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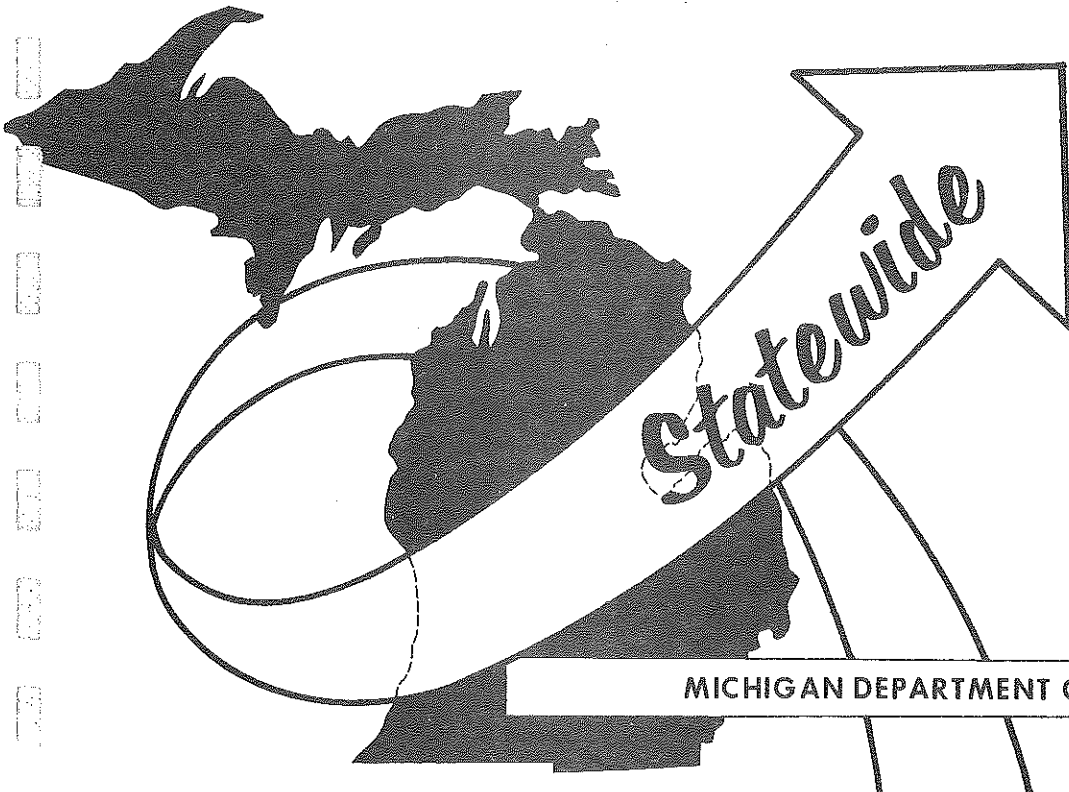
Statewide Transportation Analysis & Research

MICHIGAN'S STATEWIDE
TRANSPORTATION MODELING SYSTEM

Volume VI - C

OVERVIEW OF MICHIGAN'S
TRANSPORTATION PLANNING PACKAGE

April 1983
Transportation Planning
Procedures Section



MICHIGAN DEPARTMENT OF TRANSPORTATION

**MICHIGAN'S STATEWIDE
TRANSPORTATION MODELING SYSTEM**

Volume VI - C

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TRANSPORTATION PLANNING PACKAGE**

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Transportation Planning
Procedures Section**

T R A N S P O R T A T I O N
P L A N N I N G

by

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Transportation Planning

April 1983

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Transportation planning is an integral part of urban or regional planning. Of all the transportation systems today, travelling by various kinds of vehicles on highways or streets is by far the single most prevalent means of moving people and goods from place to place. As a result, highway planning has become ever more important not only in meeting the needs of the people, but also in shaping the future land use pattern and socio-economic developments.

Obviously, in highway planning, whether it is to modify or augment an existing system for a developed area or to design a totally new system for a new town, a proposed suburb, etc., the planner must before actual implementation evaluate his solution to see whether it will meet the present or future needs. Most likely, the goal is to evaluate many feasible solutions and choose the one that is most preferable from the point of view of efficiency as well as cost and socio-economic impact. The question is: How can the evaluation be performed?

Two basic tasks are involved: To forecast the future transportation needs and to predict how the future needs will actually be accommodated by the various sections of the proposed transportation system. In today's complex urban situation, these tasks are no longer amenable to experience or trial-and-error. They require, first of all, a theoretical methodology to predict future conditions based on the present knowledge of travel patterns, existing transportation facilities, land use and socio-economic factors. Secondly, they require a means for high speed data processing so that the results obtained will not become obsolete before they are used. The only answer to such requirements that is available today is the combination of computer technology and various predictive models developed in recent years.

In the following we shall give a general description of the over-all transportation planning process (more accurately, transportation planning evaluation process) and the Burroughs computer programs developed for that purpose. Although the emphasis is on applications to highway planning, the basic ideas of the theory can be easily applied to the evaluation of other transportation modes such as railroad, airlines, and shipping.

1.2 THE MODELS

An urban transportation system may be considered as a network consisting of a set of nodes and interconnecting links, with nodes representing intersections and links the streets. Trips are assumed to be produced at and attracted to a subset of the nodes called centroids, representing the different zones of the study area. The routes for the trips consist of one or several connecting links. A single link generally is shared by several nodes. (Figure 1)

Future Traffic Forecasting

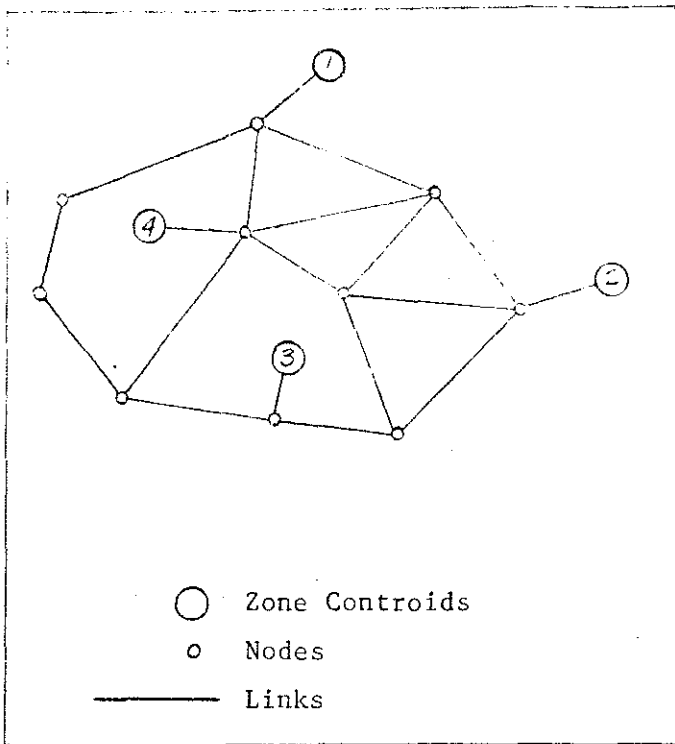


Fig. 1 Network Analysis

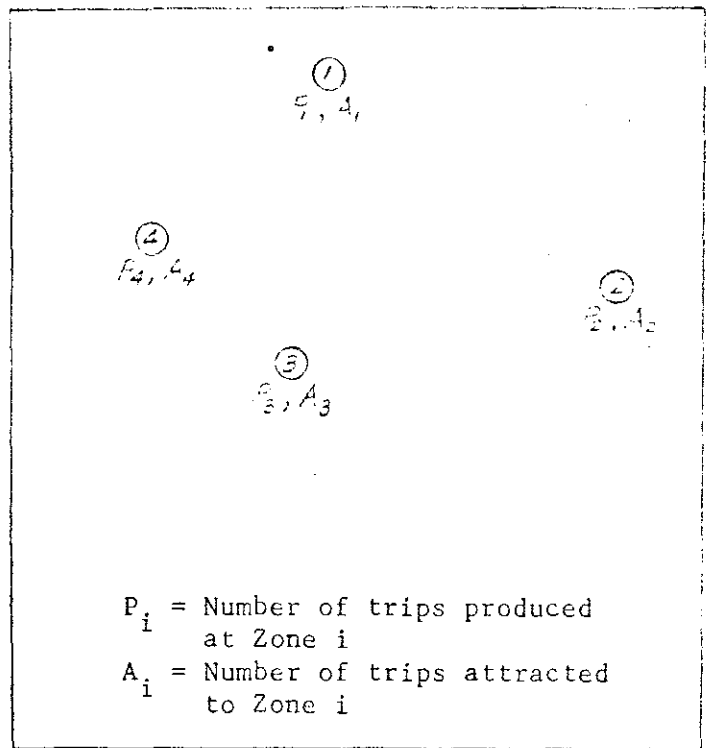


Fig. 2 Trip Generation

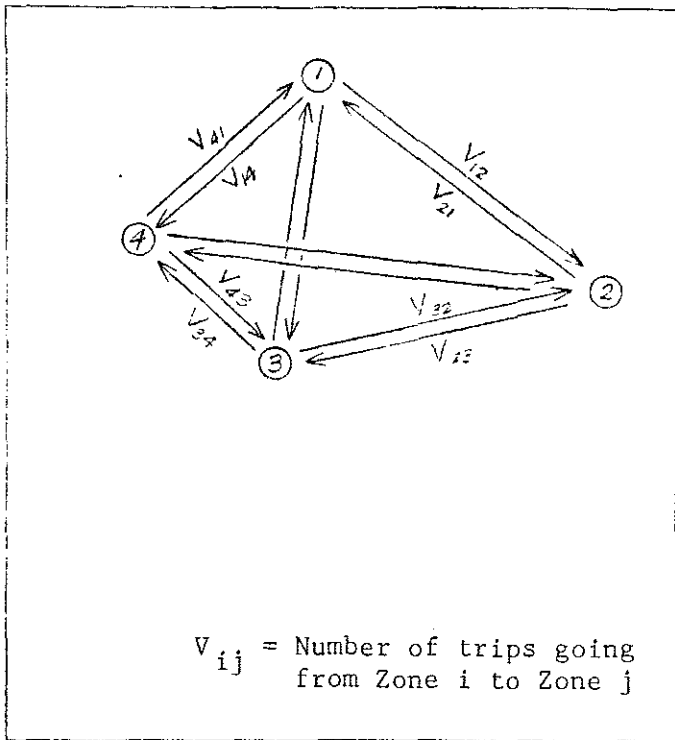


Fig. 3 Trip Distribution

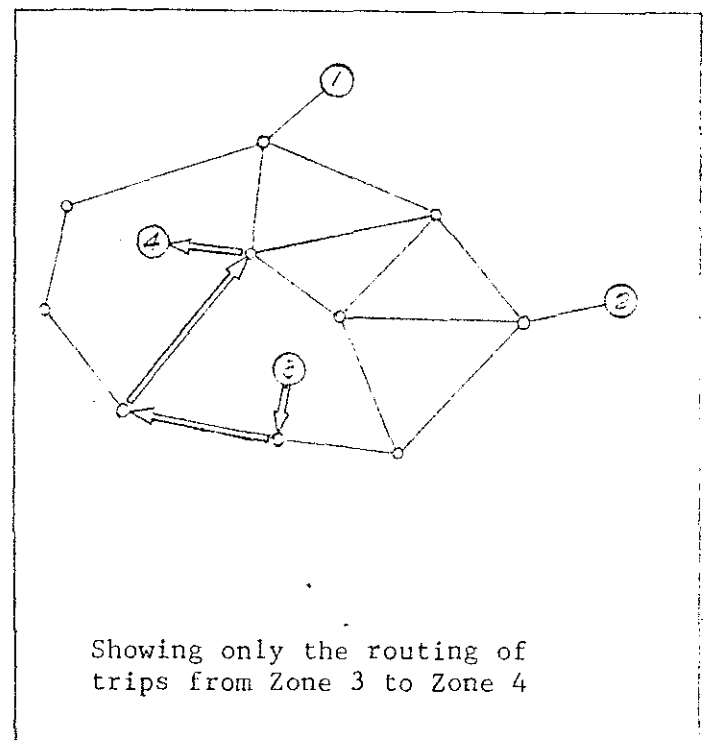


Fig. 4 Trip Assignment

Various parameters are attached to the nodes and links. To each link may be attached values indicating the length, speed, travel time, capacity, traffic flow, etc. To each node may be attached turn penalties, and to each centroid the zonal productions and attractions and terminal and intrazonal times.

The crux of the transportation planning process is a group of predictive models. These models perform (1) the forecasting of future traffic load, i.e., the future trip production and attraction at each zone within the study area, and (2) the prediction of the stress due to that load on a proposed transportation system, i.e., the traffic flow on each link in the system. The first is called trip generation (Figure 2); the second is usually separated into two supposedly independent procedures: Trip distribution and trip assignment. The former distributes the predicted future production (or attraction) at each zone to various destinations (or origins) (Figure 3). The latter then allocates the future interzonal trips to various links of the proposed system (Figure 4). We shall describe each type of model briefly.

A. Trip Generation

The model relates the trip production and attraction at each zone for a given purpose (or vehicle type) to a variety of socio-economic and land use parameters. It is usually a set of linear regression equations whose coefficients are determined by regression analysis.

B. Trip Distribution

The function of trip distribution is to determine, from the estimated number of trips produced at and attracted to each zone, the number of interzonal and intrazonal trips. Two of the most commonly used models are:

- 1) The Gravity Model - This model has a form analogous to Newton's Law of Gravitation. It assumes that the number of interzonal trips is directly proportional to zonal productions and attractions and inversely proportional to the travel impedance, measured in time, distance or cost.
- 2) The Fratar Model - This model is a growth factor method which simply assumes that the number of interzonal or intrazonal trips is proportional to the zonal growth factors of production and attraction. Fratar method is usually used for forecasting through trips, i.e., trips with both origin and destination outside of the study area.

C. Trip Assignment

The output of trip distribution is the trip table or distribution matrix giving the intrazonal and interzonal trip numbers. This output, together with the coded road network, forms the input to the trip assignment program which allocates the trips to the most probable routes of the network and accumulates the flows on each link. In addition to listing link flows, the assignment may report the turning volumes at major intersections. The outputs of assignment are used to determine whether the loaded network can operate at the design level of service.

In trip assignment procedures, trips are assigned on the assumption that each traveller chooses the cheapest route (in time, distance, or cost) from his origin to his destination. Complication arises from consideration of traffic congestion. As link flow increases, alternative routes may be cheaper than the one initially chosen. Two common assignment models are the following:

- 1) All-or-Nothing - This model assumes that link cost is independent of link flow. All the traffic is assigned to the cheapest route initially chosen and none to the others.
- 2) Capacity Restraint - This model considers the effect of link flow on link cost and is a refinement of the above model. It is an iterative procedure, alternating All-or-Nothing assignments with re-calculation of link costs from an assumed link cost-link flow relationship.

1.3 THE TRANSPORTATION PLANNING PROCESS

The models used for transportation planning, unlike those in physical sciences, are not universal models calibrated to hold true for all time and place. Their inherent nature allows them to be calibrated to fit only the base year data specific to a certain area. They are assumed to be reliable for a limited number of years provided there are no drastic changes in environmental and socio-economic conditions, after which they must be re-calibrated to fit more current data. Models calibrated for one area are generally not applicable to another.

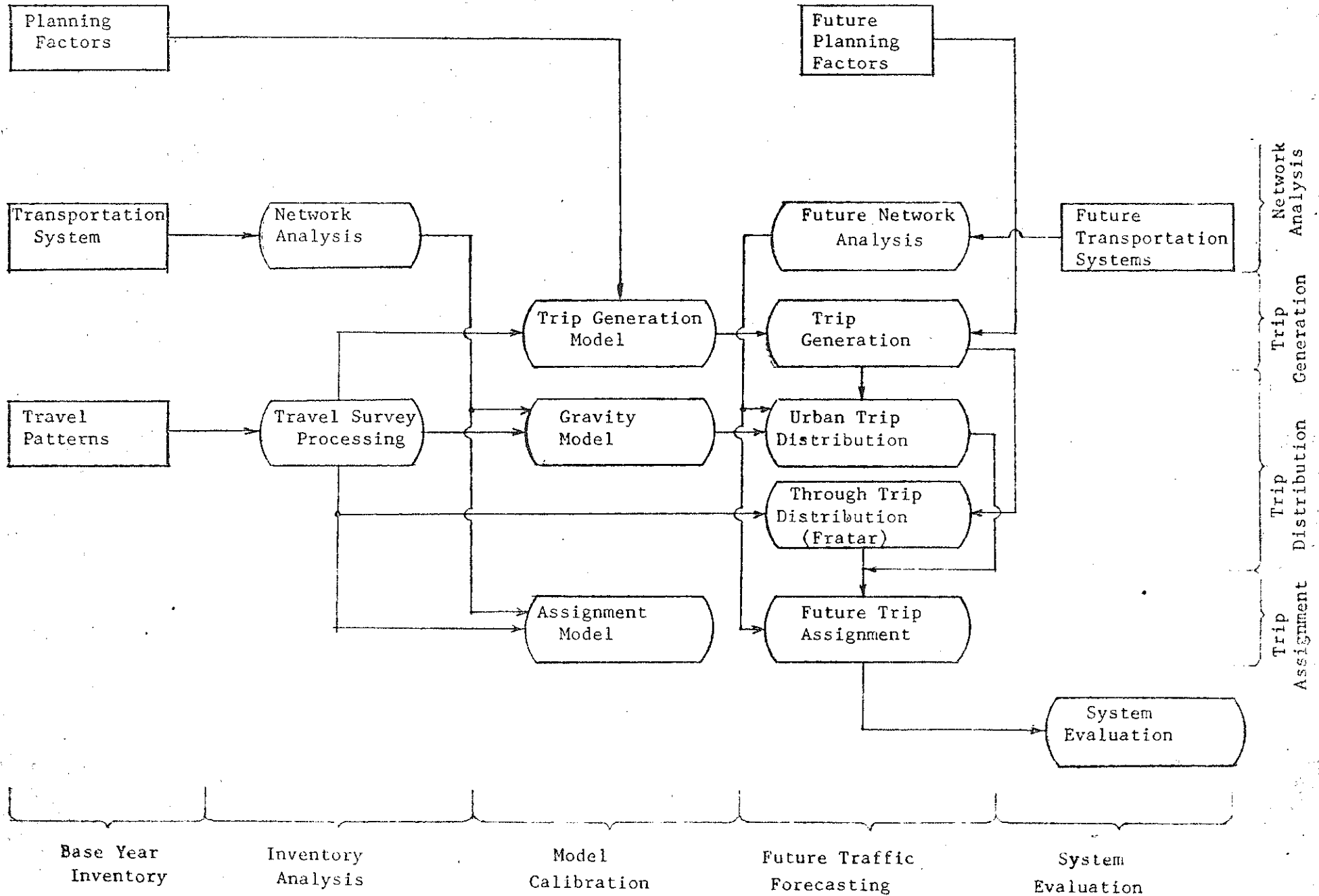
The transportation planning process can, therefore, be divided into the following phases: (See Transportation Planning Process Flow Chart.)

A. Base Year Inventory

The first phase consists of three inventory programs:

- 1) Inventory of Existing Transportation System
 - a) Map of study area divided into sectors, districts, and zones.
 - b) Map of city street, main road, and freeway networks.
 - c) Measurement of link length, speed, travel time, capacity, traffic flow, turn penalty, terminal and intrazonal times.
- 2) Inventory of Travel Patterns
 - a) Data for determination of origin-destination travel patterns for the study area.
 - b) Classification of interzonal and intrazonal trips by location (internal, external, through) by time of day (AM, PM, off) purpose (home based, non-home based) and vehicle types.

TRANSPORTATION PLANNING PROCESS



3) Inventory of Planning Factors

- a) Land use - housing, industry, business, school, recreation.
- b) Socio-economic factors - population, employment, income, car ownership, etc.

B. Inventory Analysis

The second phase is to obtain from base year inventory the information that is needed for model calibration.

1) Network Analysis

Coding and building network description, cheapest routes, minimum travel time tables from transportation system inventory.

2) Travel Survey Processing

Calculation of trip tables and zonal productions and attractions from travel pattern inventory.

C. Model Calibration

The third phase is to calibrate mathematical models for forecasting future traffic loads and link volumes.

1) Trip Generation Model

Regression analysis relating present zonal productions and attractions to present planning factors.

2) Trip Distribution Model

Calibration of Gravity model by using present zonal productions and attractions and minimum travel times.

3) Trip Assignment Models

Assignment of present trip tables to present network using either All-or-Nothing or Capacity Restraint method for testing both the models and the accuracy of the network.

D. Future Traffic Forecasting

The fourth phase is to forecast future traffic demand and the resulting link and turn volumes on the alternative future transportation systems by using the calibrated and tested models:

1) Future Network Analysis

Updating the old network and building cheapest routes and minimum travel time tables for the new system.

2) Trip Generation

Inputting predicted future planning factors to regression equations to obtain the future zonal productions and attractions.

3) Trip Distribution

Using both the Gravity and the Fratar models to obtain the total future origin-destination trip tables. The input to Gravity model is the future zonal productions and attractions and the future minimum travel times. The input to Fratar model is the present trip tables and the future zonal productions and attractions.

4) Trip Assignment

Assignment of future trip tables to future network, using either All-or-Nothing or Capacity Restraint method, to obtain future link and turn volumes.

For each alternative system, repeat steps (a), (c), (d) above.

E. System Evaluation

The last phase is to evaluate the alternative future transportation systems and to select the preferred one. For each system, the following evaluations are performed:

- 1) Volume-capacity relation of each important link in the system, congestion points, level of use, etc.
- 2) Cost
- 3) Socio-economic and land-use impact.

1.4 THE BURROUGHS TRANSPORTATION PLANNING SYSTEM

A. General Description

The Burroughs Transportation Planning System for B5500 computers was developed to execute all the phases of the transportation planning process described above. The whole system contains 32 programs, three of which are written in Compatible ALGOL, the rest in FORTRAN IV. All programs are stored on magnetic tape and are operationally independent. This library concept enables the user to execute or modify any phase of the transportation planning process by proper selection of the programs and/or incorporating his own. Further flexibility is built into the system

by providing each individual program with a variety of controls through Parameters, Options and Selections.

B. The Programs

The programs, according to their basic functions in the transportation planning process, may be conveniently classified into the following categories:

- 1) Network Analysis Programs - To build or update network and compute cheapest routes, minimum travel-time tables, etc. from coded network.
- 2) Travel Survey Processing Programs - To calculate trip tables, zonal productions and attractions from travel survey data. Programs are available to perform different kinds of operations on trip tables, e.g., compression, expansion, comparison, transposition, modification, reporting, etc.
- 3) Trip Generation Program - To calculate zonal productions and attractions using linear regression equations as input.
- 4) Trip Distribution Programs - To calibrate trip distribution model and build trip tables. Options are Gravity and Fratar models.
- 5) Trip Assignment Programs - To assign trip tables to network. Options are All-or Nothing and Capacity Restraint models. Programs are available to evaluate the loaded network, to calculate turn volumes, and to list all the trips by origin/destination using particular links.
- 6) Utility Programs - To tabulate, edit, summarize and merge data files. These are general purpose utility programs.

C. Input/Output

The input to each program consists of magnetic tapes which furnish the basic data, and System Control cards which furnish the following information:

- 1) Name of the program to be executed
- 2) I/O files
- 3) Program controls (Parameters, Options, Selections)
- 4) Data cards (when necessary)

The output of each program consists of magnetic tapes and/or reports, as well as error messages.

D. Additional Features

A few additional features or points about the programs are:

- 1) The maximum size of the network that can be accommodated by the programs is 8191 nodes, of which 2500 may be centroids. Maximum number of links is 32000. Maximum number of outbound links per node is 8.
- 2) Existing network can be updated by replacing some of the input Link Cards with new ones. Thus, alternative systems can be analyzed by changing only the effected parts.
- 3) The input Link Cards for building or updating network can be in either IBM 7090 or B5500 format.
- 4) Any tree (i.e. shortest routes from one origin to all destinations) or trees may be built separately.
- 5) Trip tables for various stratifications of trips can be built from survey data according to user specification.
- 6) Besides the listing of trip volumes on links, the assignment program also outputs a complete summary of vehicle-miles and vehicle-hours by highway class and jurisdiction.
- 7) Selected links can be separately loaded and analyzed, usually following assignment, to study special problems such as conjection that may exist on those links.

CHAPTER 2

NETWORK ANALYSIS

2.1 GENERAL

The function of analyzing an existing transportation network is to obtain the necessary information for calibrating the distribution and assignment models. It includes the following: (See Network Analysis Flow Chart.)

1. Coding and Building Network Description - To code the transportation system from survey data and store the coded representation on tape.
2. Building Trees - To find the minimum routes from any zone to all other zones in the study area.
3. Building Skim Trees - To find the travel times for the minimum routes.

Proposed future networks are analyzed similarly before forecasting future traffic. Future network description can be obtained by updating the existing network description. Trees and skim-trees are then rebuilt from the updated network.

2.2 NETWORK DEFINITIONS

A transportation system may be considered as a network consisting of a set of nodes and interconnecting links with nodes representing intersections and links the streets, freeways, etc. A link may be directed or undirected depending on whether it represents a one-way or two-way street. Trips are assumed to be produced at and attracted to a subset of the nodes called centroids, representing the different zones of the study area.

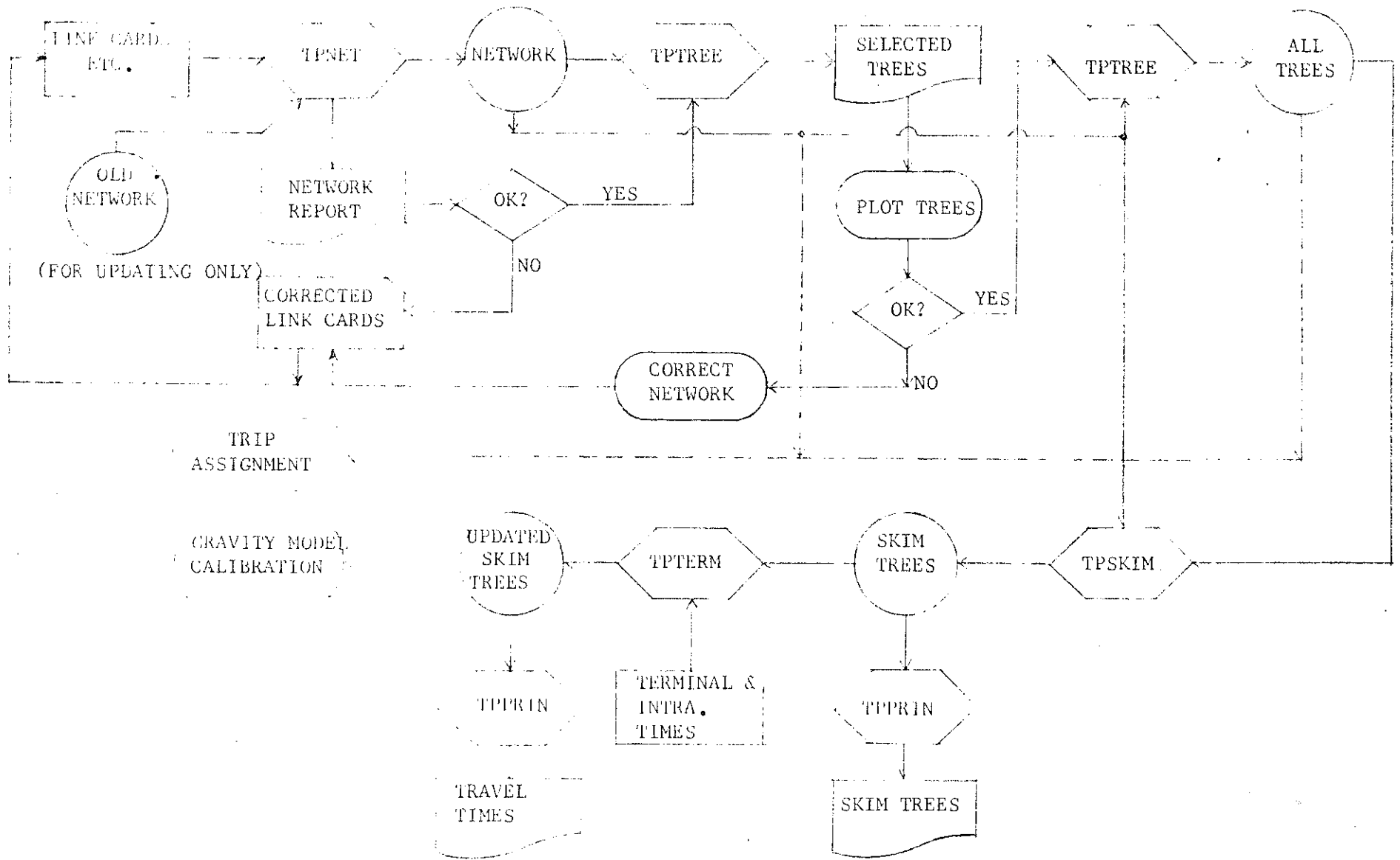
A cordon line is the boundary of the study area. External stations are centroids at the intersection between the cordon line and major arterial or freeway links.

Various parameters may be associated with nodes and links. To each node is assigned its coordinates and turn penalties and prohibitions. To each link is assigned direction, distance, travel time or speed, capacity, traffic count, type and jurisdiction, etc.

2.3 NETWORK CODING

Before an existing transportation network can be described to the computer, it must be first coded from the Transportation System Survey data. The coding involves the following steps:

NETWORK ANALYSIS
(Present or Future)



A. Locating Centroids - Zones are chosen to form areas bounded by arterial streets. All trips to and from a zone are assumed to be converging at a single point, called centroid, located at the zone's center of activity. For a residential zone, the center of activity would be the center of the zone's population. For a mixed land use zone, the location of the centroid is determined largely by judgement. Once the centers of activity are determined, the zones are represented by their respective centroids marked as circles.

B. Selection of Network - The selection of a network consisting of links and nodes to approximate the actual street system depends on the level of detail of the study. In general, all freeways and arterial streets, but not local streets, should be included. One way links are marked with arrows in the direction of travel. Nodes are represented by a small circle or dot, differentiable from the centroids.

A node may have any number of inbound links, but may not have more than eight outbound links. To provide for intersections with more than eight outbound links, fictitious nodes are introduced. The link between the fictitious node and the original node is given a zero distance.

C. Connecting the Centroids - The local streets within a zone are not simulated. Instead they are represented by fictitious links drawn as dashed lines connecting the centroid to the surrounding arterial streets. Their operating characteristics (distance, travel time, etc.) are assumed to be the average operating characteristics of the local street system for the zone. Centroids cannot be located directly on a link of the system. If they should fall on a link, they must be offset and connected by a fictitious link of zero travel time and distance.

It is recommended that a centroid be given as many connections as possible, up to eight, to the arterial streets. This tends to smooth the traffic on the adjacent links.

D. Numbering Nodes and Centroids - Centroids for zones and external stations must be numbered consecutively starting from 1. The largest permissible centroid number is 2500.

Node numbers must be greater than any centroid number, but not greater than 8191. They need not be consecutive.

E. Coding Link Parameters - Each link is defined by the two nodes it connects and the direction of travel. The parameters are distance, travel time or speed (AM, PM, or off), capacity, traffic count, link type, and jurisdiction.

The maximum time and distance which can be coded are 326.67 minutes and miles respectively. If a link has a distance or time exceeding this maximum value, it must be broken up into smaller links by inserting fictitious nodes.

- F. Coding Turn Penalties and Prohibition - Turn penalties and prohibitions at nodes are introduced to simulate driving conditions more realistically and to prevent zigzag routing. Only two values can be used for turn penalties throughout the system. A turn penalty or prohibition at any node P is specified by:

A-node of entry link

P-node

P

B-node of exit link

B

Penalty Type

A

- 1 for type 1 penalty
- 2 for type 2 penalty
- 3 for prohibition

2.4 NETWORK DESCRIPTION

After the network is coded, the information is punched on the following types of cards:

1. Label Card - giving network ID.
2. Network Coordinate Cards - giving
 - a. Node number
 - b. X-coordinate
 - c. Y-coordinate
3. Link Cards - giving
 - a. The two nodes defining the link - A to B
 - b. Distance of link
 - c. Travel time or speed (for AM, PM, or off peak)
 - d. Capacity of link
 - e. Traffic count
 - f. Link type and jurisdiction
 - g. Capacity indicator
 - h. The two nodes defining the link B to A and other similar data as above.
4. Turn Penalty and Prohibition Cards - giving
 - a. The three nodes defining the turn.
 - b. Penalty type

To build a network description, the cards are input to the Network Build/Update Program TPNET. The program reads and edits the cards and writes the following data files on tapes for use by other programs:

1. Network ID
2. Network Coordinates
3. Link Description
4. Turn Penalties/Prohibitions

The Network Coordinates File is usually used only as input to plotting programs. The program also prints various reports and summaries.

To update an existing network description, old network description files are used together with whatever necessary new data cards as inputs to the TPNET program. The UPDATE feature enables the program to create updated network description files without having to build the network from start.

2.5 MINIMUM ROUTES AND TREES

A route from an origin to a destination is composed of a set of connecting links and can be defined by a sequence of intermediate nodes. The travel cost of a route is the cost, measured in time, distance, or their weighted average, for travelling that route, i.e. the sum of the travel costs of the links plus the turn penalty costs of the nodes. The minimum route from a zone i to a zone j is the route from i to j with the minimum total travel cost.

For trip distribution and assignment, minimum routes must be determined for all the O-D pairs in the network. A tree from a zone is the set of minimum routes from that zone to all the other zones so that the set of trees from all the zones in a study area comprises the minimum routes for all the O-D pairs.

Various mathematical algorithms are available to find the minimum route from an origin to a destination. The one used in the Tree Builder Program TPTREE is known as the Moore's Algorithm.

The program TPTREE reads the binary network description output by program TPNET and builds trees from all or selected origin zones. Output is either a printed report or a binary tree table. The printed report includes the total relative travel cost from the home node to all intermediate nodes. Relative cost is computed as a linear combination of time and distance, whose coefficients are user specified. The cost on each link may also be multiplied according to link class by user specified weighting factors. Three turn penalty costs may also be input.

2.6 SKIM TREES

The skim tree for a zone is the set of the travel costs of the minimum routes going from that zone to all the other zones. The skim tree table for a n -zoned study area is the set of the skim trees for all the n zones. It can therefore be represented by a $n \times n$ matrix as follows:

$$\begin{bmatrix} 0 & c_{12} & \dots & c_{1n} \\ c_{21} & 0 & \dots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \dots & 0 \end{bmatrix}$$

where c_{ij} is the minimum travel cost from zone i to zone j .

The Skim Tree Program TPSKIM reads the network description from TPNET and the trees output from TPTREE and outputs up to three interzonal matrices which give the following values for each zone pair:

1. Zone to zone relative cost via minimum route.
2. Zone to zone distance via minimum route.
3. Zone to zone time via minimum route.

The above values can be calculated exclusively over links of user specified class and/or jurisdictions.

The skim trees output from TPSKIM or other programs can be printed using program TPPRIN (see Section 3.5).

2.7 TERMINAL AND INTRAZONAL TIMES

Terminal times are introduced to account for times spent after departing or arriving at the terminals of a trip, e.g. parking, walking to the parking lot, or bus terminals, etc. The total travel time from zone i to zone j is thus:

$$(t_{ij})_{\text{total}} = t_{ij} + t_i + t_j$$

where t_{ij} is the total driving time (or link times plus turn penalties) from zone i to zone j , and t_i and t_j are the terminal times at zone i and zone j .

The total intrazonal travel time for zone i , i.e. travel time for trips with both origin and destination at zone i , is:

$$(t_{ii})_{\text{total}} = t_{ii} + 2t_i$$

where t_{ii} is the intrazonal driving time for zone i , and t_i the terminal time at zone i .

Both terminal times and intrazonal driving times must be estimated. They are then input to the program TPTERM to update the skim tree output from TPSKIM. The Update Skim Tree Program TPTERM reads a file containing a single or merged skim tree table and adds intrazonal driving times and terminal times. It outputs a new single or merged skim tree table which may be represented as follows:

$$\begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & \dots & t_{2n} \\ \vdots & \vdots & & \vdots \\ t_{n1} & t_{n2} & \dots & t_{nn} \end{bmatrix}$$

where t_{ii} is the estimated intrazonal travel time for zone i and t_{ij} is the minimum interzonal travel time including terminal times from zone i to zone j .

This updated skim tree table is used for calibrating the Gravity Model.

CHAPTER 3

TRAVEL SURVEY PROCESSING

3.1 GENERAL

The function of Travel Survey Processing is to obtain from the Travel Pattern Inventory, generally known as O-D Survey, the necessary information for calibrating the models used in transportation planning. It consists of the following: (See Travel Survey Processing Flow Chart.)

1. Checking and editing the O-D Survey data.
2. Building present trip tables for:
 - a. Internal trips for different trip purposes.
 - b. External trips
 - c. Through trips
3. Compute present zonal productions and attractions for internal and external trips from trip tables.

3.2 TRIP TABLES

A trip table for a n-zoned study area is a table of all the interzonal and intrazonal trip numbers. It can be represented by a nxn matrix:

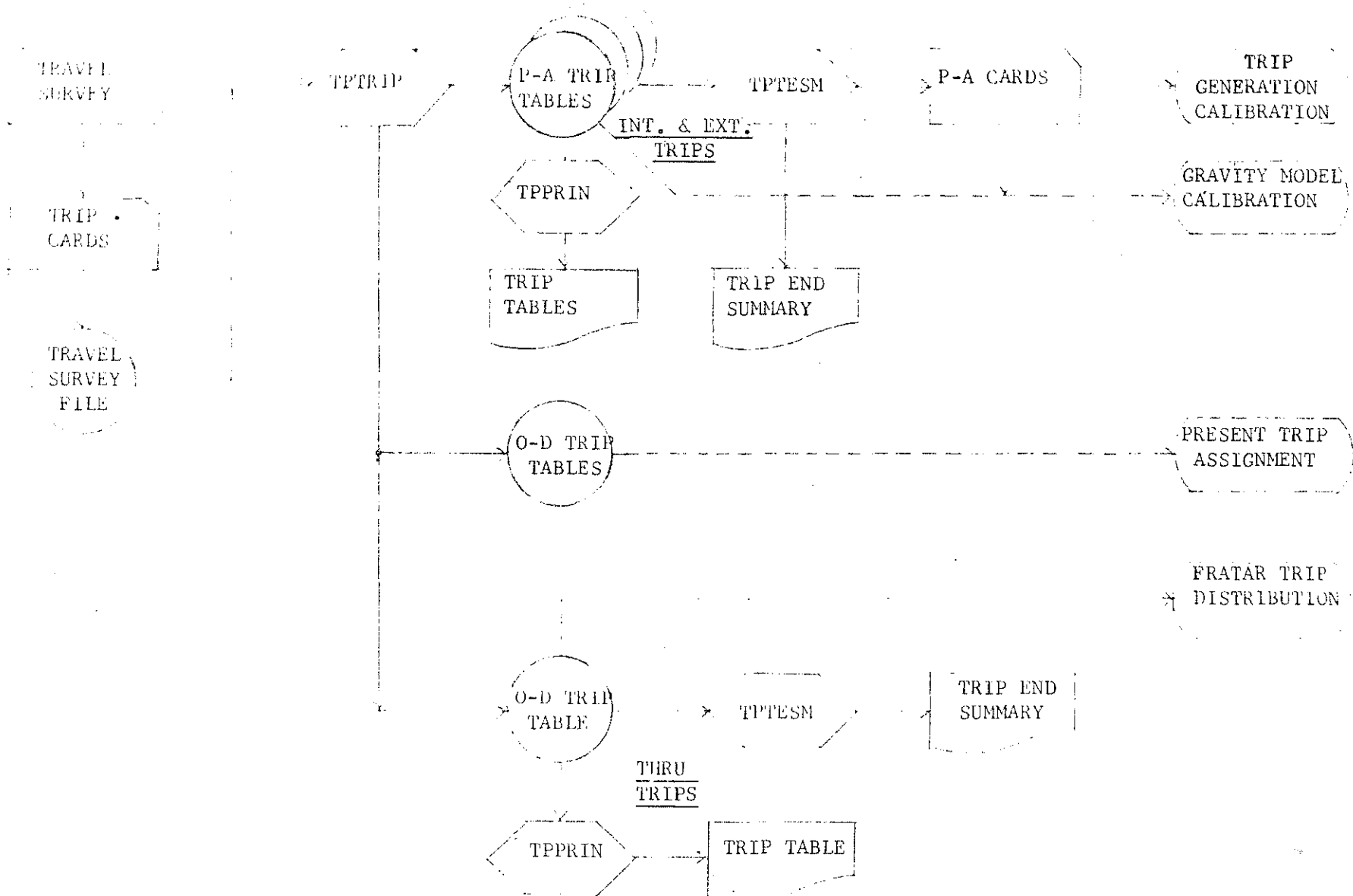
$$\begin{bmatrix} V_{11} & V_{12} & \dots & V_{1n} \\ V_{21} & V_{22} & \dots & V_{2n} \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ V_{n1} & V_{n2} & \dots & V_{nn} \end{bmatrix}$$

where:

1. The non-diagonal elements V_{ij} , $i \neq j$ are the numbers of interzonal trips from zone i to zone j , and the diagonal elements V_{ii} are the numbers of intrazonal trips for zone i .
2. The sum of the i^{th} row is the total number of trips originating in zone i plus the intrazonal trips for zone i . If the table is a P-A trip table (See Section 3.4), the row sum is defined as the production, P_i , of zone i :

$$P_i = \sum_{j=1}^n V_{ij}$$

TRAVEL SURVEY PROCESSING
(PRESENT)



3. The sum of the j^{th} column is the total number of trips attracted to zone j plus the intrazonal trips for zone j . If the table is a P-A trip table, the column sum is defined as the attraction, A_j , of zone j :

$$A_j = \sum_{i=1}^n V_{ij}$$

4. The sum of the production P_i and the attraction A_i of zone i is called the total trip end of zone i .

$$(\text{Trip End})_i = P_i + A_i = \sum_{j=1}^n V_{ij} + \sum_{j=1}^n V_{ji}$$

Example: Given the following 4 x 4 trip table.

| | | | |
|----------|----------|----------|----------|
| V_{11} | V_{12} | V_{13} | V_{14} |
| V_{21} | V_{22} | V_{23} | V_{24} |
| V_{31} | V_{32} | V_{33} | V_{34} |
| V_{41} | V_{42} | V_{43} | V_{44} |

For zone 2, we have:

$$\text{IN} = V_{12} + V_{32} + V_{42} \quad \text{INTRA} = V_{22}$$

$$\text{OUT} = V_{21} + V_{23} + V_{24}$$

$$\text{Production} = P_2 = V_{21} + V_{22} + V_{23} + V_{24}$$

$$= \text{Row Sum} = \text{OUT} + \text{INTRA}$$

$$\text{Attraction} = A_2 = V_{12} + V_{22} + V_{32} + V_{42}$$

$$= \text{Column Sum} = \text{IN} + \text{INTRA}$$

$$\text{Total Trip End} = \text{Production} + \text{Attraction}$$

$$= \text{Row Sum} + \text{Column Sum} = \text{OUT} + \text{IN} + 2 (\text{INTRA})$$

3.3 CLASSIFICATION OF TRIPS

A. Classification by Purpose - Trips are generally classified by purpose for which they are taken. The number of purposes used for classification depends on the scope and objective of the study. The primary classification is home-based trips, i.e. trips with either origin zone or destination zone being the residential area, and non-home-based trips, i.e. trips with neither origin zone nor destination zone being the residential area. A possible classification of trips by purpose is as follows:

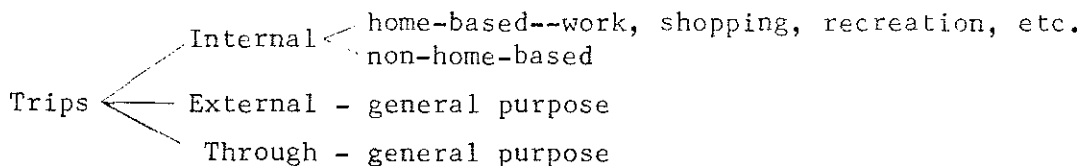
1. Home-based work
2. Home-based shop
3. Home-based social recreation
4. Home-based school
5. Home-based miscellaneous
6. Non-home-based

In the above case, there are five home-based trip purposes and one non-home-based trip purpose.

B. Internal, External, and Through Trips - Trips are also classified according to the locations of their origins and destinations relative to the cordon line defining the study area, as follows:

1. Internal trips - both origin and destination are within the cordon line.
2. External trips - either origin or destination is within the cordon line.
3. Through trips - neither origin nor destination is within the cordon line.

Internal trips are generally classified by purpose into several groups. A single purpose grouping for either external or through trips is often adequate. Thus a typical classification will be:

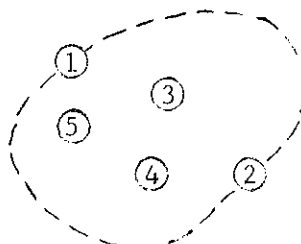


Example

Exterior Stations ①, ②

Zones ③, ④, ⑤

Cordon line



Trip Table:

| | | | | |
|----------|----------|----------|----------|----------|
| v_{11} | v_{12} | v_{13} | v_{14} | v_{15} |
| v_{21} | v_{22} | v_{23} | v_{24} | v_{25} |
| v_{31} | v_{32} | v_{33} | v_{34} | v_{35} |
| v_{41} | v_{42} | v_{43} | v_{44} | v_{45} |
| v_{51} | v_{52} | v_{53} | v_{54} | v_{55} |

Subtable at upper left — Through trips

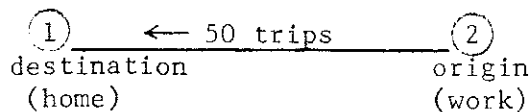
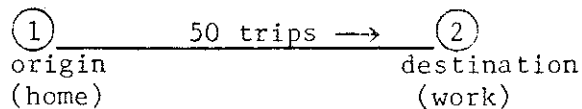
Subtable at lower right — Internal trips

Subtable at upper right > External trips

Subtable at lower left >

3.4 O-D TRIP TABLES AND P-A TRIP TABLES

For home-based trips, the home zone is always considered to be the zone of production, regardless of whether it is the origin or destination of the trip. Consider the following example. Every morning 50 trips leave home in zone 1 to go to work in zone 2, and then return home directly in the evening. Thus diagrammatically we have:

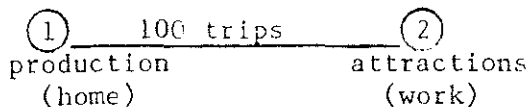


The trips are directional and the corresponding trip table

| | |
|----|----|
| 0 | 50 |
| 50 | 0 |

is called an O-D trip table.

Alternately, we may say that 100 trips are produced at zone 1 and no trip is produced at zone 2:



The trips are non-directional and the corresponding trip table

$$\begin{bmatrix} 0 & 100 \\ 0 & 0 \end{bmatrix}$$

is called a P-A trip table.

Thus, trip tables may be built for either directional, i.e. O-D trips or non-directional, i.e. P-A trips.

For non-home-based trips, the zone of production is at the origin and the zone of attraction is at the destination. Thus, the P-A trip table is same as the O-D trip table.

3.5 TRIP PROGRAMS

A. Trip Table Builder TPTRIP - The trip information obtained from O-D Survey is coded and punched on cards, called trip cards. The travel data reported on these cards usually include the following:

1. Zone of Residence
2. Zone of Origin
3. Zone of Destination
4. Purpose of Trip
5. Time of Day (AM, PM, off)
6. Mode of Travel
7. Land Use

TPTRIP reads a sorted BCL data set, and writes from one to nine merged trip tables plus an optional table which is the sum of all other tables written. The program will accommodate 2500 zones. Criteria for including trips in each of the trip tables can be specified on user control cards, e.g. value ranges for origin zone, destination zone, etc., to filter the input data to user specifications. The program has the ability to build either origin-destination tables or production-attraction tables for home-based purpose trips. P-A trip tables are built as complementary pairs of partial trip tables and must be followed by TPMNIP to add the two partial tables into a single trip table. The input file must be in sort by origin zone.

- B. Print Trip Tables/Skim Trees Program TPPRIN - TPPRIN read binary trip table or skim tree tapes which may consist of up to 2500 zones and up to 20 tables. The program either prints the cell by cell contents of the input file or interchange values (i.e. trips or costs) from selected zones to all zones. A summary of interchange values over all origins and selected origins is also produced. The program will produce multiple reports in a single run if desired, and if the input tape consists of more than one table.

- C. Trip End Summary TPTESM - TPTESM reads binary trip tape, which may contain up to 20 tables and produces a printed summary of trip ends showing the INS, OUTS, INTRAS, PRODUCTIONS, ATTRACTIONS, TOTAL TRIP ENDS, etc., from selected tables and zones. The program will punch P/A deck for TPGM.

- D. Other Trip Programs - Many other programs are available in the Burroughs Transportation Planning System to perform operations on trip tables, e.g.: Compression, expansion, comparison, splitting, manipulating, modifying, and formatting. They are used in various procedures in the transportation planning process.

CHAPTER 4

TRIP GENERATION AND DISTRIBUTION

4.1 GENERAL

The function of Trip Generation is to predict the future number of trips for each trip purpose produced at or attracted to each zone in a study area. Trip Distribution then distributes the trips produced (or attracted) at each zone to various destinations (or origins). The final output is a complete future origin-destination trip table, to be used for future trip assignment.

The models discussed in the following sections for the two procedures are:

1. Regression equations for trip generation.
2. Gravity model for trip distribution.
3. Fratar model for trip distribution.

4.2 TRIP GENERATION

The model generally used for trip generation is a set of linear regression equations, each of the form:

$$Y = C_0 + C_1 X_1 + C_2 X_2 + \dots + C_k X_k$$

which relates the independent variables X_1, X_2, \dots, X_{16} representing land use pattern and socio-economic factors such as population, employment, income, car ownership, etc., to the independent variable Y , representing the zonal production or attraction for a particular purpose. The basic assumption is of course that the land use and socio-economic factors are linearly related to zonal productions and attractions.

To calibrate the model, i.e. to determine the linear regression coefficients C_0, C_1, \dots, C_k , multiple linear regression technique is used for the following data:

1. Present zonal productions and attractions (Y)
- from Travel Survey Processing
2. Present land use and socio-economic factors (X 's)
- from Planning Factors Survey

Multiple Linear Regression is not included in the Burroughs Transportation Planning System. It may be either supplied by the user or obtained from Burroughs as an independent program.

After the regression coefficients are determined, future zonal productions and attractions for different purposes may be obtained by using the Production/Attraction Calculator Program TPCPA. The inputs to the program are the regression coefficients and the predicted future land use and socio-economic factors. The output is a set of punched P/A cards giving the future productions and attractions of each zone for each purpose.

4.3 GRAVITY TRIP DISTRIBUTION MODEL

The most widely used technique for trip distribution is the Gravity model. The basic concept of this model is that in a n-zoned study area the number of trips V_{ij} from zone i to zone j is directly proportional to P_i or the number of trips produced at zone i and A_j or the number of trips attracted to zone j, and inversely proportional to the travel impedance from zone i to zone j. Travel impedance was originally assumed to be travel time, t_{ij} , from zone i to zone j raised to some power b. Thus:

$$V_{ij} = \frac{k_i P_i A_j}{t_{ij}^b} \dots\dots\dots (1)$$

where

$$k_i = \frac{1}{\sum_{j=1}^n \frac{A_j}{t_{ij}^b}} \dots\dots\dots (2)$$

so that

$$\sum_{j=1}^n V_{ij} = P_i \dots\dots\dots (3)$$

Let

$$F(t_{ij}) = \frac{1}{t_{ij}^b} \dots\dots\dots (4)$$

then

$$V_{ij} = \frac{P_i A_j F(t_{ij})}{\sum_{j=1}^n A_j F(t_{ij})} \dots\dots\dots (5)$$

$F(t_{ij})$ is called travel time function or friction function. Equation (4) shows it to be an exponential function of travel time. This, in actual application, is found to be inadequate. Consequently, it is necessary to determine the function $f(t_{ij})$ for each trip purpose by trial and error so that the Gravity model will fit a particular situation. The resulting function for each trip purpose is a set of values called travel time factors, or friction factors, for one minute increments of travel time. This determination is the basic part of the calibration process.

4.4 CALIBRATING THE GRAVITY MODEL

The calibration of the Gravity model generally follows the following step-by-step process: (See Gravity Model Calibration Flow Chart.)

1. Balancing zonal trip attractions
 2. Determining friction factors
 3. Adjustment of socio-economic factors
 4. Adjustment for topographical barriers
- A. Balancing Zonal Attractions - Equation (2) of Section 4.2 shows that the Gravity model always guarantees that for any zone, the calculated production $\sum_{j=1}^n V_{ij}$ is equal to the given production P_i . However, it is

obvious that the calculated attraction $\sum_i V_{ij}$ is in general not equal to the given attraction A_j . The Gravity Model Program TPGM, therefore, programmatically balances the attractions, by adjusting the attractions of each zone according to the amount of under-attraction or over-attraction resulting from the previous estimate.

The input to TPGM are P-A cards, skim tree tables, and F factors. The program calculates for each purpose a trip table. It then compares the calculated attractions with the given attractions, writes the comparison of attractions and calculates a new trip table by adjusting the attractions. After the process is iterated for a user-specified number of times to force $\sum_j V_{ij}$ to equal to A_j , it will write the following final output:

1. Final attractions and comparison
2. Trip length distribution
3. Trip table

The trip table output is on tape and is optional.

- B. Determining Friction Factors - The best set of friction factors associated with each trip purpose is determined by a process of trial and error by comparing the trip length distribution from the Gravity model to that from the survey data.

For the first run of TPGM, F factors may be chosen to be all 1's or the values previously determined for a similar study area. As described in the above section, TPGM will, after balancing attractions, output a trip length distribution. This is compared with the trip length distribution from the O-D Survey data, which can be obtained by inputting a skim tree file and a P-A trip table from surveys to the Trip Length Distribution Program TPTLD. The adjusted friction factors are then calculated as follows:

$$F_{adj} = F_{used} \times \frac{\% \text{ of trips from O-D Survey}}{\% \text{ of estimated trips from GM}} \quad (6)$$

This calculation results in an adjusted friction factor for each one minute increment of travel time. The adjusted friction factors are used as input in place of the previous ones and the program TPGM is rerun. The process is repeated until the difference between the average trip length for both sets of data (O-D and GM) are within say $\pm 5\%$. Generally this trial and error procedure for determining friction factors should take no more than three runs, assuming reasonable first approximation of friction factors.

- C. Zone to Zone Adjustment Factors - Sometimes it may be necessary to introduce another set of factors into the Gravity model to account for special socio-economic conditions. These factors are called adjustment or K factors. The Gravity model of Eq. (5) becomes:

$$V_{ij} = \frac{P_i A_i K_{ij} F(t_{ij})}{\sum_{j=1}^n A_j K_{ij} F(t_{ij})} \dots\dots\dots (7)$$

The procedure used to develop K factors is to combine zones which are large generators of traffic and compare the trip interchanges obtained from the GM and those from the O-D Survey. The adjustment factor required for any zonal movements are calculated as follows:

$$K_{ij} = R_{ij} \frac{1 - Q_i}{1 - Q_i R_{ij}} \quad (8)$$

where

- K_{ij} = Adjustment factor to be applied to movements between zone i and zone j.
- R_{ij} = Ratio of O-D Survey result to the GM result for the O-D trip from zone i to zone j.
- Q_i = Ratio of O-D trips from zone i to zone j to total O-D trips leaving zone i.

For example, suppose according to O-D Survey, zone 100 produces 5000 total work trips, of which 1000 goes to CBD. The Gravity model, however, estimates that only 500 of these trips goes to CBD. Then the adjustment factor to be applied to correct the Gravity model results for this condition will be:

$$K_{100 \rightarrow \text{CBD}} = \left(\frac{1000}{500} \right) \frac{1 - \left(\frac{1000}{5000} \right)}{1 - \left(\frac{1000}{5000} \right) \frac{1000}{500}} = 2.67$$

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 O-D Survey distribution to verify its correctness.

- D. Topographical Barriers - Topographical barriers, such as mountains, rivers, etc., may cause some bias in the Gravity model trip interchange estimates. This effect can be accounted for by inserting time penalties on portions of the transportation network. The trip interchanges developed from the Travel Pattern Survey are compared directly with those of the final Gravity model calibration. If corrections in travel time are shown to be necessary, then the network description must be updated and trees must be rebuilt. The trip interchanges for each purpose are then rerun through the Trip Length Distribution Program TPTLD. The revised TLD are then used as a basis against which any subsequent Gravity model estimates are compared.

4.5 TESTING THE GRAVITY MODEL

Test is generally applied after the Gravity model is calibrated. The procedure is to compare the final Gravity model trip interchanges with the trip interchanges derived from the O-D Survey for each of the major trip purposes category. The Trip Table Comparison Program TPCOMP may be used to compare two trip tables on an I-J pair basis, a zonal trip end basis, and on a district trip end basis (both P and A). It also produces statistical analysis on all three levels. There is a limit of ten comparisons in a single run. The district trip end comparison is an optional output. A set of Zone-District Equivalence Cards must be input to compress the zonal trip ends to district trip ends.

Sometimes it may be desirable to compare trip tables on district level I-J basis. In that case, before TPCOMP is used, both the GM trip tables and the O-D trip tables must first be compressed from zonal level to district level by using Zone to District Compression Program TPSQEZ. This program reads a zone to zone trip table and a set of Zone-District Equivalence cards and outputs a district to district trip table. The program can compress up to twelve trip tables at one time.

4.6 CONVERTING GRAVITY MODEL RESULTS TO DIRECTIONAL MOVEMENTS

The Gravity model yields non-directional movements, i.e. production-attraction (P-A) trip tables. For future trip assignment, it is desirable to convert these movements to directional movements, i.e. origin-destination (O-D) trip tables. This applies only to home-based trips, since for non-home-based trips the P-A trip tables are same as the O-D trip tables (see Section 3.4).

The conversion of P-A trip tables to O-D trip tables can be accomplished by using the Trip Table Splitter Program TPFLOP. In current practices, a 50-50 split is usually assumed for all home-based trips, i.e. 50% of the trips are with origin at home-zone and the other 50% are with destination at home-zone.

4.7 FRATAR TRIP DISTRIBUTION MODEL

The Fratar distribution model is an extrapolation technique which obtains future O-D movements by applying growth factors to the existing pattern. It assumes that in a n-zoned study area, the future number of trips from zone i to zone j is directly proportional to the growth of production at zone i and the growth of attraction at zone j.

Let V_{ij} = present number of trips from zone i to zone j from survey.

$$P_i = \sum_{j=1}^n V_{ij} = \text{present production at zone } i.$$

$$A_j = \sum_{i=1}^n V_{ij} = \text{present attraction at zone } j.$$

$$\bar{P}_i = \text{predicted future production at zone } i.$$

$$\bar{A}_j = \text{predicted future attraction at zone } j.$$

$$F_i = \frac{\bar{P}_i}{P_i} = \text{growth factor of production at zone } i.$$

$$G_j = \frac{\bar{A}_j}{A_j} = \text{growth factor of attraction at zone } j.$$

Then the future number of trips from zone i to zone j is:

$$\bar{V}_{ij} = k_i V_{ij} F_i G_j \dots \dots \dots (9)$$

where

$$k_i = \frac{\sum_{k=1}^n V_{ik}}{\sum_{k=1}^n G_k V_{ik}} \dots \dots \dots (10)$$

so that

$$\sum_{j=1}^n \bar{V}_{ij} = \bar{P}_i \dots\dots\dots (11)$$

The obvious advantage of the Fratar model is its simplicity of use. Unlike the Gravity model, it does not require any calibration. The disadvantage is in its underlying assumption that trip interchanges are independent of spacial separation, measured in travel time or distance, i.e. travel impedance does not change over time. The model therefore cannot respond to any unbalanced improvement of transportation system.

4.8 THE GROWTH FACTOR TRIP DISTRIBUTION PROGRAM TPFROT

The program TPFROT reads a trip table and either production and attraction trip ends or trip end growth factors and does an iterative trip distribution by using the Fratar formula. It outputs a new trip table.

1. Initial steps:

- a. Read and write either
 - . future zonal productions and attractions, \bar{P} 's & \bar{A} 's, or
 - . zonal growth factors, F's and G's.
- b. Read present trip table (V_{ij}) from tape.
- c. Compute present zonal productions and attractions, P's and A's.
- d. If \bar{P} 's and \bar{A} 's are given, compute F's and G's.
If F's and G's are given, compute \bar{P} 's and \bar{A} 's.
- e. Optionally, either
 - . normalize future production to future attraction, i.e.:
all future attractions, \bar{A} 's, are unchanged, while all future productions \bar{P} 's are replaced by \bar{P}^* 's where $\bar{P}_i^* = \bar{P}_i \left(\frac{\sum_i A_i}{\sum_i P_i} \right)$
so that $\sum_i \bar{P}_i^* = \sum_i \bar{A}_i$, or
 - . normalize future attraction to future production, analogous to above.

2. Balancing Zonal Attractions - Equation (11) of Section 4.6 shows that the Fratar model always guarantees that for any zone the calculated production $\sum_{j=1}^n \bar{V}_{ij}$ is equal to the given production \bar{P}_i . However, it

is obvious that the calculated attraction $\sum_{i=1}^n \bar{V}_{ij}$ is in general not

equal to the given (i.e. desired) attraction \bar{A}_j . The program, therefore, follows an iterative procedure to balance the attractions:

- a. Calculate by the Fratar formula future trip table (\bar{V}_{ij}) based on
 - . present trip table (V_{ij}) and
 - . growth factors F_i, G_j for productions and attractions
- b. Compare calculated future attractions $\sum_j \bar{V}_{ij}$ with given future attractions \bar{A}_j and adjust $\sum_j \bar{V}_{ij}$
- c. Recalculate future trip table (\bar{V}_{ij}) based on
 - . previously calculated trip table and
 - . adjusted growth factors

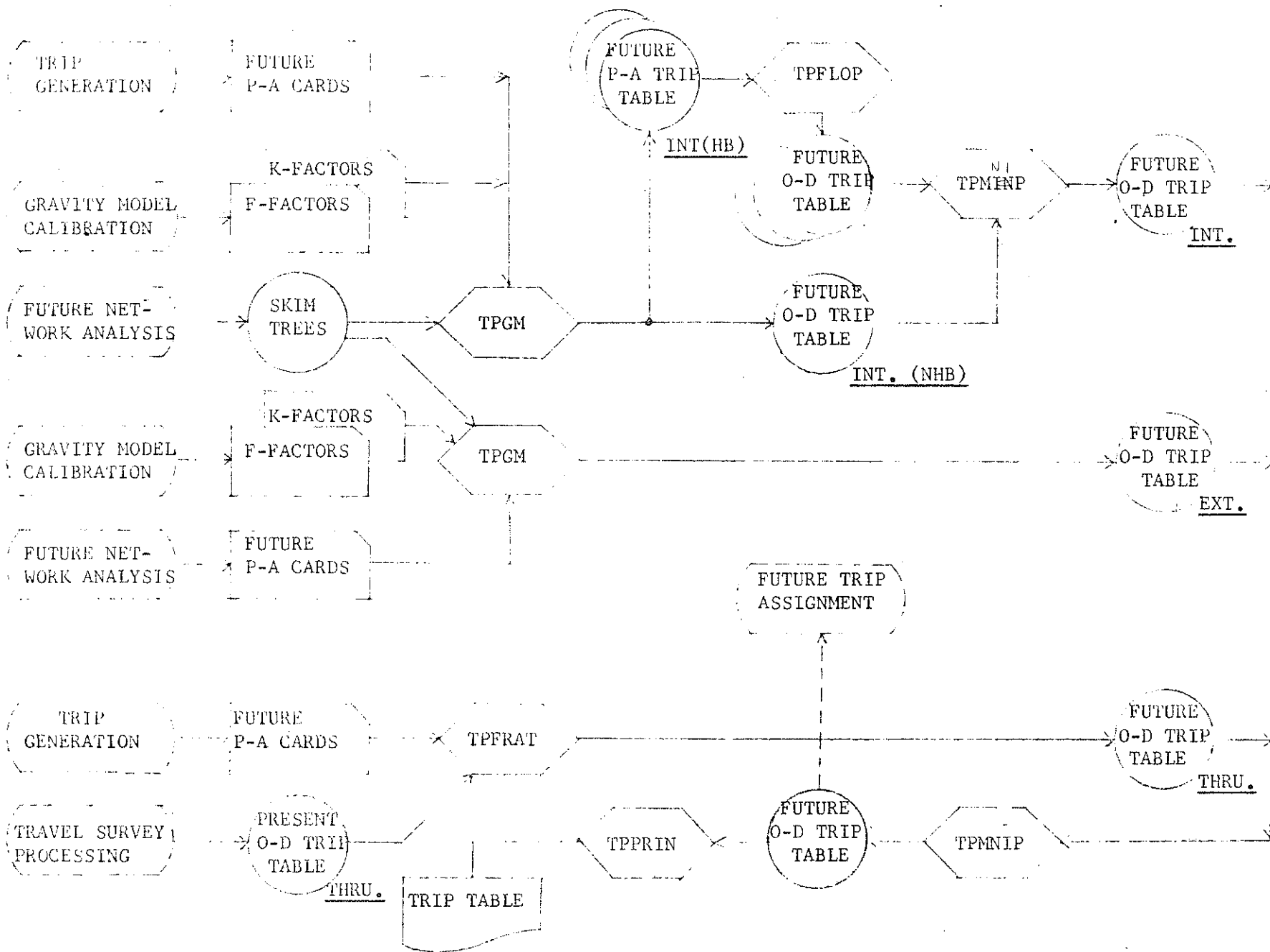
The program will iterate for a user-specified number of times.

3. Output - The program outputs a comparison of attractions for each iteration, and at the completion of iterations, the following:
 - a. Future trip table (on tape) and
 - b. Final comparison of attractions. It shows
 - . Comparison of present productions P's and future (or normalized future) productions \bar{P} 's.
 - . Comparison of present attractions, A's and future (or normalized future) attractions, \bar{A} 's.
 - . Comparison of final computed future attractions $\sum_i \bar{V}_{ij}$ and future (or normalized future) attractions, \bar{A}_i .

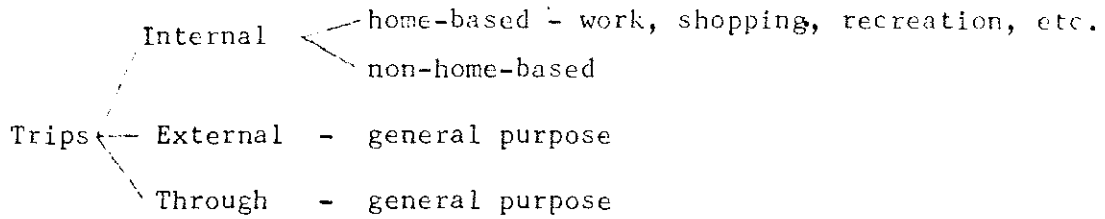
4.9 FUTURE TRIP DISTRIBUTION

Both trip distribution models discussed in the preceding sections can be used to forecast future travel patterns. Usually the Gravity model is applied only to urban, i.e. internal and external trips, while the Fratar model is applied only to through trips. The results are then combined to yield a total future O-D trip table to be used as input to the trip assignment procedure. (See Future Trip Distribution Flow Chart.)

FUTURE TRIP DISTRIBUTION



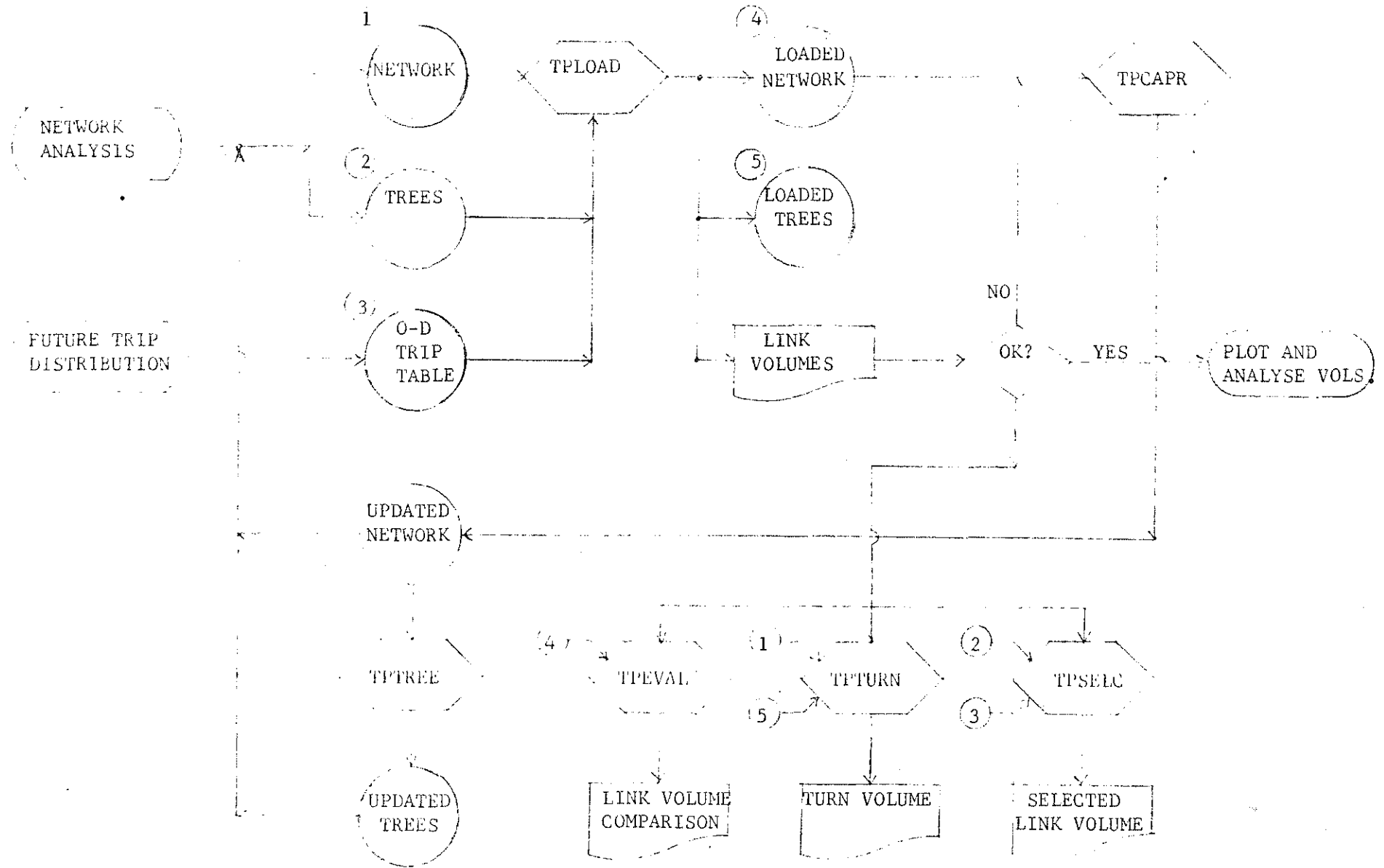
Suppose, as in Section 3.3, we classify interzonal trips as follows:



For internal home-based trips and external trips, the future P-A trip tables obtained from Gravity model must be converted to O-D trip tables by program TPFLOP (see Section 4.6). For through trips, the future trip table from Fratar model usually is an O-D trip table. Trip tables of various purposes may be added by using the Trip Table/Skim Tree Manipulator Program TPMNIP. Partial trip tables for internal, external and through trips are then combined to yield a total future O-D trip table. This trip table is the input for the assignment procedure.

d
te
-

TRIP ASSIGNMENT
(FUTURE)*



*PRESENT TRIP ASSIGNMENT
SIMILAR

The assignment can be made to include only interzonal volumes between selected origin and destination zone ranges, or for trips within a certain range of time cost or distance. The user may also elect to print only a part of the loaded link report.

5.4 CAPACITY RESTRAINT ASSIGNMENT

As mentioned in Section 5.2, link cost is dependent on link flow. When traffic flow increases, the route initially determined by TPTREE to be the cheapest may be less cheap compared to some alternative routes. The Capacity-Restraint assignment model is thus a refinement of the All-or-Nothing model described above. It considers the effort of link flow on link cost. It is an iterative procedure, alternating All-or-Nothing assignment with recalculation of link costs from an assumed link cost-link flow relationship. The recalculation is performed by the Capacity Restraint Program TPCAPR described in the next section. The iterative procedure is as follows:

1. Input network description, tree description and trip table to the All-or-Nothing Assignment Program TPLOAD to obtain a loaded network.
2. Input the loaded network to Capacity Restraint Program TPCAPR to obtain a new network description with link times (or speeds) adjusted according to the assumed link cost-link flow relationships.
3. Input the new network description with adjusted link costs to TPTREE to obtain a new tree description.
4. Input the new network description, new tree description and the trip table to TPLOAD to obtain a new loaded network.
5. Continue the process until the link times (or speeds) do not differ appreciably for two successive iterations.

5.5 CAPACITY RESTRAINT PROGRAM TPCAPR

The Capacity Restraint Program TPCAPR reads a loaded network tape and adjusts the time (or speed) required to travel a link, directionally, from the capacity restraint curve applicable to the link, using the loaded volume and the capacity of the link. It outputs an updated network description with adjusted link times (or speeds).

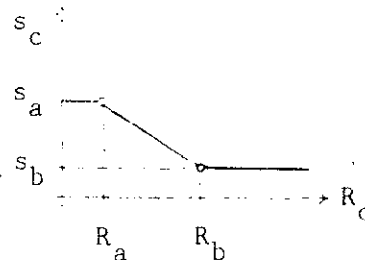
The capacity restraint curves used in the program are as follows:

Let V = assigned traffic flow on the link

C = practical capacity of the link

s_c = restrained speed

$R_c = \frac{V}{C}$ = link flow-link capacity ratio



s_a = maximum speed of the link

R_a = The ratio R_c associated with maximum speed

s_b = minimum speed of the link

R_b = The ratio R_c associated with minimum speed

Then the restrained speed is:

$$s_c = s_a \quad \text{if } R_c \leq R_a$$

$$s_c = s_b \quad \text{if } R_b \leq R_c$$

$$s_c = s_a \frac{(R_b - R_c) + s_b (R_c - R_a)}{R_b - R_a} \quad \text{if } R_a < R_c < R_b$$

A maximum of 15 such curves may be accommodated by TPCAPR. A "Capacity Indicator" (see Link Card format) is given for each link to associate the applicable capacity restraint curve to each link.

5.6 PROGRAMS TPTURN, TPSELC AND TPEVAL

After trips are assigned to the network, it is often desirable to find the turn volumes through certain selected nodes. The Turn Volume Accumulation Program TPTURN reads the loaded trees output by program TPLOAD. It accumulates and reports the turn volumes through selected nodes. Additionally, volumes on all links connected to the selected nodes are reported.

To study the traffic loading condition (i.e., the assigned traffic volume versus the capacity) of certain important links, the Selected Link Program TPSELC may be used. The program reads a trip file and a tree file and produces a report listing all the trips by origin and destination using a selected link. Also from a given O/D trip table, TPSELC will generate a new O/D trip table which includes only those trips using any one link from a group of selected links, or using all the links of that selected group.

To compare assigned link volumes with link capacities (or counts), the Network Evaluation Program TPEVAL may be used. It reads a binary network file and produces:

1. Link summaries by type and jurisdiction and,
2. Link volume and link comparison report.

All links may be included or selection may be made by various fields.