based.
13-18	Maximum number of error cards allowed
19-24	Trip scale factor. This number is usually either 1 or 10 depending on whether trips are reported in whole numbers or in tenths respectively. Immediately prior to writing, accumulated trip volumes are divided by the number punched in this field.
34-35	Contains the blocking factor for the trip cards, maximum of 50 cards per physical record.

Card columns	Contents
37-39	Last centroid number
47-48	Number of words per card. Each card must contain a number of columns equal to some multiple of six. Example: When 80 column cards are put on tape they must be expanded to 84 columns, commonly referred to as card to tape 80/84. In this example the word count would be 14, i.e., 84 divided by 6 (number of characters per word equals 14. If the card records are blocked, a card record must not exceed 14 words.

d. Format specification card

This card specifies the fields in the survey card from which certain items of data are to be extracted. For each item of data the last column of the field and the number of columns in the field must be provided.

	Data item	Last column	No. of columns
1.	Zone of residence	Cols. 2-3	Col. 6
2.	Origin zone	8-9	12
3.	Destination zone	14-15	18
4.	Purpose (from)[1]	20-21	24
5.	Purpose (to)[1]	26-27	30
6.	General purpose[1]	32-33	36
7.	Purpose flag[1]	38-39	42
8.	Trip factor	44-45	48
9.	Land use (origin)	50-51	54
10.	Land use (destination)	56-57	60
11.	Mode of travel	62-63,	66

[1] Depending on which method of reporting trip purpose is used, the first or second pair of these fields may be blank.

A "3" punch in column 72 is required to identify the format specification card.

If, for example, the survey card had the zone of residence punched in cols. 14-17, then the specification card would have "17" punched in cols. 2-3 and "4" punched in col. 6.

If mode or land use are not present in the survey cards, or if they are not required as criteria for building trip tables, the appropriate field in the specification card may be left blank. This does not apply to the purpose or zone fields. Data items not listed above (e.g., day of the week, occupation, etc.) may be specified in place of mode or land use.

PR-133 is written to accept a basic trip survey card in which at least items 1, 2, and 3 and either 4 and 5, or 6 and 7 are present. Hence these items must be accounted for in the specification card. If zone of residence is not reported in the survey card or if, as in the case of non-home based trips, it is not to be used, then item 1 should have the same specification as the zone of origin. If trip purpose is not reported, or not used, cols. 9-12 of the parameter card should be left blank and "81" and "1" should be punched as the last column and number of columns for both items 4 and 5 in the specification card.

e. Trip criteria cards

These cards provide the program with sets of criteria according to which trips are accumulated in specified tables. By means of this device, the user has complete freedom of selection over the input data (survey cards). For example, the following binary tables are typical of those which might be obtained during a single run of the program.

(1) Home-to-work auto driver trips with residential land use at the origin and industrial land use at the destination, combined with work-to-home auto driver trips having industrial land use at the origin and residential land use at the destination.

(2) Home-to-shop transit, auto-driver, and auto passenger trips having residential land use at the origin and commercial land use at the destination, combined with the reverse of this.

In general, purpose, mode, and land use are specified. Provision is made for 18 purpose codes, 10 mode codes, and 10 land use codes. Zero is recognized as a legitimate code.

Criteria cards are prepared by punching a "1" in the appropriate column. The format for these cards is as follows:

Card columns	Designation	Possible codes
1-18	From purpose	0-17
19-36	To purpose	0-17
37-46	Mode	0-9
47-56	Land use (origin)	0-9
57-66	Land use (destination)	0-9
67-72	Table (tape) number	1-6

For purposes of illustration, the following survey card codes will be assumed.

Trip purpose code	Mode code	Land use code
00 - Home	1 - Auto driver	1 - Residential
01 - Work	2 - Auto passenger	2 - Industrial
02 - Shop	3 - Transit	3 - Commercial

In order to build the trip tables described in (1) and (2) above, the following criteria cards would be required.

a. "1" punch in cols. 1, 20, 38, 48, 59, and 67.
b. "1" punch in cols. 2, 19, 38, 49, 58, and 67.
c. "1" punch in cols. 1, 21, 38-40, 48, 60, and 68.
d. "1" punch in cols. 3, 19, 38-40, 50, 58, and 68.

Trip criteria cards are used by the program in the following way: First, a table is compiled containing two words for each criteria card. Then, as each survey card is read in, the appropriate data items are encoded into two words. The pair of words thus formed is then tested against each pair of criteria words. When a pair of criteria words is found which includes (in the logical sense) the survey card pair, the trips from this card are entered in the appropriate table.

It is important to note that the program does not seek an exact match between the word pairs. Hence it is not necessary for each criteria card to contain a unique set of criteria. As seen in the example above, criteria cards c. and d. each contain mode codes 1 through 3.

When trip purpose is reported in the survey cards by means of a general purpose code and a flag it is unnecessary to punch a home purpose code in the criteria cards. In this case, when the program encodes the survey card data, either the "from" or "to" purpose fields of the code word will be ignored, depending on the direction indicated by the flag.

f. End of data card

A card with a "9" punch in column 72 will signal the program that the last criteria card has been read.

g. Zone equivalent cards

These are punched one to each survey zone (or subzone) as follows:

Card columns	Contents
1- 6	Survey zone number
7-12	Assignment zone equivalent (centroid)

These cards are written on tape in 14-word format. The first card in the file is a label card having EQUIV punched in columns 1-5. The last card in the file is a trailer card having ENDEQ punched in columns 1-5.

Note: Assignment zone numbers must be allocated to survey zones in such a way that when the survey zone numbers are ordered in an increasing sequence the associated assignment zone numbers form a monotonically increasing sequence.

h. Survey cards

Since there is complete variability of card format (and data content) between one survey and another, PR-133 has been written to accept cards in any format. Format specifications are provided by the user for a particular run of the program. (See above.)

Survey cards are written on tape in full 14-word (84-column) format. Cards may be optionally blocked by any number up to 50 cards per physical record. Any records of padding added during blocking will be rejected as cards in error.

If the user chooses to use header and trailer labels the following format must be followed: The first card on a reel is a label card having TRIPS punched in columns 1-5 and the reel number (1, 2,...) punched in column 6. The last card on a reel is a trailer card having ENDS punched in columns 1-4. The last card on the final reel has LAST punched in columns 1-4.

Home based trip cards must be sorted by zone of residence prior to use in program BS0133; nonhome based trips, which must be processed separately, should be sorted by origin zone. If the nonhome based trip cards are included with the home based trip cards, each of the former will be rejected as errors during the building of the home based tables. In the converse situation, all home based cards will be rejected as errors. This will prohibitively increase computer running times.

D. Program Operation

During the first phase of operation the program reads, interprets, and stores the program control cards up through the zonal equivalent cards. During the second phase, the survey cards are read in, decoded, and checked for errors record by record. Cards in error are written on an error tape for off-line printing.

The trip tables are built for each origin zone in increasing sequential order. Each card is matched against the criteria set by the user to determine which, if any, trip table it is to be entered in. A count is kept of all cards failing to meet any criteria. This is printed out at the end of the run. When all the trip cards for a particular origin zone are processed, the trip tables for that zone are written on the binary output tapes. Processing then continues as above for the next sequential origin zone.

As the trip tables are being accumulated, a summary of trip ends for each of the outputs is also accumulated. During the final phase of the program, the trip end tables are written on tape for off-line printing. Due to differences in rounding techniques the trip end summaries from BS0133 will vary slightly from those produced by BS0116 or BS0120.

E. Timing

Significant increases in running speed may be made by blocking the input trip cards. For 50,000 survey cards, blocked 10 cards per record, processing 160 zones requires approximately four minutes per output tape.

F. Error Conditions

1. "NO HEADER ON TRIP CARD TAPE, IGNORED."

2. "THE FOLLOWING DATA CARDS ARE IN ERROR."
   Followed directly by one or more of the following. Processing continues until the allowed number of error cards is reached.

   a. "HFLAG__________(Card in error)__________"
      Not a valid home based trip.

   b. "ALPHA__________(Card in error)__________"
      An alphabetic character is coded in a numeric field.

   c. "DZONE__________(Card in error)__________"
      Error in destination zone.

   d. "OZONE__________(Card in error)__________"
      Error in origin zone.

   e. "OSORT__________(Card in error)__________"
      Card out of origin zone sort.

   f. "RZONE__________(Card in error)__________"
      Error in residence zone.

3. "NO TRAILER LABEL."
Trailer labels not on the tapes as indicated, ignored and end of file treated as end of data.

4. "READ ERROR ON INPUT TAPE."
Redundancy on reading trip card. Program will attempt to read again.

5. "WRITE ERROR ON A3, IGNORED."

6. "FIVE TRIES HAVE BEEN MADE TO WRITE TAPE B_____, PUSH START TO ERASE GAP."
Permanent redundancy on write, if start is pushed a gap is erased and skipped and writing is attempted again.

7. "ERROR IN I.D. CARD IGNORED."

8. "ERROR IN PARAMETER CARD. JOB TERMINATED."

9. "NUMBER OF ZONES MISSING FROM PARAMETER CARD."

10. "NO. FILES OUTPUT MISSING FROM CONTROL CARD."

11. "NO OUTPUT IN COLS. 67-72 OF LAST CARD."
Tape to which a trip criteria card applies not indicated. Criteria card is not used.

12. "MORE THAN ONE OUTPUT IN COLS. 67-72 OF LAST CARD."
More than one output tape specified on a criteria card. Criteria card is not used.

13. "NO HEADER CARD ON EQUIVALENT DECK, IGNORED."

14. "THE FOLLOWING ZONE EQUIVALENT IS EITHER OUT OF SORT OR IS A DUPLICATE-CURRENT ZONE IS __(sequence zone)__
__(zone equivalent)__."

15. "ZONE EQUIVALENT LIST IS TOO LARGE."

16. "PROBLEM AS SPECIFIED EXCEEDS AVAILABLE STORAGE BY________CELLS."

Errors 8, 9, 10, 14, 15, 16 all result in a return to the senior monitor.

G. Other Messages

1. "________________CARDS FAILED TO MEET GIVEN CRITERIA."

2. "END OF FILE ON INPUT. DIAL NEW INPUT."

3. "END OF A3 OUTPUT TAPE. DIAL NEW OUTPUT."

9. PR-134, TRIP LENGTH DISTRIBUTION PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0134

Written by: Bunyan, September 1963, Alan Voorhees and Associates

Assembly date: May 22, 1965

B. Purpose

1. To prepare BCD tables, by purpose, of trip length distribution from binary interzonal traveltimes (skim trees) and binary zone-to-zone volumes.

2. To give a summary total, by purpose, of person trips and person hours of travel.

C. Data Requirements [1]

1. Tape inputs

a. Binary trip tables or skim trees

2. Card inputs (in order required)

a. Call card
b. Identification card
c. Parameter card

(1) Parameters

Card columns	Contents
6	Number of input volume tapes (can be up to 9)
37-39	Number of zones on input

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[1] See section "E" of the Appendix for standard data formats.

d. Origin zone selection card (optional)

This control card and the following card may be used to optionally select certain origin and destination zones for the trip length frequency accumulation. If the origin selection card is present, the destination selection card may be left out if all destination zones are to be accumulated. Both cards must adhere to the selected zone format described in section "E."

e. Destination selection card

f. Tape assignment card (optional)

Field	Tape	Normal tape assignments
1	Skimmed trees	A4
2	Binary trip table purpose 1	B5
3	Binary trip table purpose 2	A5
4	Binary trip table purpose 3	B6
5	Binary trip table purpose 4	A6
6	Binary trip table purpose 5	B7
7	Binary trip table purpose 6	A7
8	Binary trip table purpose 7	B8
9	Binary trip table purpose 8	A9
10	Binary trip table purpose 9	B9

Only those fields that are needed should be used.

D. Program Operation

BS0134 is called from the binary tape by means of the program call card, and control is transferred to it. The program then reads in the "1" and "2" cards, prints them off-line and stores the information.

The program then reads the first skim tree record and then the first purpose input tape followed by the next input tape. (If alternate channels are used, two purposes are read at a time.) The trip length distribution tables begin to accumulate and the next two inputs are read. This process continues until all the inputs for the current origin zone are read and then the program repeats the process until all zones have been processed.

It should be noted that the identification word (giving the zone being processed and the total number of zones) is not checked by the program. Only the number of zones specified will be processed, terminating when these have been completed, though the volume tapes may contain more zones than specified.

When all zones specified have been processed for all inputs, a BCD table of trip length distribution is written out for each input. This table includes a summary of total trips, total person hours of travel and average trip length. Trips are sorted into intervals of 1 minute, with a maximum trip length of 200 minutes. Any trips which exceed 200 minutes are placed into the 200 minute category. A printer plot of traveltime against percent of trips is also written out for each input tape.

E. Timing

BS0134 requires approximately 2 minutes to prepare tables of trip length distribution for 5 input tapes of 419 zones each.

F. Error Messages

1. "ERROR IN IDENTIFICATION CARD, IGNORED"
   No "1" punch in column 72 of I.D. card. It was accepted as "1" card and run continues.

2. "ERROR IN PARAMETER CARD, JOB TERMINATED"
   The parameter card does not have a "2" punch in column 72, columns 37-39 do not contain the number of zones on input tapes, or column 6 does not have the number of input volume tapes.

3. "BAD CHANNEL ASSIGNMENT"
   Tape assignment card has an improper channel designation. The job is terminated.

4. "BAD TAPE NUMBER."
   Tape assignment card has an improper tape number. The job is terminated.

5. "TOO MANY TAPES- - -"
   More tapes are assigned than are specified on the parameter card. The job is terminated.

6. "TAPE TRANSMISSION ERROR, JOB TERMINATED"

7. "PREMATURE END OF FILE, JOB TERMINATED"
   Both of these messages are self-explanatory I/O errors. The input tapes should be checked.

Note: Conditions 2-7 cause control to return to the senior monitor.

G. Other Messages

1. "END OF OUTPUT TAPE"
   The end of the BCD output tape has been reached. Mount another tape and press start to continue.

10. PR-135, GRAVITY MODEL PROGRAM
IBM 7090/7094

A. <u>Identification</u>

Deck No.: BS0135

Written by: Brown, WMATS, for IBM 704. Revised for IBM 7090 by Brown and Bunyan, Alan Voorhees and Associates, and S. Robertson, BPR.

Assembly date: April 21, 1965

B. <u>Purpose</u>

PR-135 distributes trips by means of the gravity model resulting in the following information:

1. Binary tables of interzonal trips.

2. Printed tables of trip length frequency by purpose plus total purpose.

3. Printed tables of accessibility index.

4. A printed comparison, by district and purpose, of actual trip attractions to the trips attracted by the gravity model.

The program also adjusts model trip attractions and reiterates them to bring the model attractions into balance with the given attractions.

C. <u>Data Requirements</u> [1]

1. <u>Tape inputs</u>

a. Binary skimmed trees

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[1] See section "E" of the Appendix for standard data formats.

2. Tape outputs

   a. Binary trip table for purpose 1
   b. " " " " " 2
   c. " " " " " 3
   d. " " " " " 4
   e. " " " " " 5
   f. " " " " " 6
   g. Total binary trip table

The tapes required for a particular run depend upon the options used.

3. Card inputs (in order required)

   a. Program call card
   b. Identification card(s) (up to 3 allowed)
   c. Parameter card

      (1) Options

Card columns	Contents	Results
1	"1"	Only identification, parameter, and zone selection cards are written on the system output tape, other BCD cards are not.
2	"1"	No binary trip tables will be written
3	"1"	Total binary trip table only
4	"1"	Do not write out BCD tables of accessibility index.
5	"1"	Read terminal times from cols. 79-80 of the "PAR" cards
6	"1"	K factors will be used

(2) Parameters

Card columns	Contents
40-42	Number of zones
46-48	Number of districts
54	Number of purposes (total not included)
58-60	Number of friction factors used
66	Number of iterations of attractions (initial calculation of distribution counts as one iteration)

d. Selected zone card (optional)

Specifies those ranges of zones for which attractions should be balanced by iteration. There should be separate selections for each purpose. If a card is absent for a purpose all zones are done for that purpose. This card must also contain a purpose number. This is not indicated in the description of the standard zone selection card. For this case only, the purpose to which the selections on a card apply is punched in card column 68. It is also possible to continue selections on another card by punching a "," (comma) in column 67. In most applications the user should iterate attractions for all zones and for all purposes.

e. Tape assignment card (must be present)

Field	Tape	Normal tape assignments
1	Binary skimmed trees	A5
2	Binary total purpose trip table	B8
3	Binary trip table for purpose 1	B5
4	Binary trip table for purpose 2	A9
5	Binary trip table for purpose 3	B6

Field	Tape	Normal tape assignments
6	Binary trip table for purpose 4	A6
7	Binary trip table for purpose 5	B7
8	Binary trip table for purpose 6	A7

Only those fields that are needed should be used.

f. Zonal parameter file identification card

Card columns	Contents
4- 6	"PAR"

g. Zonal parameter cards (one per zone)

Card columns	Contents
1- 3	Zone number
4- 6	District number
7-12	Purpose 1 productions
13-18	" 2 "
19-24	" 3 "
25-30	" 4 "
31-36	" 5 "
37-42	" 6 "
43-48	" 1 attractions
49-54	" 2 "
55-60	" 3 "
61-66	" 4 "
67-72	" 5 "
73-78	" 6 "
79-80	Terminal time, if option 5 used

All zones must have a district number, unless the number of zones equals the number of districts, in which case the program will assume all district numbers identical with the zone numbers. If district-zone equivalents are used, the program accumulates all summaries by district and balances the attractions on a district basis rather than on a zonal basis. It is recommended that district numbers be coded equal to zone numbers. The zone numbers must form an unbroken increasing sequence beginning with one. If P is the number of purposes specified on the parameter card, then the first P production fields and the first P attraction fields will be used by the program. Terminal times are rarely inserted in this manner as they are generally added by using program 130, skim and update trees. If terminal times are added during the gravity model program, the user should realize that the times in the trip length frequency tables will not include terminal times. This results in a "driving time" trip length frequency distribution. Blanks and zeros are treated as equivalent in the punched card data.

h. End of zonal parameter file card

Card columns	Contents
3- 6	"ENDP"

i. Traveltime factor file identification card

Card columns	Contents
4- 6	"TIM"

j. Traveltime (F) factor cards (one per time interval)

Card columns	Contents
4- 6	Time interval
7-12	Purpose 1 traveltime factor
13-18	" 2 " "
19-24	" 3 " "
25-30	" 4 " "
31-36	" 5 " "
37-42	" 6 " "

The time intervals are integer minutes and must form an unbroken, increasing sequence beginning with one. The program only uses as many fields of traveltime factors as there are purposes. Blanks and zeros are treated equivalently.

k. End of traveltime factor file card

Card columns	Contents
3- 6	"ENDT"

l. End of file card (if K factors are used)

Card columns	Contents
1	"7" and "8" punches

m. K factor file identification card (if K factors are used)

Card columns	Contents
4- 6	"KAY"

n. Interzonal trip adjustment (K) factor cards (if K factors are used)

These factors are used to modify the trips between specified zone pairs due to some predictable socio-economic bias in the gravity model distribution. They may be applied to movements from a single (or range of) production zone(s), to a single (or range of) attraction zone(s). The production zones must be in increasing order, low to high, and ranges of production zones must not overlap. Production zones may be repeated if the zone or range of zones is exactly the same as used immediately before. If zones are repeated in this way, the user should be careful that only one K factor may be applied to any single zone pair.

The program reads only the number of fields from the K factor card which corresponds to the number of purposes. Blanks are interpreted to mean that no K factor is to be used for that purpose. A decimal zero is not a valid K factor.

Card columns	Contents
1- 3	First zone of a range of production zones.
4- 6	Last zone of a range of production zones. Same as columns 1-3 if this is to be a single zone.
7- 9	First zone of a range of attraction zones.

Card columns	Contents
10-12	Last zone of a range of attraction zones. Same as cols. 7-9, if this is to be a single zone.
13-18	Purpose 1 K factor
19-24	" 2 " "
25-30	" 3 " "
31-36	" 4 " "
37-42	" 5 " "
43-48	" 6 " "

o. End of K factor file card (if K factors are used)

Card columns	Contents
3- 6	"ENDK"

D. Program Operation

Program 135 reads, edits, and stores all the cards up through the End of Traveltime Factor File Card. It also computes the storage required, tests to see if adequate storage is available, and initializes the counters in the main program for this particular run. If any coding errors are found, it writes a message on the system output and either continues or terminates depending upon the severity of the error.

The interzonal time record for the first production zone is read in and stored. Next the first K factor card is read, edited, and stored (if they are to be used). The total traveltime is computed by adding the applicable terminal times (if option 5 is specified) to the interzonal time read. Otherwise the time is used as read from the time file. The traveltime factor corresponding to this time is then obtained. For each attraction zone, a value (V) equal to the product of the applicable traveltime factor, number of attractions, and K factor (if required) is computed and stored. Each attraction zone is processed in sequence until all are accounted for. This continues until all attraction zones have been processed, for each purpose, for the production zone. The summation of V for a particular production zone and purpose (called the "accessibility index") is accumulated for that zone and purpose, and is saved for later use. The program then distributes the available productions to each attraction zone using the gravity model formula. These trips are then accumulated, by purpose, in the tables of trip attraction and the tables of trip length distribution.

The entire process above is repeated for each production zone in sequence, and all the tables are accumulated by purpose. After all the trips attracted to a zone are accumulated, the ratio of the given attractions to the trips attracted is computed and saved. The printed tables specified above are written on the off-line print tape.

If more than one iteration was specified in the parameter card, the program computes new attractions by multiplying the original attractions by the ratio described above, and repeats the entire distribution process.

During the final iteration binary interzonal trip tables are written (if requested) and the printed summaries for analysis are again written on the system print tape. Up to one binary trip table per purpose, plus a total purpose table, may be written out. The program is limited to a maximum of 999 districts and zones and six purposes. In addition, the following inequality must hold:

$$A\ (5P + 4 + IP + J) + 2P\ (T + D) + T < 29{,}544$$

Where:

Z = number of zones

P = number of travel purposes

T = number of traveltime factors used

D = number of districts

I = 1, if "K" factors are used

= 0, if no "K" factors are used

J = 1, if terminal times are to be read from parameter cards

= 0, if no terminal times are to be read

E. Timing

Approximately 12 minutes of IBM 7094 computer time are required to process 419 zones for 6 purposes with 7 binary output tapes and 2 iterations of attractions. Time is significantly reduced if binary output and the print-out of accessibility index is suppressed.

F. Error Conditions

1. "INVALID CARD, COL. 72 IN ERROR"
2. "CODE ERROR IN TRAVELTIME FACTOR"
3. "NO TRAVELTIME IN THIS RECORD"
4. "CODE ERROR IN TRAVELTIME"
5. "CODE ERROR IN CENTROID PARAMETER"
6. "DISTRICT OUTSIDE SPECIFIED RANGE"
7. "DISTRICT MISSING FROM PAR. CARD"
8. "CORRECT ERRORS IN TIME FACTORS"
9. "CODE ERROR IN TERMINAL TIME"
10. "CENTROID OUTSIDE SPECIFIED RANGE"
11. "NO CENTROID IN THIS RECORD"
12. "CODE ERROR IN CENTROID"
13. "THE FOLLOWING PARAMETER CARDS ARE IN ERROR"
14. "THESE TRAVELTIME FACTOR CARDS HAVE ERRORS-"
15. "WRONG LABELS ON BCD INPUT FILE"
16. "CORRECT ERRORS IN ZONE PARAMETERS"
17. "INCORRECT TRAILER RECORD"
18. "ERROR IN PARAMETER CARD, RUN TERMINATED"
19. "ERROR IN CONTROL CARD, RUN TERMINATED"
20. "WRONG IDENT ON K FACTOR FILE"
21. "K FACTOR RECORD OUT OF SORT - ZONE__________ TO ZONE__________ "

All of the above error messages are the result of program input card edits and refer to the card read immediately before the message. All cause control to be returned to the senior system.

22. "TOO MANY TAPES---"

23. "BAD CHANNEL ASSIGNMENT"

24. "BAD TAPE NUMBER"

The three messages above refer to the tape assignment card and refer to edits of the information in it.

25. "OVERFLOW IN ACCESSIBILITY INDEX, JOB TERMINATED"

The accumulation of accessibility index for a production zone exceeded the limits of the computer.

26. "PROBLEM AS SPECIFIED IS TOO BIG FOR THIS MACHINE"
Self-explanatory

27. "NO TRAVELTIMES FOR ZONE__________"

Indicated production zone is out of sequence or missing from the binary skimmed trees.

28. "ZERO TRAVELTIME, ZONE________ TO ZONE________"

11. PR-151, FACTOR TRIP TABLE PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0151

Written by: Vogt-Ivers Associates, modified by Robertson, BPR

Assembly date: July 20, 1964

B. Purpose

To modify or update a binary trip table or skim tree tape or entries through:

1. Multiplication by a constant,
2. Substitution of a constant,
3. Addition of a constant, or
4. Subtraction of a constant

C. Data Requirements [1]

1. Tape inputs

    a. Binary trip tables

2. Card inputs (in order required)

    a. Call card
    b. Identification card
    c. Parameter card

        (1) Parameters

Card columns	Contents
37-39	Number of zones on input tape

---

[1] See section "E" of the Appendix for standard data formats.

d. Control cards[2]

Card columns	Contents
4- 6	First origin zone in this range
10-12	Last " " " " "
16-18	First destination zone in this range
22-24	Last " " " " "
25	Modifying symbol[3]
26-30	" constant[4]
34-36	First of next range of origin zones
40-42	Last " " " " " "
46-48	First of next range of destination zones
52-54	Last " " " " " "
55	Modifying symbol[3]
56-60	" constant[4]
72	"3" (necessary)

---

[2] Up to 100 control cards, but origin zones must be in order (although all origin zones need not be specified).

[3] "X" = Multiply by the constant
"S" = Substitute the constant
"A" = Add the constant
"M" = Subtract the constant

[4] If "X" is specified the constant is punched as 000.00 (assumed decimal point between columns 28 and 29, or 58 and 59). For any other type modification, it is specified as a whole number right-justified on column 30 or 60.

e. Tape assignment card (must be last card)[5]

Field	Tape	Normal Assignments
1	Input tape unit	A5
2	Output tape unit	B5

D. Program operation

The cards described under "Card inputs" are read, checked for validity, printed off-line, and stored. These cards may be in any order providing the tape assignment card is last. If any data cards are in error, the program prints a message and returns control to the controlling monitor. When the tape assignment card is reached, any necessary reassignments are made and the program goes into execution.

A tape record is read and the identification word is tested for proper sequence and record count. Then the next record is read from the input and previous record is processed.

The origin zone is checked to determine if any modification is to be applied. The proper destination zones, as required, are modified as per the control cards and the modified record is moved to an output area and writing on the output tape is started. If no modification is specified, the record is copied as is onto the output tape. The program then reads another record and repeats.

A counter is incremented each time a record is read and compared with the number of zones. When the proper number of records have been processed, the output tape is file-ended and both tapes are rewound. The number of records processed is printed off-line, an end-of-job message is printed on and off-line, and control is returned to the BELMN control program.

Any errors cause control to return to the monitor.

E. Timing

The program runs at nearly tape speed, so time is dependent upon the tape units used.

---

[5] This program is fully buffered and input and output tapes should be placed on opposite channels to achieve optimum program speed.

F. Error Messages

1. "INVALID CARD, COL. 72 IN ERROR"
   Column 72 does not contain a 0, 1, 2, or 3.

2. "IMPROPER MODIFYING SYMBOL, ORIGIN ZONE = ________"
   Column 25 or 55 of a data card does not contain an X, S, A, or M.

3. "IMPROPER ID WORD, ZONE = ____________________"
   The indicated record number on the input tape is not in correct sequence.

4. "MISSING OR IMPROPER PARAM CARD"
   Parameter card not found.

5. "TOO MANY TAPES____________________"
   More tapes are assigned than are specified on the parameter card.

6. "BAD TAPE NUMBER"
   Tape assignment card has an improper tape number.

7. "BAD CHANNEL ASSIGNMENT"
   Tape assignment card has an improper channel designation.

   All errors retun control to the senior monitor.

12. PR-183, INTERZONAL VOLUMES SUMMARY PROGRAM
IBM 7090/7094

A. Identification

Deck No.: BS0183

Written by: Manning, BPR, December 1962; revised April 1964 by Seiders, BPR.

Assembly date: April 15, 1964

B. Purpose

To accumulate and print selected interzonal interchanges from a binary trip table.

C. Data Requirements [1]

1. Tape inputs

   a. Binary trip table

2. Card inputs (in order required)

   a. Call card
   b. Identification card (up to 10)
   c. Parameter card

      (1) Parameters

Card columns	Contents
37-39	Last zone number
41-44	Number of sets of origin and destination selection, right-justified

---

[1] See section "E" of the Appendix for standard data formats.

d. Identification card for set (1 per set). A "1" punch is required in column 72.
e. Control card (origin zone selection. A "3" punch is required in column 72.) (Up to 5 per set.)
f. Control card (destination zone selection). Same as standard control card except a "5" is punched in column 72. (Up to 5 per set.)
g. Tape assignment card (unique for this program).

Card columns	Contents
12	Channel - A or B
13	Unit 0 thru 9
72	"0" (zero)

D. Program Operation

The program reads in the sets of selected origins and destinations first, then it reads in a trip record and checks the table of origins to see if it is selected. If the record is selected in the origin selections the volumes for selected destinations are accumulated. When all the records have been read in and the accumulations completed, the set totals are written out together with their identification.

Following the program call card, which is read by the control program, are the program cards in the following order:

1. Identification cards for page headings, up to 10 cards -
2. Parameter card, 1 card -
3. First set identification card, 1 card -
4. First set origin selection cards, up to 5 cards -
5. First set destination selection cards, up to 5 cards -
6. Second set identification card, etc....
7. At end of last set, tape assignment card, 1 card - (Maximum of 65 sets)

After PR-183 is located on the library tape by the BELMN control program and loaded into core storage, control is transferred to it. The identification cards (up to 10) are read in and then the parameter card is read in and the parameters stored for program use. Next the sets of origin (up to 5 cards per set) and destination selections (up to 5 cards per set) lead by their set identification cards (up to 65 sets) are read in until the tape assignment card is encountered. After the tape assignment card is read in, the program reads in the first trip record, checks it for errors and looks into the origin selection table for each set. When it finds a set in which the record is selected it accumulates the volume according to the set's destination selections. When it has read in the last record and processed it, writing out begins. At the top of each page identification cards are written out, then the set identification card and, on the same line, the sum accumulated for the set.

E. Timing

It takes about two minutes to process a 552 zone tape for about 40 selections.

F. Error Conditions

1. "ONLY 65 SETS ALLOWED"
   Maximum number of separate volume accumulations exceeded.

2. "TOO MANY ID CARDS_____ NO PARAMETER CARD"

3. "CARD IN ERROR - 77 RETURNED FROM CARD"
   Improper origin or destination selection card.

4. "SELECTED ORIGIN ZONE_______ SET________ IS LARGER THAN________"
   Origin zone selection out of sort.

5. "ORIGIN ZONE______ SET_________ IS LESS THAN RECORD BEING ACCUMULATED__________"
   Origin zone out of sort.

6. "DEST. ZONE ERROR AT_______ FOR ORIGIN ZONE______ SET________"
   Invalid destination zone.

7. "RECORD NUMBER_______ WORD COUNT WRONG_________"
   Improper word count in identification word on indicated record.

8. "TAPE RECORD______________ WRONG ID"
   Improper record number in identification word on indicated record.

9. "ERROR ON TAPE________ COULD NOT READ CORRECTLY, NHEK___________ TRIPS FROM ORIGIN ZONES 1 THRU________ SHOULD BE VALID"

10. "ERROR IN TAPE READ OPERATIONS NHEK = (operation error code) DATA FOR ORIGIN ZONES 1 THRU_______ SHOULD BE VALID."
    In both 9 and 10 a tape error terminated accumulations; origin zones processed prior to error are OK.

11. "END-OF-FILE DETECTED WHILE TRYING TO READ RECORD (ORIGIN ZONE) ________________ TRIPS FROM ORIGIN ZONES LESS THAN ________ SHOULD BE VALID"

12. "END-OF-TAPE REACHED AT RECORD (ORIGIN ZONE)________ON TAPE UNIT______________ PRINT RESULTS FOR ONE INPUT TAPE ONLY."

All errors return control to the submonitor.

13. 501, EDIT PROGRAM
14. 502, EDIT PROGRAM
IBM 1401/1410

A. Identification

Deck No.: 501 (Program #1)
502 (Program #2)

Written by: H. C. Galloway and E. J. Michener, BPR. 1961.

B. Purpose

This "general" edit program is designed to be applicable to any data editing situation. The program edits up to 50 fields of data for unacceptable characters and can transfer these fields into any desired format; in this particular battery the format must be acceptable to the IBM 1401 trip linking program (see page A-85).

C. Requirements

The two programs referenced are very similar. Program deck 501 has an upper limit on any field length of 5 digits. Program deck 502 has an upper limit on any field length of 10 digits. The first deck (501) should be used whenever possible because it permits greater testing flexibility and reduces operating time.

D. Data Preparation

Input consists of card or tape records (of 80 characters or less) containing trip data from an origin-destination survey. These data may be in any format.

E. Card Formats

Several parameter cards are necessary for testing and/or transferring fields with this program. The parameter cards that are needed include one Control Card, N "Routine" cards (N refers to the number of fields to be tested or operated on and must be between 01 and 50), one "Extra" card, and one Zone card.

The parameter cards for this program are loaded following the program deck in the order in which they are described below.

1. One "Control" card (BOTH DECKS)

Card column	Contents
01	Punch a "C"
02-08	Blank
09-10	Number of fields to be operated on, (N) Range: 01 to 50
11-80	Identification to be printed on-line

2. N "Routine" cards (DECK 501 ONLY)

One "Routine card is required for each of the N fields to be tested or operated on.

Card column	Contents (DECK 501 ONLY)
01	"R" punch (must be punched)
02	"Routine" card master test switch. "0" - If "Routine" tests are NOT required (columns 3-72 are left blank). "1" if "Routine" tests ARE required.
03	Number of times EXAM 1 is to be used, (1-4, "0" if EXAM 1 not used).
04	Number of times EXAM 2 is to be used, (1-8, "0" if EXAM 2 not used).
05	Number of times EXAM 3 is to be used (maximum of 1, "0" if EXAM 3 not used).
06	Number of times EXAM 4 is to be used, (maximum of 1, "0" if EXAM 4 not used).
07	Number of times EXAM A is to be used, (1-8, "0" if EXAM A not used).

Card Column	Contents (DECK 501 ONLY)

The sum of two times column 3 plus columns 4-7 may not exceed 8.

08	Number of times EXAM B is to be used, (1-4, "0" if EXAM B not used).
09	Number of times EXAM C is to be used, (1-4, "0" if EXAM C not used).
10	Number of times EXAM D is to be used, (1-4, "0" if EXAM D not used).
11	Number of times EXAM E is to be used, (1-4, "0" if EXAM E not used).

The sum of columns 8-11 may not exceed 4.

12-14 Blank

(See separate diagram - "Routine" Card Test Switch - page A-72.)

15-54 a. EXAMS 2, 3, 4, and A

If any combination of EXAMS 2, 3, 4, and A are specified in columns 4-7, the first X fields (where X is the sum of columns 4-7) should be punched, beginning in column 15, with each constant right-justified in a 5-column field in the same order that the EXAMS appear in columns 4-7.

15-54 b. EXAM 1

If EXAM 1 is specified in column 3, the last 2Y fields, ending in column 54, (where Y is the number punched in columns 3) are punched with the high and low constants to be used in the tests, with the low constant field to the left of the high constant field. For example: The first high constant would be right-justified in a 5-digit field and ending in column 54; the first low constant would be right-justified in a 5-digit field ending in column 49; the second set of constants would end in columns 44 and 39 respectively; etc.......

All fields punched in columns 15-54 must be 5-column fields punched with leading zeros. All unused fields should be blank.

Card Column	Contents (DECK 501 ONLY)
55-62	EXAMS B, C, D, And E
	If any combination of EXAMS B, C, D, and E are specified in columns 8-11, the first Z fields (where Z is the sum of columns 8-11) should be punched, beginning in column 55, with the card column numbers of the "other" fields in a 2-column field in the same order that the EXAMS appear in columns 8-11. Leading zeros must be supplied.
63-72	Message to describe field being tested. This will be printed on-line in case of an error and must be entered when a "Routine" test is to be used.
73-74	Test field number, from 01 to N, in unbroken sequence.
75-76	Input field high order card column number.
77	Input field length, 1-5 digits only.
78-79	Output field high order column number. (The range is 01 through W, where W is as defined in columns 7 and 8 of the "Extra" card.) These columns should be blank if the field is to be omitted from the final form of the edited data record.
80	Output field length. 1-5 digits permitted. Blank field is to be omitted from the final form of the edited data record. Output field length must be equal to or greater than input field length.

3. N "Routine" cards (DECK 502 ONLY)

One "Routine" card is required for each of the N fields to be tested.

Card column	Contents (DECK 502 ONLY)
01	"R" punch (must be punched)
02	"Routine" card master test switch. "0" - If "Routine" tests are NOT required (columns 3-72 are left blank), "1" - If "Routine" tests ARE required.

Card column	Contents (DECK 502 ONLY)
03	Number of times EXAM 1 is to be used, (1-2, "0" if EXAM 1 not used).
04	Number of times EXAM 2 is to be used, (1-4, "0" if EXAM 2 not used).
05	Number of times EXAM 3 is to be used, (maximum of "1," "0" if EXAM 3 not used).
06	Number of times EXAM 4 is to be used (maximum of "1," "0" if EXAM 4 not used).
07	Number of times EXAM A is to be used, (1-4, "0" if EXAM A not used).

The sum of two times column 3 plus columns 4-7 may not exceed 4.

08	Number of times EXAM B is to be used, (1-4, "0" if EXAM B not used).
09	Number of times EXAM C is to be used, (1-4, "0" if EXAM C not used).
10	Number of times EXAM D is to be used, (1-4, "0" if EXAM D not used).
11	Number of times EXAM E is to be used, (1-4, "0" if EXAM E not used).

The sum of columns 8-11 may not exceed 4.

12-14 Blank

(See separate diagram - "Routine" Card Test Switch- page A-72.)

15-54 a. EXAMS 2, 3, 4, and A

If any combination of EXAMS 2, 3, 4, and A are specified in columns 4-7, the first X fields (where X is the sum of columns 4-7) should be punched, beginning in column 15, with each constant right-justified in a 10-column field in the same order that the EXAMS appear in columns 4-7.

Card column	Contents (DECK 502 ONLY)
15-54	b. EXAM 1 If the EXAM 1 is specified in column 3, the last 2Y fields, ending in column 54, (where Y is the number punched in column 3) are punched with the high and low constant field to be used in the tests, with the low constant field to the left of the high constant field. For example: The first high constant would be right-justified in a 10-digit field, ending in column 54, the first low constant would be right-justified in a 10-digit field, ending in column 44, the second set of constants would end in columns 34 and 24 respectively; etc.. All fields punched in columns 15-54 must be 10-column fields punched with leading zeros. All unused fields should be blank.
55-62	EXAMS B, C, D, and E If any combination of EXAMS B, C, D, and E are specified in columns 8-11, the first Z fields (where Z is the sum of columns 8-11) should be punched, beginning in column 55, with the card column numbers of the "other" fields in a 2-column field in the same order that the EXAMS appear in columns 8-11. Leading zeros must be supplied.
63-72	Message to describe field being tested. This will be printed on-line in case of an error and must be entered when a "Routine" test is to be used.
73-74	Test field number, from 01 to N, in unbroken sequence.
75-76	Input field High order card column number.
77	Input field length, 1-10 digits. Zero is punched for 10-digits.
78-79	Output field high order column number. (The range is 01 through W, where W is as defined in columns 07-08 of the "Extra" card). These columns should be blank if this field is to be omitted from the final form of the edited data record.

Card column	Contents (DECK 502 ONLY)
80	Output field length. 1-10 digits permitted. Blank, if field is to be omitted from the final form of the edited data record. Output field length must be equal to or greater than input field length.

4. One "Extra" card (BOTH DECKS)

Card column	Contents (BOTH DECKS)
01	"E" punch (must be punched)
02-06	Blank
07-08	W, the number of digits in the output record. The range of W is from 01 through 99.
09-10	V, the number of data cards to be in each blocked tape record. The range of V is from 01 through 50, but W times V must be less than or equal to 4200.
11	Master "Pull" switch. a. If no "Pulling" is desired, punch a zero and leave columns 12-29 blank. b. If "Pulling" is desired, punch the number of columns to be checked, 1-6 is permitted.
12-29	Punch the 2-digit column number and the single test digit alternately in columns 12-14, 15-17, etc. Unused positions are left blank when column 11 is less than 6. Example: Assume that you wish to test column 16 for a 1, 2, 3, 4, 7, or 9 digit. Columns 12-29 would be punched as follows: 161162163164167169.
30	"Extra test Master Switch." If No "Extra" tests are required punch a zero and leave columns 31-80 blank. If "Extra" tests are required, (See - J. Options).
31-80	"Extra" Test Switches (See - J. Options).

"ROUTINE" CARD TEST SWITCH

			GROUP 1 "OR" TYPE COMPONENTS				GROUP 2 "AND" TYPE COMPONENTS							
EXAM	***	**	1	2	3	4	A	B	C	D	E			
"Routine" Card Column No.	.01	02	03	04	05	06	07	08	09	10	11	12	13	14
Deck I. Max. f. length = 5	R	0 or 1	*0 or 1-4	0 or 1-8	0 or 1	0 or 1	0 or 1-8	0 or 1-4	0 or 1-4	0 or 1-4	0 or 1-4	blank	blank	
Deck II. Max. f. length = 10	R	0 or 1	* 0 or 1-2	0 or 1-4	0 or 1	0 or 1	0 or 1-4	0 or 1-4	0 or 1-4	0 or 1-4	0 or 1-4	blank	blank	
			Max. No. tests = a variable (8 for deck 501, 4 for deck 502)				Max. No. tests = 4							

"OR" TYPE

EXAM 1	$L \leqq F_i \leqq H$
EXAM 2	$F_i = C$
EXAM 3	$F_i > C$
EXAM 4	$F_i < C$

"AND" TYPE

EXAM A	$F_i \neq C$
EXAM B	$F_i < F_{other}$
EXAM C	$F_i \leqq F_{other}$
EXAM D	$F_i = F_{other}$
EXAM E	$F_i \neq F_{other}$

* If Master Switch (Column) is zero (no test), then columns 3-14 may be blank

** 0 = No test, 1 = Test

*** "R" Must be punched in this column

5. One Zone card (BOTH DECKS)

Card column	Contents (BOTH DECKS)
01	A load punch and a zone test switch punch are needed in this column. A "+" (12 punch) is the load punch. The test switch punch is as follows: Punch a Zero if column 1 is to be skipped; punch a "1" if column 1 is to be tested for a zone punch.
02-80	"0" - If a card column is Not to be tested for a zone punch. "1" - if a card column is to be tested for a zone punch.

F. Output

Output is on one or more magnetic tapes containing edited trip data. Regardless of the original form of the data, the edited cards or tape records are written on tape unit one.

Error records will be printed out on-line with an error message indicating the card column that contains the erroneous zone punch or bad blank. The error records are also punched out and sent to the normal punch stacker. They may be corrected and resubmitted to the edit program again and later merged with the previously accepted records.

The record format of the output from the 1401 Edit program should be standard to be used as input to the 1401 Trip Linking. This standard format is shown on a separate page - Standard Format Table, page A-74.

G. Method

The features of the General Edit program follow in the same order that each is performed on a particular data card.

A data card (or tape record), may be "pulled" if a given digit is present in a specified column. The pulled data card goes to special read stacker "1," and the pulled tape record is punched as a card and sent to special punch stacker "4." These are not error cards, they are only data cards that are not to be processed with the regular set of data cards because of some distinction. The pulling is controlled by the "pull" switch on the "Extra" card.

The next feature involves testing for zone punches in the card. A zone punch is an "11" or "12" punch in a card; zone punches in a field will often cause erroneous conclusions in the IBM 1401 compare operations. It is possible to check each column on the card for a zone punch or to bypass certain columns

STANDARD FORMAT TABLE

Standard Output Record Format from IBM 1401 Edit Program[1]

Card columns	Contents[2]
4- 6	Zone of origin
10-12	Zone of destination
15	Purpose from
18	Purpose to
24	Mode of travel
28-30	Trip factor in tenths. Example: 12.1
36	Blank (reserved for general purpose code)
49-51	Start time
52-54	Arrival time
71-76	The sample number, right-justified
77-78	Person number
79-80	Trip number

---

[1] Output is standard in this instance only, because the IBM 1401 Trip Linking Program requires standard input. Actually the edit routine can create any desired format for output records.

[2] Contents of card columns not specified may vary in any desirable manner. However, the edit program must be set up so that output from it is in the above format.

which may contain legitimate zone punches. This test is controlled by the "Zone" card. If a data card (or tape record) isn't "pulled," then its columns will be edited for zone punches. Every column tested which contains a zone punch will cause an error message, ZONE PUNCH XX, to be printed (see error messages). The XX represents the variable column number.

"Bad" blank testing is the next feature. Random blanks within a given field, which is not completely blank, usually represent a punching error. These blanks will often cause erroneous conclusions in the IBM compare operations. The individual card columns will be checked only if a given field on a data card is being tested later by "routine" or "extra" tests and the entire field is not blank. Every individual column which contains an erroneous blank will cause an error message, BAD BLANK XX, to be printed. The XX represents the variable column number. Each of the N fields, as specified by the "Routine" cards, are considered in this manner.

A data card will be rejected at this point if it contains any zone punch errors and/or bad blank errors (see error messages). If no errors of this type are present, the Routine Program continues and testing and transferring is done for each of the N fields. A "Routine" test for a given field must be composed of a logical combination of the following:

Group 1

EXAM 1	$L \leqq F_i \leqq H$
EXAM 2	$F_i = C$
EXAM 3	$F_i > C$
EXAM 4	$F_i < C$

Group 2

EXAM A	$F_i \neq C$
EXAM B	$F_i < F_{other}$
EXAM C	$F_i \leqq F_{other}$
EXAM D	$F_i = F_{other}$
EXAM E	$F_i \neq F_{other}$

F_i = Data field to be tested.

L = Lower value constant for EXAM 1 test.

H = Higher value constant for EXAM 1 test.

C = Constant for EXAM 2, EXAM 3, EXAM 4, and EXAM A.

F_{other} = Field for EXAM B, EXAM C, EXAM D, or EXAM E.

Group 1 contains the four components of the "OR" type. Group 2 contains the five components of the "AND" type. If a "Routine" test contains only the "OR" type, the particular field value of the data card must satisfy only one of the components for a success. If a "Routine" test contains only the "AND" type, then the field value on the data card must satisfy every one of the components for a success. If both types are present in a "Routine" test, then only one of the "OR" components and all of the "AND" components must be satisfied by a particular field value for a success. A "Routine" test for a given field is controlled by its "Routine" card. There is a "Routine" card corresponding to each of the N fields. After the "Routine" test is completed, and if no success is encountered the error message, the field number, the input field high order column, and the input field length will be printed on-line.

Take the following example to illustrate the construction of a logical "Routine" test: Assume that the two digit field, "Tract," can have the values 1-50, or 60, or 70, or 80, or 90. A "Routine" test is necessary to compare the data card field value with the acceptable ones. Thus a <u>one</u> is punched in column 2 of the "Routine" card for this field to indicate testing. Since EXAM 1 is needed once and EXAM 2 is needed four times, a 1 is punched in column 3 and a 4 is punched in column 4. Zeros are punched in columns 5-11, since these components are not used. Constant 00001 and constant 00050 are punched in columns 45-49 and 50-54, respectively. Constants, 00060, 00070, 00080, and 00090, are punched in columns 15-19, 20-24, 25-29, and 30-34, respectively. An error message, such as "TRACT NO" is punched in columns 63-72. Deck 501 is being used as the constants for this "Routine" test exceed 4.

The transferring or omission of a particular field is also controlled by its "Routine" card. In each case, the output field length must be greater than or equal to the input field length. Thus, within the above limits, the field length can be increased. If input field length is less than output field length and the specific field value on a data card is nonblank the appropriate number of leading zeros is inserted. Thus, it is possible to rearrange the order of the fields or leave the order unchanged, to increase the length of certain fields, or to delete the data of certain fields from the final form of the data record. After a "Routine" test and/or transfer have been performed on each of the N fields, the data card will be in its edited form. At this point, "Extra" testing could be considered (see - J. <u>Options</u>, page A-78.)

At the time that the first error is encountered, the actual data card (or tape record) is printed on-line as well as the error message. This is to assist in the rapid determination of the error(s). Also, the data card (or tape record) is punched and sent to the normal punch stacker to facilitate later removal of the bad cards from the original deck. The bad cards must be corrected and then used as data for a new run of the program.

H. Program Usage

1. Operator setup instructions

a. Input on cards

If the input data are on cards the following procedure is used:

Sense switch A "on," all other sense switches "off."

Output tape on tape unit 1.

The data are loaded directly behind the parameter cards in the following order:

(1) One control card (has a "C" coded in column 1).

(2) N routine cards (all have an "R" coded in column 1).

(3) One Extra card (has an "E" coded in column 1).

(4) One Zone card (has a "+" (12 punch) in column 1).

(5) All of the data cards.

b. Input on tape

If the input data are on tape the following procedure is used:

(1) Sense switch E "on," if, and only if, the first record on the particular input reel is identification. The program user must supply this information, and this identification is not transferred.

(2) Sense switch G "on."

(3) All other sense switches "off."

(4) Output tape on tape unit No. 1.

(5) Sense switch F "on," if the last input reel has been processed completely and an end of reel halt has been encountered.

The parameter cards are loaded in the card reader in the following order:

(1) One Control card (has a "C" coded in column 1).

(2) N Routine cards (all have an "R" coded in column 1).

(3) One Extra card (has an "E" coded in column 1).

(4) One Zone card (has a "+" (12 punch) coded in column 1).

The input data tape reel is mounted on tape unit No. 4.
The output tape reel is mounted on tape unit No. 1.

2. Procedures to run program

a. Mount tapes as just described.

b. Load the program deck, data cards (if data are on cards), and the parameter cards as just described, (each parameter card must be used).

c. Set sense switches as described.

d. Turn punch on.

e. Hit load key.

f. For halts see on-line printed instructions or halt list.

g. If input is on tape, set sense switch "F" when the end-of-reel halt occurs after the last input reel has been processed and then hit start.

I. Tapes

Unit 1	Output (correct records)
Unit 4	Input (all records if cards on tape)

J. Options

1. When data are in card form: an unlimited number can follow the zone card, sense switch A must be "on," all other sense switches must be "off."

2. When data are on tape: The 1401 General Edit program accepts tape records containing only 80 characters or less. If the records are blocked or longer than 80 characters it will be necessary to make a preliminary run using the Tape Record Separator program.

When data are on tape sense switch G must be "on" and all other sense switches "off" EXCEPT - a) when the first record on a particular input reel is identification, sense switch E must be "on" and b) when the last input reel has been processed and an end of reel halt has been encountered sense switch F must be "on."

3. "EXTRA" Tests

After a "Routine" test and/or transfer has been performed on each of the N fields, the data card will be in its edited form. At this point, "Extra" testing will be considered.

"Extra" tests are of a more complex nature - those involving two or more fields. Typical "Extra" tests are the conditional, "if - then," type. "Extra" tests might actually serve as "Routine" tests when using Deck 501, but several fields would be longer than 5 digits.

"Extra" tests must be constructed for each different set of data cards and the whole program deck (501 or 502) must be re-autocoded in most cases. Constants must be added to the program deck when they are needed for new "Extra" tests. Each "Extra" test error message is a 10-digit field, and the set of "Extra" test error messages are stored sequentially as constants in core storage. "Extra" testing is controlled by the "Extra" card, columns 30-80. The limit is 50 "Extra" tests.

"Extra" tests are easily written by using a system of two constant entrance instructions and two constant exit instructions per test, and several basic rules. The last "Extra" test marks the end of testing on a data card (or tape record), which appears at the end of the program. If no errors have been found on the data card, the reassembled, edited card will be sent to a storage block in core memory. When a specific number (V) of these have accumulated, the whole block is sent to tape unit one as a permanent record.

K. Timing

Running time data on this program are approximate only. Recently some 34,000 records were edited and several items of data in these records were transferred in 90 minutes. Differences in running time, however, may be encountered depending on the number of fields edited and/or transferred as well as the actual number of records processed.

L. Error Messages

Cards containing errors are printed out and the errors are labeled. (See G. Method.)

M. Program Halts (DECK 501 ONLY)

Location	Symbol	Explanation
9940	HALTC1	Illegal punch in column 1 of "Control" card. Check sequence of parameter cards. Correct and start over.
9976	HALTC2	Illegal punches in columns 9-10 of "Control" card. Check N, number of fields. Correct and start over.
10157	HALTR1	Illegal punch in column 1 of "Routine" card. Check sequence of parameter cards. Correct and start over.
10174	HALTR2	Illegal punch in columns 73-74 of "Routine" card. Check sequence of cards.
10259	HALTR3	Illegal punch in column 3 of "Routine" card. Check limits for EXAM 1. Correct and start over.
10260	HALTR4	Illegal punch in column 4 of "Routine" card. Check limits for EXAM 2. Correct and start over.
10261	HALTR7	Illegal punch in column 7 of "Routine" card. Check limits for EXAM A. Correct and start over.
10278	HALTR5	Illegal punch in column 5 of "Routine" card. Check limits for EXAM 3. Correct and start over.
10295	HALTR6	Illegal punch in column 6 of "Routine" card. Check limits for EXAM 5. Correct and start over.
10408	HALTR8	Total of two times column 3 plus columns 4-7 exceeds 8 on "Routine" card. Correct and start over.
10479	HALTR9	Illegal punch in column 8, 9, 10, or 11 of "Routine" card. Check limits for EXAMS, B, C, D, and E. Correct and start over.

Location	Symbol	Explanation (DECK 501 ONLY)
10534	HLTR10	Total of "Routine" card columns 8-11 exceed 4. Correct and start over.
10588	HLTR11	Illegal punch in column 77 of "Routine" card. Check limits on input field length. Correct and start over.
10660	HLTR12	Illegal punch in "Routine" card. Output field length is greater than 5.
10687	HLTR13	Illegal punch in "Routine" card. Input length, column 77, is greater than output field length, column 80. Correct and start over.
10848	HALTE1	Illegal punch in column 1 of "EXTRA" card. Correct and start over.
10905	HALTE2	Illegal punch in column 11 of "EXTRA" card. Correct and start over.
10975	HALTE3	Illegal punch in column 11 of "EXTRA" card. Correct and start over. Range 1-6.
11046	HALTE4	Illegal punch in columns 9-10 of "EXTRA" card. The value of "V" must be between 1 and 50. Correct and start over.
11082	HALTE5	Illegal punch in columns 7-8 of "EXTRA" card. Value of "W" must be between 1 and 99. Correct and start over.
11113	HALTZ1	Illegal punch in column 1 of "Zone" card. Must be a + punch (12 punch) AND a zero or a one in this column. Correct and start over.
11148	HALTZ2	Illegal punch in columns 1-80. Must be a zero or a one in each column of the "Zone" card. Correct and start over.
11458	HLTRT2	End-of-Reel Halt. This halt means that the input reel on Unit 4 has been completely read. The used input reel should be removed and the next reel (if any) should be mounted. Depressing the start key will resume the processing. If no more input, sense switch "F" on and hit start for End-of-Job routine.

Location	Symbol	Explanation (DECK 501 ONLY)
11503	HLTRT1	Tape Read Error. Correct tape and start over.
13308	NONE	Last Card, end of run.
13427	HLTWT2	End-of-reel halt. Output reel on unit one is full. Remove filled reel and replace with empty reel. Depress start to resume processing.
13481	HLTWT1	Tape write error. Mount new tape and start over.
14014	SWERR	Error in columns 30-80 of the "Extra" card.

N. Program Halts (DECK 502 ONLY)

Location	Symbol	Explanation (DECK 502 ONLY)
9986	HALTC1	Illegal punch in column 1 of "Control" card. Check sequence of parameter cards. Correct and start over.
10022	HALTC2	Illegal punches in columns 9-10 of "Control" card. Check N, number of fields. Correct and start over.
10189	HALTR1	Illegal punch in column 1 of a "Routine" card. Check sequence of parameter cards. Correct and start over.
10206	HALTR2	Illegal punch in columns 73-74 of "Routine" card. Check sequence of cards. Correct and start over.
10291	HALTR3	Illegal punch in column 3 of "Routine" card. Check limits for EXAM 1. Correct and start over.
10292	HALTR4	Illegal punch in column 4 of "Routine" card check limits for EXAM 2. Correct and start over.
10293	HALTR7	Illegal punch in column 7 of "Routine" card. Check limits for EXAM A. Correct and start over.

Location	Symbol	Explanation (DECK 502 ONLY)
10310	HALTR5	Illegal punch in column 5 of "Routine" card. Check limits for EXAM 3. Correct and start over.
10327	HALTR6	Illegal punch in column 6 of "Routine" card. Check limits for EXAM 4. Correct and start over.
10440	HALTR8	Total of two times column 3 plus columns 4-7 exceeds 8 on "Routine" card. Correct and start over.
10511	HALTR9	Illegal punch in column 8, 9, 10, or 11 of "Routine" card. Check limits for Exams B, C, D, and E. Correct and start over.
10566	HLTR10	Total of "Routine" card columns 8-11 exceed 4. Correct and start over.
10620	HLTR11	Illegal punch in column 77 of "Routine" card. Check limits on input field length. Correct and start over.
10711	HLTR12	Illegal punch in column 80 of "Routine" card. Check limits on output field length. Correct and start over.
10783	HLTR13	Illegal punch in "Routine" card. Input length, column 77, is greater than output field length, column 80. Correct and start over.
10959	HALTE1	Illegal punch in column 1 of "Extra" card. Check sequence of parameter cards. Correct and start over.
11016	HALTE2	Illegal punch in column 11 of "Extra" card. Correct and start over.
11086	HALTE3	Illegal punch in column 11 of "Extra" card. Correct and start over. Range is 1-6.
11157	HALTE4	Illegal punch in columns 9-10 of "Extra" card. The value of "V" must be between 1 and 50. Correct and start over.

Location	Symbol	Explanation (DECK 502 ONLY)
11193	HALTE5	Illegal punch in columns 7-8 of "Extra" card. Value of "W" must be between 1 and 99. Correct and start over.
11224	HALTZ1	Illegal punch in column 1 of "Zone" card. Must be a + punch (12 punch) AND a zero or a one in this column. Correct and start over.
11259	HALTZ2	Illegal punch in columns 1-80. Must be a zero or a one in each column of the "Zone" card. Correct and start over.
11562	HLTRT2	End-of-Reel Halt. This halt means that the input reel on unit 4 has been completely read. The used input reel should be removed and the next reel (if any) should be mounted. Depressing the start key will resume the processing. If no more input, sense switch "F" on and hit start for end-of-job routine.
11591	HLTRT1	Tape Read Error. Correct tape and start over.
13408	NONE	Last Card. End-of-Run.
13527	HLTWT2	End-of-Reel Halt. Output reel on unit one is full. Remove filled reel and replace with empty reel. Depress start to resume processing.
13581	HLTWT1	Tape write error. Mount new tape and start over.
14114	SWERR	Error in columns 30-38 of the "Extra" card.

15. 401, TRIP LINKING PROGRAM
IBM 1401/1410

A. Identification

Deck No.: 401

Written by: T. Synott, BPR, revised by C.E. Sweet, Jr., BPR

Assembly Date: March 24, 1965

B. Purpose

This program links all trip records with a "purpose to" or a "purpose from," of "serve passenger" or "change mode of travel" according to the concepts outlined in this volume beginning on page IV-4. If desired it will also determine the zones of production and attraction for each trip record and classify records according to a standard general trip purpose classification.

C. Data Preparation

Input data consists of one or more magnetic tapes containing trip records formatted by the IBM 1401 Edit Program and sorted by any of the sort routines according to sample number, person number, and trip number; the field of major sort is the sample number. The format is the same as that shown in the Standard Format Table on page A-74 of this volume, except that only the sample number may appear in card columns 71-76. Columns 61-70 may contain any information desired for subsequent processing.

D. Card Format - Parameter Card

A parameter card is necessary to indicate the order of priority for the modes of travel and the trip purposes used in the study. The parameter card is loaded directly behind the program deck.

Card columns	Contents
1-10	Order or priority (from highest to lowest) for the modes of travel used in a particular study (maximum of 10 modes). Single digit numbers are entered starting in column 1 and unused columns are blank. Codes of 0 through 9 are allowed.
11-22	The trip purpose codes used in the survey, maximum of 12, must be punched in a special order from left to right. Single digit numbers, 0 through 9, are allowed; (the two zone punches are also allowed, if necessary). The purpose codes of 0 through 9 can be assigned in any order to the trip purpose codes which are punched into card columns 11 through 20; the 11-zone punch is assigned to the column 21 code and the 12-zone punch is assigned to the code in column 22, if they are used.

Trip purpose codes must be punched in the following order:

Card columns	Contents
11	Home purpose code
12	Work purpose code
13	Shop purpose code
14	School purpose code
15	Social-recreation purpose code
16	Eat-meal purpose code
17	Personal business purpose code
18	Serve-passenger purpose code
19	Change-mode purpose code
20	Medical-dental purpose code
21	Miscellaneous purpose code No. 1, if necessary (11-zone punch only)
22	Miscellaneous purpose code No. 2, if necessary (12-zone punch only)
23-80	Blank

E. Output

Output data consist of one or more magnetic tapes containing unchanged, linked, and adjusted records. Each linked record has an 11-zone punch in column 60 and each adjusted record has a 12-zone punch in column 60, for identification purposes. The format of the output records from the linking option would be the same as the input format except for linking identification punches in column 60. The general purpose option permits the addition of a general purpose in column 36. The output format from the general purpose option is shown on page A-74, except that card column 60 is used for the linking identification punches and only columns 71-76 are used for the sample number. When both options are used, the output format is the same as is shown on page A-74, except for the linking identification punches and the sample number field. The Trip Table Builder does not interrogate card column 60.

A printed output is also included. An option provides for printing all unchanged records as they are processed. After processing a record, another option provides that the linked or adjusted record may be printed and identified. After all of the records have been processed, a line of totals is printed. The totals include - the number of records read, the number of records adjusted, the number of records requiring linking, the number of linked records, and the number of records that required no changes.

F. Method

This program consists of two basic options. The first option (trip linking) causes each record to be examined to see if it requires linking. Any record with a "purpose to" or a "purpose from" of "serve passenger" or "change travel mode" will be linked. A home-to-home trip or trip codes in error in the original data can be converted to a home-to-personal business trip. Since all records have been sorted by sample number, person number and trip number, the computer can trace all of the trips which require linking in order to locate both the first and last trip record for each group of records to be linked. The records to be linked may be printed out and then the program combines the necessary data from the first and last trip record into one record which completely describes the linked trip. The mode of travel code is assigned in accordance with the order of priority in the parameter card. The "purpose to" and "purpose from" are then checked for a home-to-home trip. At this point a linked record or the record to be adjusted may be printed. A home-to-home trip is then adjusted by changing the "purpose to" of the first trip card to the personal business code and then changing the "purpose from" code to the personal business code in the last trip card of the group of records to be linked. At this point an adjusted trip may be printed out.

The second option (general purpose) consists of two additional steps. These steps put the basic trip data in a revised format as required for gravity model analysis. Each trip record can be examined to determine the zone which produces the trip and the zone which attracts the trip. These zone numbers are then transferred to the fields which previously contained the zones of origin and destination. Each trip record is then examined to determine the general purpose of the trip. The code to identify the general purpose is inserted into column 36. The following general purpose codes are always assigned based upon the trip purpose codes as they are specified in the parameter card. The program does not allow the general purpose codes to be varied.

<u>Home Based Trips</u>

Purpose "to" or "from"	General Purpose
Work	1
Shop	2
Social-recreational	3
School	4
Eat-meal	5
Personal business	5
Medical-dental	5
Miscellaneous No. 1	2
Miscellaneous No. 2	2

<u>Nonhome Based Trips</u>

Purpose "to" and "from" do not have a home purpose code	6

The output record is written out on tape unit 3 in a format identical to the input except for the following: 1) the linking option provides identification codes in column 60; 2) when <u>not</u> using the general purpose option, the zone numbers will remain as origins and destinations; 3) the general purpose option changes the zone numbers to production and attraction zone numbers and inserts a general purpose in column 36.

G. <u>Program Usage</u>

1. Mount input tape on tape unit 2 and output tape on unit 3.

2. Load the condensed deck followed by the single control card into the reader.

3. Set sense switches for the options desired (see I. <u>Options</u>).

4. Sense switch G is normally "off." This switch is turned "on" in conjunction with switches E and F to bypass all printing, switch G controls the printing of all error messages, end of tape reel messages and the end of job message. The purpose of this switch is to provide for a user without an on-line printer. The Halt locations should be consulted when using this option.

5. Sense switch D must be turned "on" at the start of processing the last input tape; a message is written and a halt occurs at the end of each input so that the sense switch may be changed, when necessary. In the case of a single input tape sense switch D is "on" at the beginning.

6. Push LOAD.

7. For all halts (see L. Program Halts).

8. For all messages, follow printed instructions or see K. Error Messages.

H. Tapes

Input tape(s) must be mounted on tape unit 2, and output tape(s) on tape unit 3. This program requires that there be no header labels on the input tapes.

I. Options

1. If Sense switch B is "on" - only the general purpose option is to be used. No trip records will be linked if this switch is "on."

2. If Sense switch C is "on" - only the trip linking option is to be used. The general purpose will not be added and the zones of production and attraction will not be determined if this switch is "on."

3. If Sense switches B and C are "off" - both the linking and general purpose options are to be used.

4. Sense switch E controls the printing of the linked and adjusted records. If sense switch E is turned "on," the linked and adjusted records will not be printed.

A partial run of the program might be checked with Sense switch E "off" to see if the program is operating on the purpose codes in the required manner. With Sense switch E turned "off," each record to be linked will be printed followed by the message "record to be linked"; second, the linked record will be printed followed by the message "linked record"; third, any record to be adjusted will be printed followed by the message "record to be adjusted"; and last, the adjusted record is printed followed by the message "adjusted record." After the partial run has been checked, the full run could be made with Sense switch E "on" to cut down on the running time. The switch may be turned on and off during operation.

5. A fifth option is also available, but it should not be used unless absolutely necessary. The option to print each unchanged record followed by the message "unchanged record" is controlled by sense switch F. The printing will occur with Sense switch F "off." The use of this option for an entire run will more than double the running time of this program. This switch may be turned on and off during operation.

6. A sixth option is controlled by switch G in conjunction with switches E and F. If switches E, F, and G are "on," all printing is bypassed.

J. Timing

The running time on this program is approximate only. Recently, 22,000 records were run in about 45 minutes on an IBM 1401. Both the linking and general purpose options were performed on these data records and some printing was obtained.

K. Error Messages

Special error messages will be printed for two halt conditions (see HALT1 and HALT, in L. Program Halts). For each case, the carriage is double spaced and the card which was in the print area is printed on the first line. On the second line, the B address register is printed first followed by the card which is in the input area. The B address register gives the location of the next sequential instruction after the halt (to identify the halt), and the input area provides the next card to be processed. These data should enable the user to locate the cards which are causing these particular errors. These halts are irrevocable.

L. Program Halts

Message	Symbol	Location	Explanation
"END OF INPUT REEL ON UNIT 2. MOUNT NEW TAPE AND SWITCH D ON IF LAST INPUT. PRESS START TO CONTINUE.	CHNGE	3495	End-of-reel on tape unit 2. For multiple input reels, mount the next input tape on unit 2, check if switch D is needed and press start.
Last card printed, B address register, and the card in the input area printed.	HALT1	3881	Press start to print the error messages. The error messages will assist in locating the card which has caused the error, as the number of trip cards to be linked has exceeded the maximum of 30. See ERROR, halt location 7155.

Message	Symbol	Location	Explanation
Last card printed, B address register, and the card in the input area printed.	HALT	4274	Press start to print the error messages. There is an invalid unequal-compare and the error messages will assist in locating the card which has caused the error. See ERROR, halt location 7155.
Total and "END OF JOB."	HALT3	4777	End-of-job.
"BAD PURPOSE CODE IN ORIGINAL CARD. PUSH START TO MAKE A PERSONAL BUSINESS TRIP OF IT."	HALT4	6162	Invalid purpose codes in trip purpose columns. The card has been printed. Push start to make a home to personal business trip out ot it. New card is printed.
None	ERROR	7155	This halt is caused by HALT or HALT1. Check the address at the beginning of the second line of the error message to identify the halt location. See K. Error Messages.
"END OF OUTPUT REEL ON UNIT 3. MOUNT NEW TAPE AND PRESS START TO CONTINUE."	HALT7	7203	End of reel on tape unit 3. For multiple reels, mount a new output tape on unit 3 and press start.
"READ ERROR TAPE X" or "WRITE ERROR TAPE X"	None	7385	Tape read or write error on tape unit 2 or 3. Press start to try 10 more times. For a read error, skip record manually, if permissible. For a write error, mount a new tape, reload the program and begin again.

Appendix III
STANDARD FORMATS

The following sections include standard data input and output formats and standard control card formats for both the BELMN monitor and for subject programs.

1. BELMN Submonitor Control Cards

Title of Card	Columns	Contents
Remarks	1	"*"
	3-72	Any alpha-numeric message desired
Pause	1- 2	"**"
	3-72	Any alpha-numeric message desired
Program call card (For a binary program number)	1- 2	"PR"
	4- 6	Program number, right-justified
	7-72	Blank or as desired
Program call card (For a 6-character BCD program name)	1- 5	"PROG."
	6	Blank
	7-12	Alpha-numeric program name, exactly as it appears in the program.
Time cards	1- 2	"TS"-for time at start
	1- 2	"TP"-for the time since last time card
	1- 2	"TJ"-for total time since start
	3-72	Anything desired

Title of Card	Columns	Contents
Load card	1- 4	"LOAD"
	7-72	blank or as desired
System card	1- 6	"SYSTEM"
	7-72	blank or as desired

2. Program Control cards

Those cards which remain the same from program to program will be described here and referred to in the abbreviated program descriptions.

Title of Card	Columns	Contents
Identification	1-71	These columns will be used to identify the output data for off-time printing.
	72	"1" (necessary to identify the card)
Parameter	1-36	Options for this particular program. Specified by punching a "1" in the specific column of the option desired. If the user does not wish to express the option, the card column should be left blank.

This card varies sufficiently that its content will be described in each writeup.

	72	"2" (necessary to identify the card)

Zone Selection

This card is used to designate the zones or series of zones to be selected for processing in a particular program. The zones to be included are specified in columns 1 to 66, in a format of 6 column fields. In preparing the card, place the first zone right-justified in column 6. If it is to be a single zone a comma (,) should follow in column 7. If it is to be the first zone of a consecutive series, punch the last zone of the series in column 12 (right-justified), followed by a comma if more zones are to follow. Additional single zones or series of zones may be selected by using the successive 6 column fields through card column 66. Any combination of grouped and single zone selections may be made as long as column 66 is not exceeded. A "3" punch in column 72 is required to identify the zone selection card.

For example, suppose zones 6, 9-15, 18-20, 27, and 133 are to be selected. The control card would be as follows:

Columns	Contents
6	"6"
7	"," (comma)
12	"9"
17-18	"15"
19	"," (comma)
23-24	"18"
29-30	"20"
31	"," (comma)
35-36	"27"
37	"," (comma)
40-42	"133"
72	"3"

Tape Assignment

This card allows the user to designate, at run time, the specific input and output tape units to be used by the program. It is composed of two-column fields separated by commas. The last tape punched must be followed by a blank. The normal assignments, as described in the program description, will be used if the user does not reassign a particular tape unit. If a tape unit is to remain unchanged the user may punch the corresponding field with a zero, or a comma may be punched immediately following the preceding comma. The first blank column which is encountered will terminate the reassignment of tape units. This card is identified by a "0" (zero) punched in column 72.

Field Number	Columns	Contents
1	1- 2	Channel and unit for Tape 1
	3	"," (comma)
2	4- 5	Channel and unit for Tape 2
	6	"," (comma)
3	continue as above	
	72	"0" (zero)

When this card is required in a particular subject program, the [illegible] units to be used in that program will be defined in terms of the Tape Assignment Card field number as used directly above.

The tape assignment card should always be present if the [illegible] to read control cards from the card reader is used.

3. Binary Tape Formats

(a) Binary Network Descriptions

The binary network description consists of a single record on tape composed of 4N+1 words, when N is the number of nodes in the system. The first word contains four times the highest node number (the count of words in the record excluding the first word). Taken in groups of four, the remaining words of the record describe the links from a common node (A node). In each word, bits 6-17 (decrement) indicate the connecting node (B node). Thus, the A node is determined by word position in the record and the B node is designated in the decrement portion of the word. [illegible] remainder of the word contains the descriptive information [illegible] link. Unused words are filled with zeros.

The complete word format is:

Word Bits	Contents
Sign	Director of link
1- 4	Turn prohibitors for links connected at the B Node .
5	Not used
6-17	[illegible] node
[illegible]-17	[illegible]nicipality or jurisdiction code

Word Bits	Contents
21-26	Distance (in 63rds) from A to B
27-29	Not used
30-35	Time (in 63rds) from A to B

Further information on the network description and its creation is available in the Traffic Assignment Manual(1).

(b) Binary Loaded Network

This file is composed of three records. The first record is the same as the network description (see above), except that in each word the tag (bits 18-20) is blank and the address (bits 21-35) contains link volume rather than time and distance. To eliminate overflow possibilities, the volume in the record is one-fourth the actual volume assigned to the link.

The second record is a turn table containing a "2" in the decrement of the first word and the remaining word count in the address. The turn table consists of two words for each four-way arterial and for each freeway node. The relative position in the record determines the A node of the word pair beginning with the first designated turn node and continuing to the last designated turn node. The decrement contains the B node, and the address contains one-fourth of the turn volume between the B node indicated and the highest node connected to Node A.

(c) Binary Trip Table

This tape is in the form of a single file composed of N records, where N is the number of zones. Each record contains N+1 words. The first word of the record is the identification word with the decrement containing the origin zone number and the address containing N. The second word contains the integer trips from the origin zone to zone one. The third word contains the trips to zone two, and so on until all zones are accounted for. The origin zones are in ascending order on the tape.

(d) Binary Skim Tree

The binary skim tree file is exactly the same as the binary trip table file (see above) except that trips are replaced with whole minute times between zone pairs.

4. BPR Trip Record Formats

Detailed descriptions of the information contained in the various types of survey cards are available in the Traffic Assignment Manual(1). The procedures to follow in building trip tables from these cards are also described in this publication.

Appendix IV
DETAILS OF BELMN OPERATIONS

The user must initiate the BELMN submonitor by calling in the two programs which comprise the control program (PR-101 and PR-102). This may be done in several ways:

(1) Using a small program called the BELMN loader under the control of the Senior System.

(2) Mounting the Library Tape on unit A1 and pressing "Load tape."

(3) Using a binary BELMN loader in the on-line card reader and pressing "Load cards."

In all of these cases the following sequence of instructions must be placed in core storage and executed:

```
1        8        16

BELMN    REWX     T
         RTBX     T
         RCHX     BELMN+6
         TCOX     BELMN+3
CLOCKE   NOP      HUB
         TRA      START
         IORP     SELFLD,,-1
MONITR   BCI      1,
SELFLD   BOOL     75
START    BOOL     64000
NOCLOK   BOOL     135
HUB      EQU      6
```

X refers to Channel (A or B)
T refers to Unit (1-10)

These instructions must also remain in storage, as described above, to allow re-initiation of the control program and to insure it is resident in core storage. The BELMN loader should be located starting at location 2150 (octal), though by revising the transfer vectors (see <u>Traffic Assignment Manual</u>(1)) this may be changed as desired.

The BELMN loader reads the first two records from the tape unit specified in the loader (this may be varied) and places them in storage. The first record (PR-101) is loaded into locations 100-2000 (octal), and second record (PR-102) is loaded into locations 64000-64777 (octal). Included as part of the second record is the resident portion of the BELL system which is loaded into locations 0-77 (octal) and 65000-77777 (octal) of core storage. The first record contains the transfer table, the input-output subroutines, and the other subroutines used by the subject programs. The second record is the portion of the control program which performs the various operations required to link subject programs together and maintain continuous operation. These operations are requested by means of several control cards which may be prepared by the user. Control of processing must reside with BELMN for these cards to be valid. As BELMN was originally developed for use under the control of the BELL Monitor, the BELL system is also included with BELMN to make available the BELL subroutines.

Format details for the control cards used with BELMN are summarized in appendix III, part 1. The uses of these cards will be described in the following material. Communication with the machine operator to allow input-output tape changes and other run-time modifications is accomplished with Remark and Pause Cards. The message on a Remark Card is written on-line and on the system print tape. A Pause Card, in addition to being written on-line and on the system print tape, causes the machine to halt. When the operator presses "START" program execution continues.

When a Program Call Card is encountered, the BELMN control program searches the BELMN program library tape until it finds the required program. It then begins loading the subject program into storage.

Two types of Program Call Cards are now available; one for programs with a binary number as the program name, the other for programs with a BCD program name of up to 6 characters. The first word of the program record on the program library tape contains the program name in one of two forms: (1) as a binary number in the decrement (left half) of the word, or (2) as a BCD word of 6 characters.

Time cards are used to keep track of the running time of an entire job or various portions thereof. The use of the three time cards as described in the Traffic Assignment Manual(1) is no longer required. If they are omitted, the BELMN control program automatically clocks each program and records the running time on the system print tape. However, the "TJ" card should be used as the normal end to the processing of BELMN programs and to cause a return to the senior monitor in control. If other control cards are used for this purpose the machine may halt, or an incorrect return may be taken. If the user's computer installation does not have the same clocking method as used in the BELMN Control Program, the BELMN loader may be used to modify the clocking operation. If the clock is interrogated through a printer hub other than 6, this may be changed by modifying the instruction:

```
HUB  EQU   6
```

If the user does not desire to make use of the clock at all, the symbolic location "CLOCKE" in the loader should be changed to:

```
CLOCKE  TSX   NOCLOK,4
```

Two special purpose cards are also available to the user. The "SYSTEM" card causes a transfer to the BELL system portion of the control program (be sure that it is still resident in core) to allow the processing of BELL system control cards. Refer to the Traffic Assignment Manual(1) for a description of these cards and their uses. The "LOAD" card simulates a tape load and performs the same function as pressing "LOAD TAPE" on the console. This allows the user to initialize a system from tape A1 to storage, as desired.

Each subject program processes the control cards necessary to specify the parameters for the run. At the end of the subject program run, control is returned to the BELMN control program. The programer should refer to the Traffic Assignment Manual(1) for the specific return procedures to be employed in given instances. At this point the control program continues processing BELMN control cards and initiating subject programs as requested by the user until control is relinquished to the installation's senior monitor. By specifying the system which has control (BELL, IBSYS, or FORTRAN MONITOR) in the BELMN loader, the user is able to gain and relinquish control in almost any commonly used system. The system actually in use is specified by using one of the following instructions in the symbolic cell "MONITR" in the BELMN loader:

```
8        16                                        (Ø = zero)
BCI      1, ØMONTR        (FORTRAN MONITOR)
BCI      1, ØIBSYS        (IBSYS)
BCI      Anything else    (BELL)
```

Certain tape units are always required for each job run. Tape unit A2 for card input (unless sense switch 5 is on) and tape unit A3 for printed output are fixed and required by all subject programs. If BELMN is operated under a system, several system tapes may be required, including the system tape, an accounting and general purpose scratch tape, and a tape for punched card output. Other tapes may be required depending upon the system used. This should be checked by the user at the installation where runs will actually be processed. In addition, one tape unit will be required for the BELMN program library tape. At present, the program library tape generally is placed on tape unit A8, although this may be modified by changing the loader as described above. It should also be noted that any time the BELL system included with the BELMN control program is in use, it may require some of the above mentioned system tapes.

The fixed tape requirements of the BELL System may be found in the Traffic Assignment Manual(1).

Appendix V
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