

A STATE OF THE ART REPORT ON STATEWIDE
TRAFFIC ASSIGNMENT MODELS

by

JAMES HENRY JATKO

B.S., Rensselaer Polytechnic Institute, 1972

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Approved by:


Major Professor

LD
2668
R4
1976
J37
C.2
Document

205

INTERIM REPORT

SECTION I

Project No. 2625

A STATE OF THE ART REPORT ON STATEWIDE
TRAFFIC ASSIGNMENT MODELS

by

James H. Jatko

Graduate Research Assistant

Kansas State University

Manhattan, Kansas 66502

In Cooperation With

Planning and Development Division, Kansas
Department of Transportation

and

U.S. Department of Transportation
Federal Highway Administration

April 1976

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of this University, the State Department of Transportation or the Federal Highway Administration.

ILLEGIBLE DOCUMENT

**THE FOLLOWING
DOCUMENT(S) IS OF
POOR LEGIBILITY IN
THE ORIGINAL**

**THIS IS THE BEST
COPY AVAILABLE**

**THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH DIAGRAMS
THAT ARE CROOKED
COMPARED TO THE
REST OF THE
INFORMATION ON
THE PAGE.**

**THIS IS AS
RECEIVED FROM
CUSTOMER.**

ACKNOWLEDGEMENT

The writer expresses his appreciation to Dean Landman, Planning and Development Division, Kansas Department of Transportation and Professor Eugene R. Russell, Civil Engineering Department, Kansas State University for their advice and assistance in assembling the information provided in this report; to the Federal Highway Administration, U. S. Department of Transportation, and to all the State Highway Departments, consultant firms, and other transportation research agencies which provided valuable information on statewide and regional transportation studies.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT.	1
ACKNOWLEDGEMENT	11
LIST OF FIGURES	iv
SECTION	
I. INTRODUCTION.	1
Purpose and Sources of Information.	3
II. DEVELOPMENT OF AVAILABLE TECHNOLOGY	4
Transportation Need Studies	4
Origin-Destination Survey	5
Intercity Traffic Generation Models	13
Trip Distribution Models.	22
Growth Factors.	27
Zone and Network Development.	31
Computer Technology	41
III. SELECTED ABSTRACTS OF STATEWIDE TRANSPORTATION STUDIES.	49
California (1966)	50
Pennsylvania (1966-67).	53
Wisconsin (1968).	56
Oklahoma (1968)	60
Minnesota (1971).	63
Michigan (1972-1975).	68
Tennessee (1973).	70
Rhode Island (1975)	72
West Virginia (1975).	77
Nebraska (1975)	79
Wyoming (1975).	84
Kentucky (1976)	86
IV. SUMMARY AND CONCLUSIONS	92
LIST OF REFERENCES.	95

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
II-1	LOCATION OF MVID SCREENLINES AND INTERVIEW STATIONS IN WISCONSIN.	7
II-2	INSERT FROM QUESTIONNAIRE MAILED TO OWNERS OF VEHICLES OBSERVED PASSING VIDEO CAMERA STATIONS IN THE RHODE ISLAND STATEWIDE STUDY.	11
II-3	FIRST PAGE OF QUESTIONNAIRE USED IN WYOMING'S YEAR- LONG ORIGIN-DESTINATION STUDY	14
II-4	ORIGIN AND DESTINATION TRIPS AS A FUNCTION OF POPULATION AND DISTANCE	19
II-5	BASE-YEAR PERCENTAGE PARTICIPATION OF FOUR MODES OF TRANSPORTATION FOR TWENTY SELECTED CITY PAIRS WITHIN THE CALIFORNIA CORRIDOR	30
II-6	HIGHWAY NETWORK TYPICAL OF ONES USED IN STATEWIDE TRAFFIC ANALYSIS.	32
II-7	TRAFFIC ANALYSIS ZONES BASED ON COUNTY AND TOWNSHIP BOUNDARIES IN WYOMING	35
II-8	GRID SYSTEM USED BY CONNECTICUT FOR ASSIGNMENT OF TRAFFIC	37
II-9a	LOCATION OF "CELL" BOUNDARIES IN WISCONSIN CONFORMING TO MVID LINES	39
II-9b	LOCATION OF TRAFFIC ANALYSIS ZONES WITHIN CELLS FOR THE STATE OF WISCONSIN.	40
II-10	PLOT OF TRAFFIC VOLUME ASSIGNED TO HIGHWAY LINKS USING A BANDWIDTH PLOTTING PROGRAM FOR THE KANSAS STATEWIDE TRANSPORTATION STUDY.	43
II-11	SPIDERWEB NETWORK PLOTTED FOR CHARLESTON, WEST VIRGINIA	45
II-12	POSSIBLE FORECAST YEAR SYSTEM FLOW CHART.	47
II-13	NETWORK LINK DATA CODING CHART.	48
III-1	AREAS SELECTED FOR OBTAINING ORIGIN-DESTINATION DATA FOR MINNESOTA'S STATEWIDE MODEL	64
III-2	PLOT OF TRIPS PER PERSON AGAINST TRIP LENGTH FOR GROUPS OF TOWNS IN MINNESOTA.	66

<u>Figure</u>		<u>Page</u>
III-3a	QUESTIONNAIRE DISTRIBUTED TO INBOUND AIRLINE PASSENGERS IN RHODE ISLAND'S SURVEY.	74
III-3b	QUESTIONNAIRE DISTRIBUTED TO OUTBOUND AIRLINE PASSENGERS IN RHODE ISLAND'S SURVEY.	75
III-3c	QUESTIONNAIRE DISTRIBUTED TO MASS TRANSIT PASSENGERS IN RHODE ISLAND'S SURVEY	76
III-4	REGRESSION EQUATIONS FOR TRIPS DEVELOPED FOR THE WEST VIRGINIA STATEWIDE ASSIGNMENT MODEL	80
III-5	NEBRASKA'S TRAFFIC ANALYSIS ZONES SHOWING DIVISION BY POPULATION DENSITIES IN COUNTIES.	83
III-6a	FIRST PAGE OF MAILED QUESTIONNAIRE USED IN KENTUCKY'S STATEWIDE STUDY.	89
III-6b	CONTINUATION OF MAILED QUESTIONNAIRE USED IN KENTUCKY'S STATEWIDE STUDY.	90
III-6c	SAMPLE OF COMPLETED "TRAVEL DATA" SECTION OF KENTUCKY'S MAILED QUESTIONNAIRE	91

INTRODUCTION

Over the past 45 years, this nation has observed rapid changes in all social and economic conditions from an increase in the amount of time its people can spend on recreation and leisure to a growth in family income. In the transportation industries these changes have been paralleled by greater automobile ownership and a drastic modification of the travel patterns throughout the country.

The national interest in this new travel trend was evidenced by the initiation of the 41,000 mile National Interstate and Defense Highway System over twenty years ago. The improvements in travel time and safety resulting from this system have in turn caused a rise in intercity travel which cannot be wholly explained by population growth. With the Interstate Highway System nearing completion, the Federal Highways Administration and the U.S. Department of Transportation are looking closely at the transportation needs of the country since a transportation problem still exists for areas in and around large urban centers all across the nation. This new national concern for intercity travel along congested corridors is shown in the development of high speed intercity land travel such as in the Washington, D.C. to Boston corridor.

During the past several years, individual states, too, have shown a growing concern over how well the primary state trunk line systems are meeting statewide transportation needs. These studies, conducted by state highway commissions and departments of transportation and highways using many of the ideas developed over the past 25 years for trip generation, have taken on highly individualized and interesting appearance as former

metropolitan area transportation study techniques are applied on rural, regional, corridor, and statewide highway networks in conjunction with comprehensive statewide origin and destination studies.

The State of Kansas began work on statewide traffic analysis in the early 1960's. The results of initial work was published in 1962 entitled the "Jorgensen Report." Later work concerned with many of the social, economic, and geographic factors influencing the regional freeway system in south east Kansas was published in 1975 as the "South East Kansas Corridor Study, 1975." Another report related to statewide highway analysis is the "Kansas Rural Highway Sufficiency Report" which was first printed in the late 1960's and has since been updated every two years. At the present time, in Kansas as in many other states, efforts are being directed to develop and test transportation planning models to be used for synthetic production of statewide intercity trips for all modes of transportation available in the state.

The State of Kansas has undertaken a research project to test and evaluate available techniques in statewide planning. Its primary objective is to ultimately develop multi-modal models relating to existing and planned social, economic, geographical and environmental factors. This research project consists of five phases -- the literature review, the development and testing of travel generation and assignment models, the identification of data needs for a multi-modal commodity transport model, the determination of the optimum detail of the network, and the identification of future research needs. This section is the documentation of the first phase. Subsequent sections will contain the results of later phases.

Purpose and Sources of Information

The literature review has three major purposes. First, it provides needed background information in the field of statewide intercity travel to those involved with this research project. Secondly, it identifies from existing literature, those theories and hypotheses describing intercity travel which are most suited for this research. Thirdly, it provides current information concerning the development and outcome of similar studies which would aid in obtaining a better analytical process.

To accomplish these purposes, literature was obtained from many varied sources. Letter questionnaires were sent to national and state transportation agencies, universities, consultants and other research agencies in conjunction with an extensive library search for both published and unpublished literature on the subject.

The information obtained through the literature review is presented in this report in three basic areas which will be ordered in such a way that each succeeding topic will demonstrate how ideas preceding it are applied. First will be a current look at transportation need studies, followed by a listing of both old and new traffic generation and assignment models being used in transportation planning, and finally, an extensive look into general trends being followed by individual states who are presently using or developing statewide transportation models. It was found that some reports and publications relevant to this statewide planning were not available, including reports on work currently under way in many state agencies, as of 1976. However, the information presented here is believed to be as current as possible and should be of particular value to those agencies who are contemplating the development of a statewide transportation modeling system.

SECTION II

DEVELOPMENT OF AVAILABLE TECHNOLOGY

Transportation Need Studies

In order to formulate a mathematical model which will describe intercity travel and be able to synthesize travel patterns for the future, careful studies must be conducted over the routes concerned. Perhaps the most basic of these studies is the volume count; it is, however, useful only in determining how much traffic is using a particular route and hence only in checking the reliability of a given model or combination of models over a given route or corridor. Volume data alone should not be used to calibrate a model which is synthesizing trips for the future; some knowledge has to be gained about the travel patterns and trends which may differ drastically between regions and even specific cities. It is only reasonable today to assume that the travel patterns 10 miles away from a rural community of 5,000 populations will be very much different than they are 10 miles outside an urban center of 200,000 population. Questions have to be answered regarding the traffic, such as: where are these trips going, why are they going there, and how often do they go there as opposed to someplace else.

The Origin and Destination Survey was developed in the 1930's to answer some of these questions concerning trips, and it is still widely used for transportation need and travel pattern studies. This section will describe many of the different techniques presently being used to conduct "O-D" Surveys and hopefully show their relative successes or failures when applied in different statewide studies.

Origin-Destination Surveys

The primary reason the Origin-Destination Surveys were developed was to assist in describing travel patterns on urban streets and arterials. Because the nature of the traffic in urban areas tends to be very repetitive from day to day and week to week with most trips being either business, work, or shopping, it was relatively easy for transportation engineers and planners of the past to develop reliable ways to collect O-D data. The two most common forms of data collection developed were the home interview and roadside interview methods. The home interview survey, as it was developed, selected a sampling of households from different but nearly homogeneous areas. A form asking for information on all trips for that household for one day was usually left or filled out by the interviewer. Through this process the travel patterns for a particular neighborhood or urban sector could be identified. On the other hand, the roadside interviews were concerned with a sampling of the actual traffic along a certain street and collected information only on one specific trip while the trip was in progress. Because of its reliability and the increases in amount of information that could be collected by each interview, the home interview survey became the most widely used in urban and metropolitan origin-destination studies. Conversely, because of the low densities of households in rural areas, the roadside interview initially became the most widely used survey method for collecting data on rural travel patterns.

Screenlines and cordon lines, too, were taken from the urban transportation analysis field and applied in locating interview stations on a statewide network. It was soon found that the problem of placing screenlines in rural areas was a difficult one. Screenlines, poorly placed,

would give the traffic engineers and planners data that could not be correlated with existing information. Many improvements in methods of locating screenlines and cordon lines on a statewide basis will be covered later in this section.

Perhaps the most widespread and comprehensive screenline origin and destination survey completed in the early years of intercity traffic analysis was the Mississippi Valley Origin and Destination Survey (MVOD) conducted in 1960 by eight adjoining states in the midwest. Wherever possible available urban area external O-D data were included. The MVOD screenlines were placed across the participating states roughly at each degree of latitude and longitude with variations occurring throughout the states with respect to civil and geographical boundaries. Figure II-1 shows the location on these screenlines in Wisconsin.

The following information is typical of the type collected from all vehicles interviewed crossing these screenlines:

1. Type of vehicle
2. Vehicle occupancy
3. Trip purpose
4. Trip origin and destination
5. Location where vehicle is owned and garaged
6. Time of interview

The roadside interview stations which Iowa used during the MVOD study were located wherever a major road crossed a screenline (1)*. Interviewing was conducted so that at least 80 percent of the traffic passing the station was recorded. Each station was operated on one week day for a minimum of 16 hours. For the remainder of the 24 hours when the station was not operating a volume and classification count was kept. Both directions of traffic were interviewed. The interviews were conducted

*Numbers in parentheses refer to the list of references at the end of the report.

MISSISSIPPI VALLEY ORIGIN-DESTINATION STUDY

Station Location and Numerical Designation
Summer Weekday, 1960

LEGEND

● = INTERVIEW LOCATION

894316 = INTERVIEW STATION NUMBER

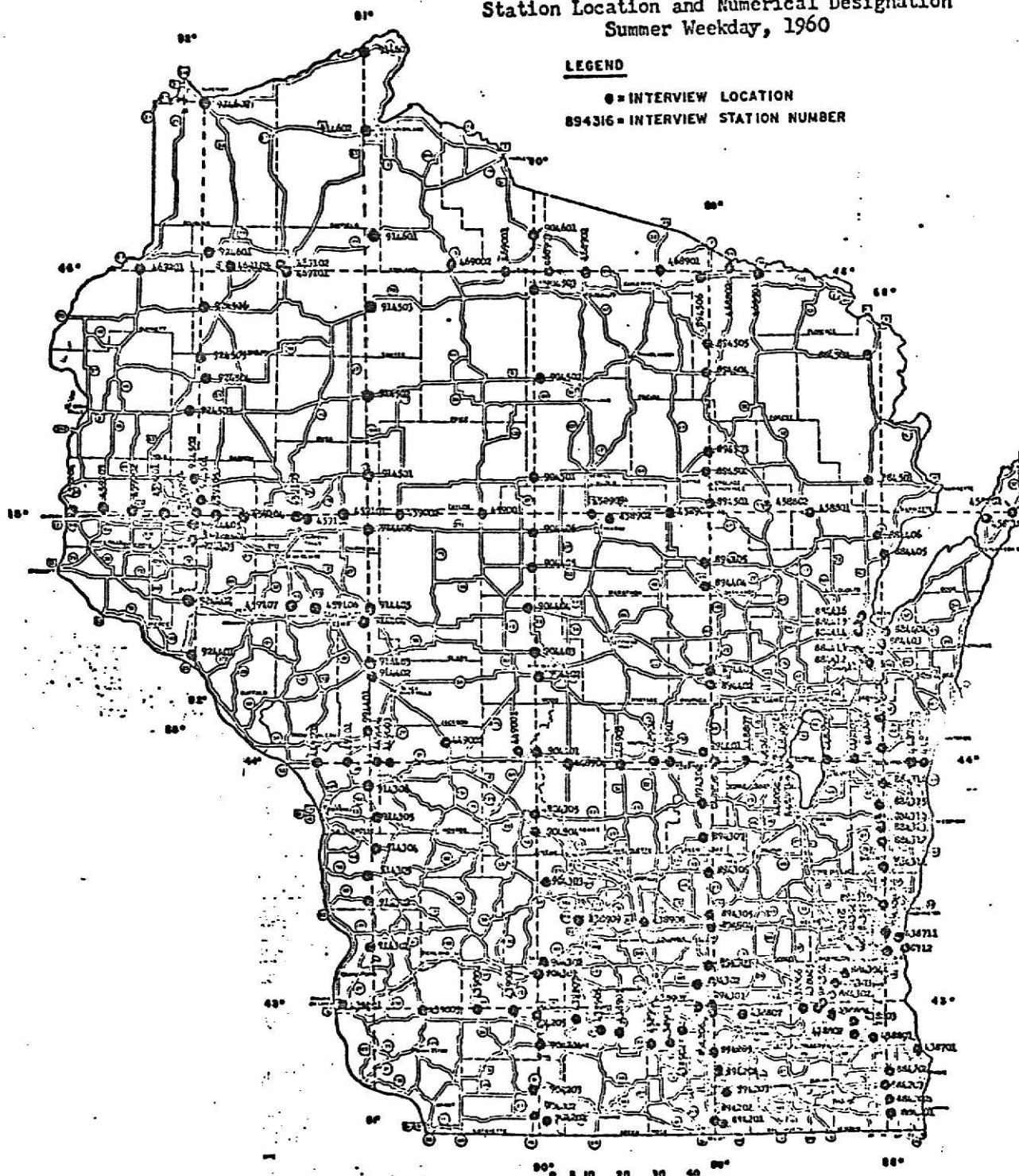


FIGURE II-1

LOCATION OF MVOD SCREENLINES AND
INTERVIEW STATIONS IN WISCONSIN

for one day at each location, but a volume counter covered the station for 5 days to provide data for expansion factors. In Wisconsin on highways of only moderate importance or low volume, interview stations operated only during the 8 hours of heaviest traffic during the day, 10 AM to 6 PM (2). On a few highways with high truck and heavy night traffic, interviewing was conducted 24 hours a day. Still another modification in collecting data for this early study was used by Illinois in their feasibility study for a Central Illinois Expressway (3). Stations along high volume routes were established and manned so that a minimum of 25 percent of the peak hour traffic could be interviewed. Stations there were operated anywhere from 8 to 20 hours per day depending on the importance of the route.

Available information indicates that several other states had conducted multiple screenline Origin-Destination studies early in the 1960's. These included Pennsylvania, Arizona, Rhode Island and Massachusetts. Indeed, by the mid 1960's at least 25 states were conducting motor vehicle use studies relating primarily to intercity travel (3).

The Home Interview Method of collecting trip data for intercity trips has taken on a completely new look compared to its predecessor used in urban transportation analysis. In collecting data for intercity travel, it becomes obvious that the sample population will reside in several different urban centers and may be spread over a considerable area. In addition, the data collected must represent many different occupations, businesses, recreational needs, socio-economic strata and other conditions depending on what the basis of the study is. These were some of the problems that initially discouraged the use of home interview type surveys in intercity studies. The most economical method found in collecting this kind of

information is a mail survey. The mailed home interview survey gained acceptance very slowly in statewide transportation analysis because of problems with lack of response and the often cumbersome and involved follow-up procedures found necessary. However, with the development of better sampling and administrative techniques and a better understanding of where this type of survey works best, its acceptance has grown.

Some of the major developments in the intercity mailed home interview survey will be presented here along with summaries of their evaluated effectiveness. In Section III of this report, it will be shown specifically how some of these surveys have been used in Statewide Transportation studies.

The Federal Highways Administration, in its recommendations for intercity trip analysis, has set minimum response criteria for mailed questionnaire surveys to provide a correction, if necessary, for any socio-economic bias in the responses.

The Kentucky Department of Transportation used a mailed survey to collect travel data from a sampling of household units on a single day (4). A one percent random sample of automobile registrations was used as a mailing list and a minimum number of households were selected at random in each county to be used to check the accuracy of the remaining data. The subsample of at least 30 units per county would be interviewed by telephone or in person while the remaining units were sent questionnaires through the mail. The administrative procedures also included TV, radio and newspaper releases which were put out on a continuing basis at the time of the mailing. A reminder letter was automatically sent to all sample households 3 days after the initial mailing and a second mailing of all of the initial package was sent to all those who had not responded within

12 days. The response rates ranged from 33 percent to 65 percent with an average of 45 percent.

Rhode Island offers another variation of the home interview survey (5). The survey was conducted as far as possible by telephone interview over a dwelling unit sample of 1420 units. Names and addresses were selected at random from electric company records and the State Department of Transportation found the telephone company most helpful in supplying current phone numbers for the survey. The use of reverse phone directories was tried and found unsatisfactory because the information was usually outdated in the available editions. A total of 393 units or about one third of the total sample was scheduled for field checks and it was planned to re-interview 20 percent of all telephone interviews to check for accuracy. In conjunction with the home-interview survey, surveys were made at hotels and motels, nursing homes and military installations by telephone, and on airlines, taxis, and mass transit by questionnaires which were distributed to the various passengers. A combination of the roadside interview and the mailed questionnaire was attempted with great success. A video camera and tape recorder system was set up at stations along major state arterials. The traffic was then channelized and directed past the camera so that the license numbers could be recorded. Using this sampling technique and obtaining portions of the motor vehicle registration files for the surrounding 3 states, it was possible to send out questionnaires to all the various types of vehicles which were photographed by the system (see Figure II-2). This camera system would operate for one day at each station, after which it was moved to another location.

QUESTIONNAIRE

(THIS INFORMATION WILL BE HELD IN STRICTEST CONFIDENCE)
THE VEHICLE IDENTIFIED AT THE BOTTOM OF THE NEXT PAGE WAS OBSERVED ON

LISTED BELOW ARE SEVERAL QUESTIONS. PLEASE ANSWER THESE QUESTIONS AND RETURN THIS FORM.

1. a. AT THE TIME YOU OBSERVED MY VEHICLE, I WAS COMING FROM

STREET NUMBER STREET NAME CITY OR TOWN STATE

b. I HAD LEFT THIS LOCATION AT

TIME

2. AT THAT TIME I WAS DRIVING TO

STREET NUMBER STREET NAME CITY OR TOWN STATE

FOR THE FOLLOWING REASON AND I
ARRIVED AT

TIME

3. WHICH OF THE FOLLOWING CHOICES BEST DESCRIBES THE ABOVE REASON FOR THAT TRIP:

☐ WORK TRIP

☐ SOCIAL
(VISIT FRIENDS, CHURCH, ETC.)

☐ SCHOOL
(STUDENTS ONLY)

☐ SHOPPING

☐ RECREATION
(ON VACATION)

☐ PERSONAL AFFAIRS

☐ GOING HOME

4. THERE WERE PEOPLE IN THE VEHICLE;
OF THESE WERE 5 YEARS OF AGE OR OLDER.

5. IS THE VEHICLE KEPT AT THE ADDRESS SHOWN BELOW?
IF "NO", AT WHAT ADDRESS IS THIS VEHICLE PRINCIPALLY KEPT?

☐ YES

☐ NO

STREET NUMBER STREET NAME CITY OR TOWN STATE

6. TO HELP US IDENTIFY SPECIAL TRAFFIC PATTERNS, PLEASE LIST ALL TRIPS YOU MADE ON THE TRAVEL DAY. THE TRAVEL DAY IS THE 24 HOUR PERIOD WHICH STARTS AT 4:00 A.M. ON THE DAY AND DATE SHOWN AT THE TOP OF THE PREVIOUS PAGE.

TRIP LOG	ADDRESS					TIME OF DAY		TOTAL NUMBER OF PEOPLE IN VEHICLE 5 MIN. BEFORE 5 MIN. AFTER	TOTAL NUMBER OF PEOPLE IN VEHICLE
	STREET NUMBER	STREET NAME	CITY OR TOWN	STATE		ARRIVED	DEPARTED		
START									
TRIP 1									
TRIP 2									
TRIP 3									
TRIP 4									

VEHICLE IDENTIFICATION

FIGURE II-2

INSERT FROM QUESTIONNAIRE MAILED
TO OWNERS OF VEHICLES OBSERVED
PASSING VIDEO CAMERA STATIONS IN
THE RHODE ISLAND STATEWIDE STUDY

The State of Wyoming approached the home interview problem in yet another way (6). It was thought to be desirable to be able to observe any seasonal changes if they existed in statewide travel patterns. For this reason it was decided to conduct all surveys over a full year.

For commercial travel, both light and heavy, questionnaires were mailed out in May, August, November and January. A 67 percent sample of heavy trucks and a 35 percent sample of lightweight commercial vehicles were taken from State Department of Revenue files for survey purposes. With no follow-up, the response rate of this survey averaged 35 percent; and it reflected data for approximately 31 percent of the total heavy commercial vehicle trips and 8.75 percent of the total lightweight vehicles trips for the surveyed year.

Noncommercial travel by Wyoming residents was obtained by distributing questionnaires at Drivers License Examination Stations. Since most of the counties had a centralized examining station, this method was chosen for its convenience during a year when the maximum number of drivers licenses would be up for renewal. For counties without centralized stations the questionnaires were mailed to a sample of the households listed in the automobile registration files. Wyoming noted the age bias in data gained from using automobile registration so it was necessary to correct for this bias using data collected from the other counties. The questionnaires distributed at the examining stations were distributed to all persons applying for or renewing their drivers license and the information requested was a log of all trips for the previous seven days. Using no follow-up, the response rate was surprisingly good with a range from 6 percent to 33 percent and average of 28 percent of the handed out form

and a range from 17 percent to 26 percent and average of 20 percent of the mailed form. Figure II-3 provides a sample of the first page from Wyoming's questionnaire.

Waltz and Grecco (7), reported on the results of a detailed evaluation and comparison of the combined application of mail and non-mail follow-up procedures for reducing non response in Home Interview Surveys. They concluded that a mailed home-interview type survey is, "not likely to achieve much more than 50 percent response unless followed up by some form of non-mail interview." In addition the combined successive use of telephone and simplified personal follow-up to a mailed survey is likely to be comparable to an interview follow-up on the basis of cost versus information obtained.

Intercity Traffic Generation Models

Nearly 100 years ago, in the early 1880's, H. C. Carey was credited for the statement that men are attracted by the law of gravitation. This classic statement has, ever since, guided engineers and researchers in developing hypotheses describing intercity travel. E. G. Ravenstein, in 1885 defined the migration of individuals to a city as (10):

$${}_iM_j = \frac{f(P_i)}{D_{ij}}$$

where ${}_iM_j$ = migration from source j to center i

$f(P_i)$ = some function of the population of center i

D_{ij} = distance between the source j and the center i.

All of the synthetic trip generation models dating from this early one in 1885 to the present have two common factors considered very important in travel studies:

The Wyoming State Highway Department
and
The University of Wyoming

WYOMING TRANSPORTATION DEMAND SURVEY

1. What city or town do you live in?

Or, if you do not live in a city or town, which of the following best describes your place of residence?

____ Farm or ranch
____ Rural, not a farm or ranch

2. What is your age? _____

3. Please check whether you are _____

____ Male or ____ Female

4. How many persons, including yourself, are currently living in your household? _____

5. How many vehicles are owned or leased by household members? _____

6. How many licensed drivers are there in your household? _____

Before attempting to answer question 7, please read the instructions.

Instructions for answering question 7

This question requests specific information about motor-vehicle trips that you have taken during the last seven days, either as a driver or as a passenger. Do not record trips taken within the limits of your town. Record all out-of-town trips. If you do not live in a town, then record those trips whose one-way length were in excess of five (5) miles.

Items A thru E:
These items are self-explanatory.

Items F, G, H:
Give the names of the towns involved, or if not a town, then give the direction and distance from the nearest town or landmark. (A landmark could be a highway junction, recreational area, etc.)

Item I:
If possible, check one trip purpose which you consider to be the primary purpose of the trip. If you cannot classify the trip under a single purpose, you may check more than one.

Items J and K:
These items are self-explanatory.

Item L:
If you periodically make trips between the same origin and destination, you may record the trip only once, and indicate in item L whether the trips are made daily, weekly, etc.

EXAMPLE: The Smith family takes a Sunday drive from Cheyenne to Laramie, where they visit friends, and then proceed to the Snowy Range for a picnic. They return to Cheyenne the same day.

The response shown in the first column of question 7 is the correct way of recording this information. If you need more space to complete question 7, please use the reverse side.

7. A. Day of week that the trip started		EXAMPLE	TRIP 1	TRIP 2	TRIP 3
B. Day of week that the trip ended		Sunday			
C. WERE YOU A driver? passenger both driver and passenger		Sunday			
D. TYPE OF VEHICLE		X			
passenger car					
pickup or panel truck, not a pickup or panel other (specify)					
E. TYPE OF LICENSE PLATES		X			
Wyoming plates					
Wyoming ESC					
Out-of-state					
F. FROM: point of origin		Cheyenne			
G. TO: point(s) of destination		Laramie Snowy Range			
H. RETURN TO: end of trip		Cheyenne			
I. PRIMARY PURPOSE OF TRIP					
school or work trip					
personal business, visit friends or relatives		X			
recreation, vacation, touring, shopping		X			
medical or dental visit					
haul merchandise					
other (specify)					
J. Number of persons in vehicle at origin of trip		4			
K. Number of persons in vehicle at end of trip		4			
L. Frequency of trips					

FIGURE II-3

FIRST PAGE OF QUESTIONNAIRE USED IN
WYOMING'S YEAR-LONG ORIGIN-DESTINATION STUDY

1. There is defined a force or power of interaction between zones of localities which is measured in trip ends produced or attracted by each zone.
2. Trip interchange is a function of the producing and attracting powers of each (usually a population or socio-economic factor) and the spatial separation between them.

Spatial separation may be measured in travel time, distance, sufficiency of route, or cost over a specified transportation system. An important consideration in modeling trips over various forms of transportation serving separate groups with different social or economic interests is the selection of the proper spatial separation between groups to match the existing travel characteristics. For instance, in an area of wide-spread cattle ranching, a rancher may choose to go to a more distant stock yard to buy or sell his cattle for a better price. For him there is a careful balance between the cost and the distance (or convenience). A businessman may balance cost and time as he is deciding on a mode of transportation to another city.

The obvious importance of these factors can be seen as they appeared in intercity traffic models developed over the first half of the 20th century. The historical development of the models can be found in detail in publications by Borg (1), Titlemore (8), Olsson (9), and Carrothers (10).

The more important ones are discussed briefly below:

1. E. C. Young (1924) (10)

Young formulated the following equation. Note the use of K as a proportionality constant. This has been found to be necessary whenever models are in terms of power or force of interaction to adjust to existing volumes.

$${}_iM_j = K \frac{Z_i^2}{D_{ij}}$$

where: M_{ij} = migration from j to i
 Z_i = force of attraction of destination i
 K = constant of proportionality

2. G. I. Zipf (1949) (11)

Zipf proposed the following model:

$$F_{ij} = \frac{P_i P_j}{D_{ij}^2}$$

where: F_{ij} = Force of interaction between concentrations i and j
 P_i, P_j = populations i and j
 D_{ij} = distance between places i and j

When compared to actual intercity highway, bus, rail and air travel, it was found that Zipf's formulation provided a good fit only on highway data.

3. S. C. Dodd (1950) (12)

Dodd did considerable work on the interaction hypothesis for travel between two population centers. The following interaction model was among the first to use a weighting factor (or index) to better equate the heterogeneity of the population centers:

$$I_e = \frac{K I_a P_a I_b P_b T}{L^l}$$

where: T = time allowed for measured interaction
 L = distance between two groups (l is some calculated exponent)
 P_a, P_b = population of groups
 I_a, I_b = specific indices of level of activity; such as per capita activity in a unit period of time
 K = constant for each type of interaction
 I_e = expected interaction

Thus with this model a time factor was explicitly taken into consideration. J. Cavanaugh (13) in 1950 found Dodd's interaction formula to vary in different geographical regions; however, with the factor adjusted to fit the situation, in a study of 27 interactions involving automobiles entering national parks, airline travel, tourist travel and commuter travel within the State of Washington, the results were good. Cavanaugh found a correlation of 0.8 or better was achieved for 70 percent of the interactions studied.

4. F. C. Ikle (1954) (14)

$$H_{ij} = \frac{P_i P_j}{(D_{ij})^b}$$

where: H_{ij} = number of trips between i and j for a given time period

P_i, P_j = population of cities i and j

D_{ij} = distance between cities i and j

b = exponent constant for various types of interactions.
Values varied from -0.69 in Texas to 2.57 in
Indiana and 2.6 in Washington

Ikle noted a difference between interactions dealing with the movement of people and those regarding the movement of communities. Also, the population product $P_i P_j$ was taken as a linear product since it was found that the greater the number of pairs of people, overall analysis, only a linear product of the population was acceptable. Car ownership or vehicle registration was noted as a weighting factor for population but it was found that the use of the ownership factor was only valid within a given range of trip lengths. Beyond the limit of these lengths a change in mode of travel is anticipated. The hypothesis stated is that the increased automobile registration in dense urban areas will be reflected only in commuter type traffic, and that as travel spreads to more distance communities, the effects will be less noticeable. Ikle also introduced the concept of a "saturation point" of trips made by an individual.

5. T. R. Anderson (1955) (15)

As has been seen in some of the earlier traffic models, the distance factor exponent has been a constant which has to be determined for specific circumstances. Anderson proposed that the distance exponent (" α " in this case) was inversely related to the population size.

$$V_{ca} = K \frac{P_a}{D_{ca}^\alpha}$$

where: V_{ca} = the potential for travel exerted at location c by population a

D_{ca} = distance from c to a

$$\alpha = f\left(\frac{1}{P_a}\right)$$

6. W. Mylroie (1955) (16,17)

Based on the assumption that the actual through traffic volume on any section of road can be represented by the minimum ADT, the following relationships were developed from multiple regression equations:

$$F = \frac{\sqrt{P_i P_j}}{d_{ij}}$$

where: F = desire to travel

P_i, P_j = populations of urban centers i and j

d_{ij} = distance between i and j

The above equation, as can be seen, measures the relative desire for travel between cities. In order to obtain synthetic trip information from the desire factor the following equation was used:

$$\log T = \log a + b \log F$$

or $T = a F^b$

where: T = average daily travel

B = desire for travel

a, b = regression constants

Note that the form of the second equation is that of a straight line on a log-log plot. Hence it is possible using this relationship to form a plot of trip data versus the desire factor on log-log paper as shown in Figure II-4. The slope, or change in T per logarithmic cycle can be computed as b thus producing a mathematical model of the existing travel patterns.

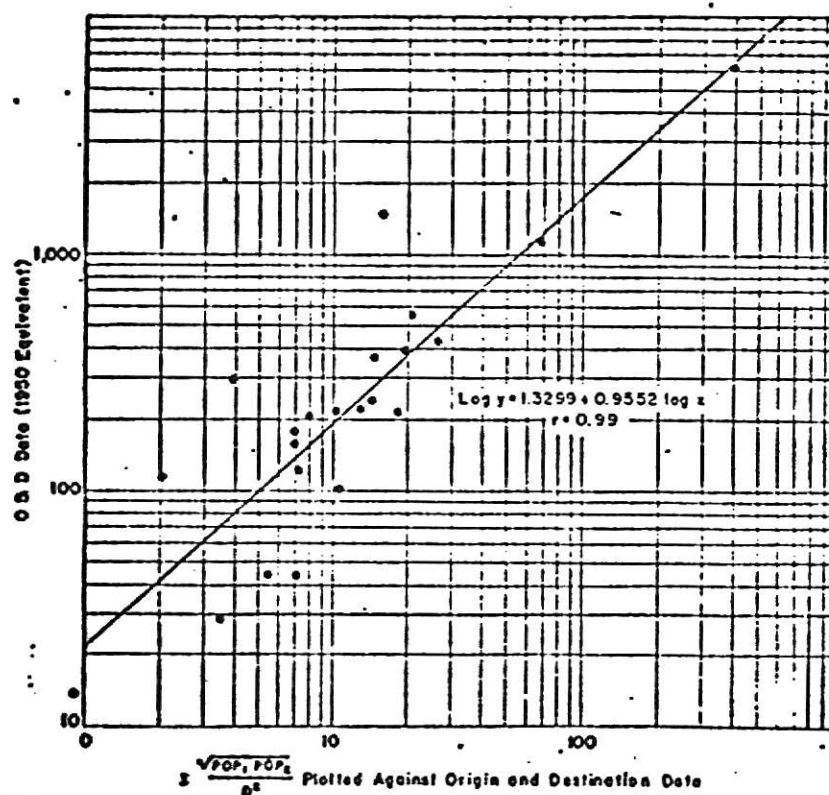


FIGURE II-4

ORIGIN AND DESTINATION TRIPS AS A FUNCTION OF POPULATION AND DISTANCE

In applying this model where two parallel routes exist between a pair of cities and the mileage between the two routes differ by 15 to 20 percent, the allocation of F between the two routes is dependent upon their relative distances. Also, in a model developed for the State of Washington, a discount was imposed for urban centers separated by more than 250 miles because automobile travel on a daily basis becomes less attractive at this distance. It was claimed that this travel model was valid for both trip generation and distribution. However, the model does not seem capable of determining the demand for a new route since no separation point was noted for trips emanating from any urban center. Competing opportunities are also not directly reflected in this model.

7. W. R. Bellis (1956)

Bellis (18) developed several new concepts for use in the following equation formulated for the New Jersey State Highway Department:

$$V = \frac{R_i f_j}{T^2}$$

and

$$f_j = KR_j \frac{R_i}{P_i} F_i$$

where: V = volume of travel from center i to center j . V is doubled for return trips to i or added to trips attracted from j to i (return or otherwise)

R_i, R_j = motor vehicle registration

f_j = force of attraction which center j exerts on center i

T = total elapsed time to travel from center i to center j

K = constant

P_i = population of center i

F_i = attractive force in addition to normal attraction

$F_j = \begin{cases} = 1 & \text{in most areas} \\ > 1 & \text{in recreational and highly industrial areas} \end{cases}$

Note the use of travel time as an impedance to travel and the use of an index to account for additional interaction. Bellis indicates that since automobile travel is being predicted it is recommended that automobile registration be used in the equation rather than population; however, as can be seen, in determining the force of attraction, the population of the origin of the trip is required to adjust the formula.

8. J. S. Burch (1961)

Burch (19,20) modified the Mylroie travel desire factor and applied it to a model based on roadside interview data available for five North Carolina cities. The resulting equation was:

$$T = 0.04m^2 + 4.9m + 160$$

where: T = ADT starting in city A and entering city B, but excluding any partial or through trips

$$m = \frac{\sqrt{P_A P_B}}{(d_{AB})^2}$$

It was concluded from this study that where there were as many as 175 trips between places, the equation provided values with less than 20 percent error when compared to origin-destination data. The accuracy was best where the distances between points were less than about 50 miles. With distances over 100 miles the formula could not be compared with actual data due to the small number of long trips observed. The overall level of confidence in the formula was better than 80 percent for any pair of cities in North Carolina which were reasonably near each other. Indications were that the existence of a sizeable third town C between the two major towns A and B, might decrease the amount of interaction between A and B below the value which would be indicated by the formula.

9. R. Borg (1964)

Borg (1) conducted research with several forms of the gravity model for assignment of trips to all cities of 20,000 population or more in Iowa. The following model, which was the basis for Borg's tests has become valuable in synthesizing multi-modal travel:

$$T_{ij} = \frac{K(P_i P_j)^a (E_i E_j)^b}{t^n e^{ct}}$$

The variables e^{ct} , t^n , $(E_i E_j)^b$ and $(P_i P_j)^a$ were tested independently and compositely.

where: E_i, E_j = total retail sales of city i and j

T_{ij} = average 1960 summer weekday trips between city i and j

t = travel time between cities

c, b, a, k, n = constants from regression

It was concluded that the best correlation was given by:

$$T = \frac{8.52 (P_i P_j)^{0.75}}{t^{2.05} e^{0.0045t}}$$

The use of retail sales as an index of a city's activity showed little effect on these larger cities. It is however, suspected that in the case of small cities, retail sales may be a good index of activity and could be successfully employed.

Trip Distribution Models

From the historical review of mathematical models designed to synthesize or generate travel patterns, there has been a development from equations which would describe the simple movement of people from one point to another to equations which would describe travel patterns between several pairs of cities over an entire state. These later forms of traffic models would more accurately be termed trip distribution or traffic assignment models since they are synthesizing and distributing a large variety of trips over an entire network. Of the distribution models in use by states today, there are three major types: The Fratar Model, the Gravity Model and the Intervening Opportunity Model. These will be described briefly here since their use in different statewide transportation projects is covered in the next section.

It is important to note the role that trip distribution models play in today's transportation research. No longer are we satisfied with knowing about the travel patterns for 15 or 20 cities across a state. There is a need to know how to synthesize travel patterns between all possible cities, towns, recreational areas and other places of interest within a state over a complete highway network. Also, to meet the requirements of transportation systems in the future, methods have to be developed to develop growth factors in order to project existing travel patterns into the future.

GRAVITY MODEL (21). As has been seen throughout the historical development of traffic models, one specific type seems to be patterned in the majority of equations. This type is the Gravity Method which is the most widely used and best documented of the models used to synthesize traffic distributions. The gravity model, as it will be described here in its most general form, has long been the most popular method of synthetic trip distribution because it is simple to understand and apply. The approach loosely paralleling Newton's gravitational law, is based on the assumption that all trips starting from a given zone are attracted by the various traffic generators of other zones, and that this attraction is in direct proportion to the size of the attractor and in inverse proportion to the spatial separation between the areas. In its original mathematical form the gravity model is expressed as follows:

$$T_{ij} = P_i \frac{\frac{A_j}{(D_{ij})^b}}{\frac{A_j}{(D_{ij})^b} + \frac{A_k}{(D_{ik})^b} + \dots + \frac{A_n}{(D_{in})^b}}$$

where: T_{ij} = number of trips produced in zone i with destination in zone j

P_i = total number of trips produced in zone i

A_j = total number of trips attracted to zone j

$D_{ij} \dots D_{in}$ = measure of spatial separation between zone pairs i-j...i-n

b = empirically determined exponent which expresses the average area wide effect of spatial separation on trip interchange.

This model has many advantages in that many socio-economic variables related to trip generation, i.e., number of jobs, family income, land use, can be substituted for A_j in the formula. This flexibility was a major

break through in transportation models and for the first time allowed changes in future land use or development to be handled directly by the model.

There were two major disadvantages of the early form of the gravity model which led to its present day revision. These were: (1) the inverse power of distance was found unsatisfactory as an impedance function for all ranges of trips and; (2) the comprehensive iteration process required to calibrate the model, coupled with wide variations in interzonal traffic that had to be accounted for, gave rise to serious computational problems (21). A more efficient spatial separation function termed "travel-time factor" was found more applicable in expressing interzonal trips. It was recognized that the impedance function was more complex than a single exponent could handle; thus travel time factors attempt to combine various functions of travel as related to distance into a form which reduces the computational process involved with the model. The revised gravity model now has the formula:

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

where: F_{ij} = empirically derived travel-time factor expressing the average area-wide effect of spatial separation

K_{ij} = specific zone to zone adjustment factor to account for other socio-economic factors influencing the travel pattern.

OPPORTUNITY MODEL (21). The second most widely used travel model in synthetic trip distribution is the Intervening Opportunities Model. This model was developed in its present general form by the Chicago Area Transportation Study. So far, this model has found most of its use in or near

large urban areas but, with increased emphasis being placed on statewide traffic analysis, models using this format have had an increasingly large part in the analysis of recreational travel. This model utilizes a probability concept which in essence requires that a trip remain as short as possible to meet its purpose, lengthening only as it fails to find an acceptable destination. All trip opportunities or destinations are considered in sequence by travel time from the origin zone. Further these destinations are placed in band widths of equal probability based on distance (or travel time) from the origin. In considering consecutive opportunities for trip ends, each succeeding destination within a band width has the same initial probability of acceptance; however, the probability is decreased by the fact the trip being distributed has a chance of accepting the first opportunity and any number of other opportunities closer to the point of origin. The model takes the mathematical form:

$$T_{ij} = T_{i(G)} P_j$$

where: T_{ij} = predicted number of trips from zone i to zone j

$T_{i(G)}$ = total number of trips originating in zone i

P_j = calculated probability of a trip stopping in zone j.

The model is generally calibrated by varying the probability values of destinations until the simulated trip distribution produces the same vehicle miles of travel by major geographic subareas as the surveyed trip distribution.

The most serious disadvantage to the use of the intervening or opportunity model, as found in its use in urban areas, has been the inability for the model to account for relative change in the time-distance

relationship of zones, such as might be the case where there are major land use modifications or where there are changes in the transportation network. Considering that on a statewide basis these changes do not occur very often, this form of model could have a good future in statewide analysis.

FRATAR MODEL (22). The Fratar Method is perhaps the oldest of the widely used methods of trip distribution and forecasting. The procedure was presented by Thomas J. Fratar to the Highway Research Board in 1954. It is based on the assumption that the change in trips in an interchange is directly proportional to the change in trips in the origin and destination zones contributing to the interchange. The distribution technique employed in trip distribution is mathematically represented as follows:

$$T_{ij(k+1)} = (T_{ijk} F_{jk}) F_{ik}$$

$$\text{where: } F_{jk} = \frac{T_j}{\sum_{i=1}^n T_{ijk}} \quad F_{ik} = \frac{T_i}{\sum_{j=1}^n (T_{ijk} F_{jk})}$$

and where: T_{ijk} = trips between i and j for iteration k

F_{jk} = destination factor j

F_{ik} = destination factor i

T_j = final desired total for destination j

T_i = final desired total for origin

i = origin zone numbers ($i = 1, 2, 3, \dots, n$)

j = destination zone numbers ($j = 1, 2, 3, \dots, n$)

n = number of zones

K = iteration number

It is evident that the calculation:

$$T_{ijk} F_{jk} \quad , \quad j = 1, \dots, n$$

must occur before F_{jk} can be obtained. Hence the initial formula above represents a two-step programming process. The application of this process to all zones represents one iteration.

Two major disadvantages of applying this method are: 1) the use of special trip tables and 2) the complex method of iteration. The Fratar method requires trip tables and growth factors for all origins in the study area. The FHWA program which is available to perform this method of trip distribution is capable of applying the technique to more than one trip table at a time. This is particularly convenient in statewide studies where trips are divided into several types and purposes; however, there is a limit on the number of trip tables which the program can handle as a function of core area available for data storage. Using this technique, an area with an extremely large number of zones may require more computer data storage than might be available and be rejected.

Growth Factors

The most widely accepted method of projecting a synthetic trip distribution pattern into the future is the use of growth factors. The factors are developed for each zone based upon the trip purpose within the zone and projections are carried out in a series of successive approximations. To insure that these factors are realistic, a large amount of socio-economic data which relates both to the type of distribution model being used and to the development of the zone or community is required. For this reason the growth factor technique is most easily applied where there is home-

interview type data. The growth factor is used most extensively in forecasting trips using the Fratar Method but the basic ideas can be adapted to most types of trip distribution models provided that the model can accept this type of data. In this method the number of future trips between any pair of zones is directly proportional to the product of the growth factors for the two study zones, adjusted for the relative attractiveness of other competing zones, and the factor that has been used for trip generation.

When growth factors are used, it is necessary to make adjustments to account for zones now vacant but which are expected to be developed. Also, adjustments must be made for zones in which future land uses will be materially different from existing land uses.

The greatest advantage of the growth factor techniques is that they reflect the many unique travel relationships that exist between many zones. They are most applicable in slow growing areas which makes them ideal for rural statewide studies. When applied to urban areas, however, the rapid growth and development of suburbs and industrial areas make extensive adjustment to the procedure necessary and the use of other mathematical models is more practical.

California (23) developed a method of projecting modal allocations for intercity travel between 16 major cities into the future given overall growth rates in travel. Through a number of surveys, specific growth rates were determined for each of four separate modes of transportation. For accuracy, these growth rates were correlated to socio-economic factors on which data could be obtained. Population and average family income were found to be the major factors influencing traffic volume within the corridor;

therefore, it was decided to determine whether the present rates of growth in travel over the four modes would remain constant or change with changes in future projections of population and family income. For example, the future modal split was based on a total passenger volume projection arrived at by using growth factors in the generation model and rate of growth over each particular system.

The first step in making these projections from the base year modal split, shown on Figure II-5, was to establish some assumptions as to why the participation rates varied as they did. These same assumptions then could be used to estimate future rates. The basis for making these modifications were listed as follows:

1. Analysis of the relative performance characteristics of each mode over the corridor in 1960, projected for the future (this included a projection as to whether the existing trends in the participation rate for that mode will show an increase, decrease, or remain about the same in the future).
2. Analysis of data collected in the 1960 and 1962 National Travel Market Survey conducted by the Survey Research Center.
3. Analysis of the participation rates themselves.

All of the four modes were considered, comparing their present growth rates with expected service and demand for service projected into the future. It was found that a projected increase or decrease in participation of one of the carriers would create definite changes in the other modes and further that through careful analysis these changes could be predicted based on economic factors. Perhaps one of the most important factors noticed in this study was technological development. The future of each mode except the automobile seemed to be extremely dependent on future developments in technology for transportation systems, and these developments could not be easily inserted into the growth factor technique.

FIGURE II-5

BASE-YEAR PERCENTAGE PARTICIPATION OF FOUR MODES OF TRANSPORTATION FOR TWENTY
SELECTED CITY PAIRS WITHIN THE CALIFORNIA CORRIDOR
1960

City Pair Code No.	City Pair	Percentage of Total Traffic				Intercity Distance (air miles)
		Auto	Air	Bus	Rail	
1	Bakersfield - Los Angeles	99.1%	0.2%	0.7%	a	101
2	Bakersfield - San Diego	89.7	1.2	9.1	--	212
3	Fresno - Los Angeles	92.8	2.5	3.8	0.9%	204
4	Los Angeles - Sacramento	78.8	14.4	4.7	2.1	361
5	Los Angeles - San Diego	95.3	1.6	1.8	1.3	111
6	Los Angeles - San Francisco	75.1	19.8	1.6	3.5	347
7	Los Angeles - San Jose	88.9	5.2	1.7	4.2	305
8	Los Angeles - Santa Barbara	99.2	0.1	0.4	0.3	87
9	Los Angeles - Stockton	92.0	1.7	5.6	0.7	319
10	Sacramento - San Diego	63.2	22.0	14.8	--	473
11	Sacramento - San Francisco	98.0	0.3	1.7	--	74
12	Sacramento - San Jose	99.2	0.2	0.6	--	88
13	San Diego - San Francisco	60.1	30.6	9.3	--	458
14	San Diego - San Jose	83.9	1.7	14.4	--	416
15	San Diego - Santa Barbara	93.6	1.7	4.7	--	188
16	San Diego - Stockton	97.3	2.7	--	--	430
17	Bakersfield - Fresno ^b	92.4	0.5	6.2	0.9	103
18	Bakersfield - San Francisco ^b	83.9	6.8	5.1	4.2	241
19	Fresno - San Diego ^b	80.3	4.5	15.2	--	315
20	Fresno - San Francisco ^b	87.1	3.9	6.1	2.9	161
Twenty-route weighted average		94.0%	3.3%	1.7%	1.0%	

-- means none.

a. Less than 0.1 percent.

b. Total traffic and auto traffic based on estimates made, using Eq. (2).

Source: Stanford Research Institute.

Zone and Network Development

As previously discussed, data collected in Origin Destination Surveys has to be coded to some form of coordinate or grid system. In urban transportation studies, in order to apply social or economic factors to trip origins or destinations, zone boundaries have to be defined and tied to the data. In an urban area, a zone may be anything from several adjacent blocks to an entire neighborhood or suburban community. Whatever the size of the zone, the models used in synthesizing urban traffic have given reliable results for many years. There are, however, many problems encountered when attempting to apply these techniques on a statewide basis. Modifications of the basic models that are necessary where applied to intercity traffic have been discussed. Additional problems encountered in developing a statewide network of zones and highways will be presented next.

The question of how to divide a state of several thousands of square miles into zones is a complex one. Whatever zone size is established, it will have to be serviced by a portion of a total statewide highway and road network consisting of many thousands of miles of highways of various quality. If one seeks to deal with a system of small zones, he faces a very detailed network and the problem becomes enormous. If, on the other hand, a pattern of large zones is chosen, the network becomes generalized and the assignment process may become poor and unrealistic. Each state, therefore, has had to expend a considerable amount of effort in order to find the level of fineness or coarseness in their network which works best for them. Figure II-6 illustrates a typical network. It is hoped that the differences between zone and network assignment techniques presented in

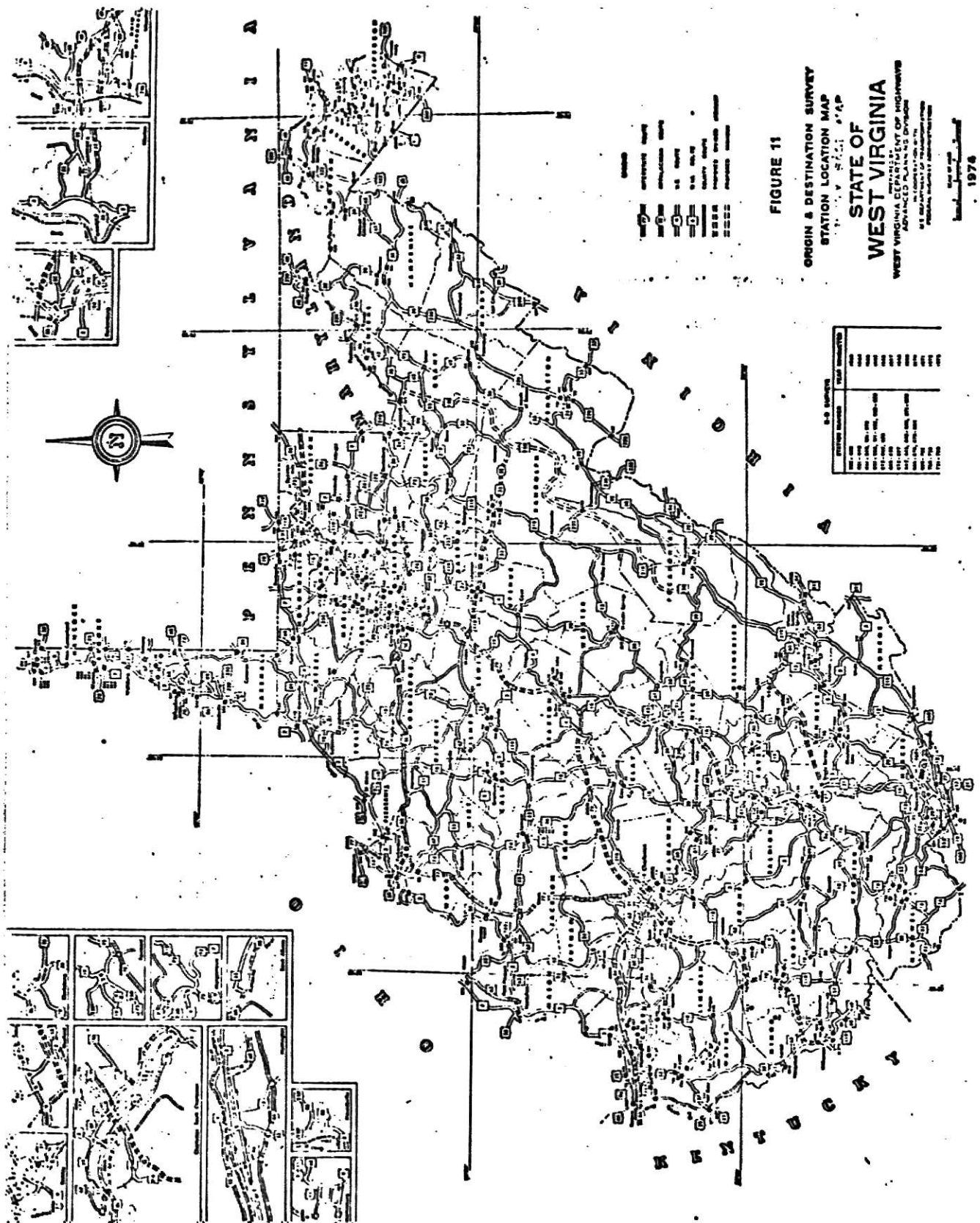


FIGURE II-6

HIGHWAY NETWORK TYPICAL OF ONES USED
 IN STATEWIDE TRAFFIC ANALYSIS

this section may be of some benefit to states which are in the process of drawing up zones and highway networks for intercity traffic analysis.

The first statewide traffic analysis work was accomplished using multiple screenline studies. These studies left the states with a myriad of O-D data which had to be coded onto some system. Care had to be taken, however, in selecting the zone system if an older screenline study was to be used as a basis since the new zone system could be no more detailed than the data collected over the screenline. Also, where screenlines were improperly placed in the past or did not conform to existing jurisdictional or demographic boundaries, problems arose in a few states regarding the uniformity of zones and the accuracy of trip information. In Missouri, an earlier cordon line study around urban areas conducted at the time of the Mississippi Valley O-D Survey placed the cordon lines considerably closer to the city proper than was later found appropriate (24). This error was reflected throughout the zones surrounding urban areas and, as a consequence, estimates of originating volume were too large, and the use of these originating volumes in the original estimates of zone-to-zone volumes produced results which were significantly larger than those observed in the survey. Therefore, a correction factor had to be used to adjust these volumes to agree with the survey data.

In assigning O-D data to zones, three different systems of selecting zone boundaries have become common. The first and most widely used is the use of civil or jurisdictional boundaries. This method allows for the most convenient means of collecting socio-economic data since much of the census data is compiled using identical boundaries, and other required information is often available through local sources. Since a traffic analysis zone attempts to represent a specific homogeneous aggregation of population,

economic development, recreational activity, land use or any combination of these, the zone's size and characteristic will differ considerably from one geographic area to another. Zone size will also vary according to the nature of the transportation survey.

The Kentucky Statewide Traffic Model Study presents a good example of selecting zone boundaries based on civil boundaries (4). Under "Instate Zone Development Criteria" the report stated,

"Zones should be defined so as to contain a relatively homogeneous set of activities. Zone definition should take into account the availability of activity and travel data for the analysis areas, both present and future... In rural areas of Kentucky the zone will, in most cases, be coterminous with the Census County Division Boundaries. The Census County Division presents a convenient analysis area of appropriate size and for which data are generally and conveniently available. In addition these units should retain their identity for a considerable period of time since the boundaries are established as physical features... Urban places between 5000 and 25,000 usually are significant traffic generators and should be treated as individual zones. Urban areas greater than 25,000 have all been divided into analysis areas for urban transportation studies. These urban study zones will be aggregated into analysis areas to a size more appropriate for statewide analysis... Areas which for one reason or another, because of the nature of their activity, are capable of generating traffic volumes greater than 5,000 interzonal trips and similar areas which are currently being planned will also be considered for delineation as separate zones."

Figure II-7 illustrate zones established over civil jurisdictions in Wyoming.

The second most widely used system of coding trip information to a zonal system is the use of a grid-coordinated system. In an early study in Illinois, origin and destination data were coded to a coordinate system defined by 1/10 degree of latitude and longitude. Trip terminals in cities of 2500 population or more in Illinois and neighboring states were coded on the same grid system within the city boundaries. Likewise smaller cities with more than 250 population were coded on the system. Trip ends for

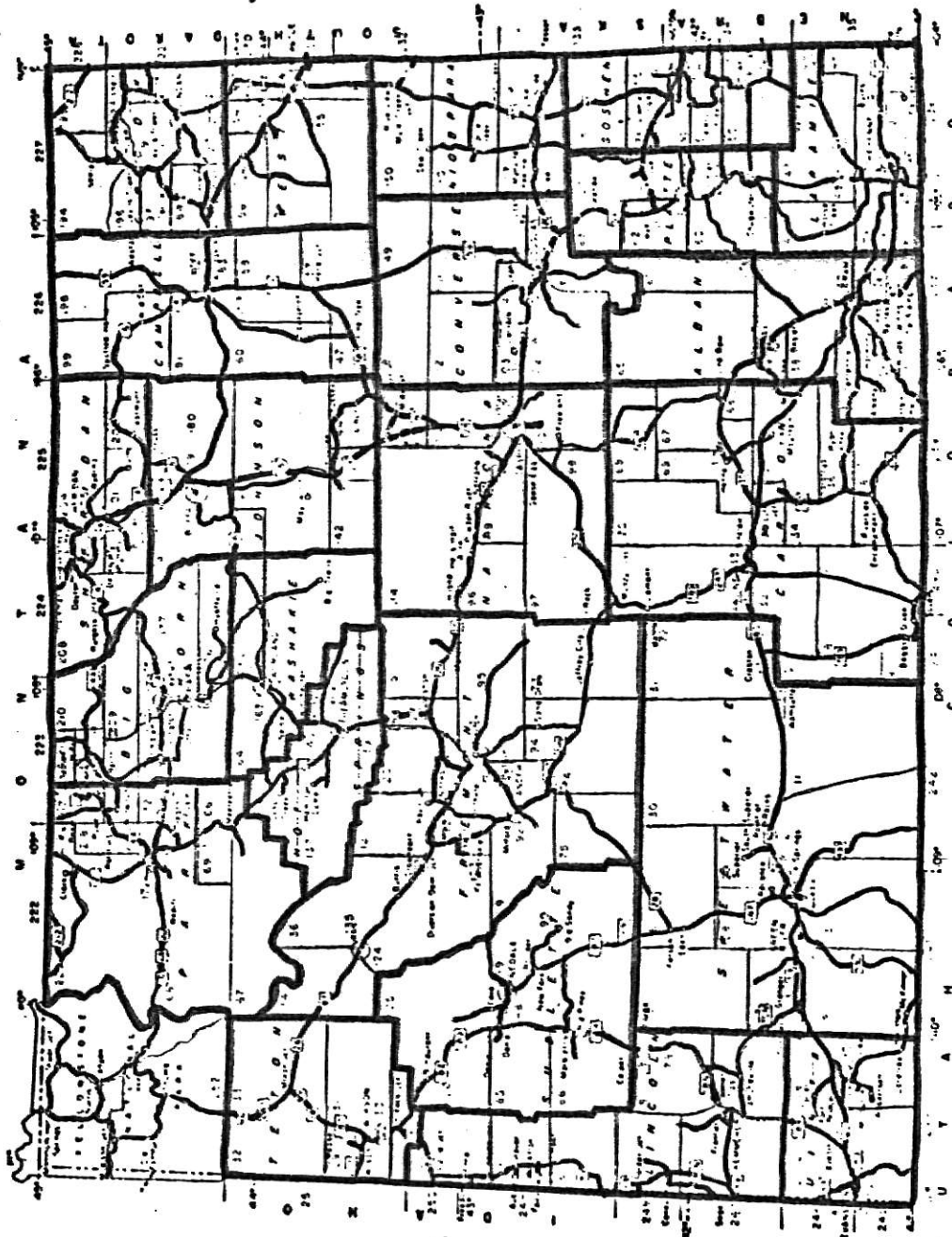


FIGURE II-7
 TR
 TRAFFIC ANALYSIS ZONES BASED ON
 COUNTY AND TOWNSHIP BOUNDARIES IN WYOMING

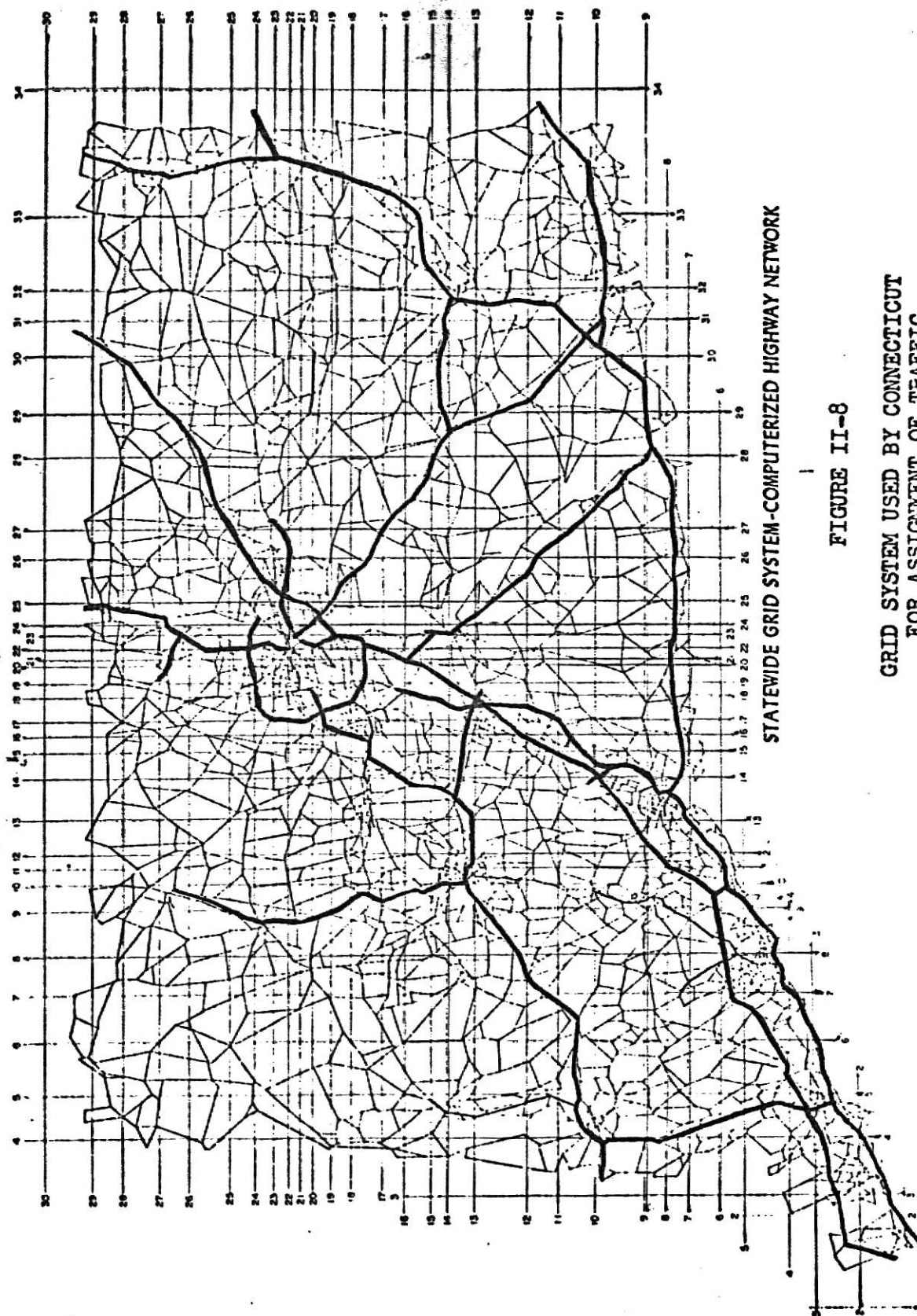
places in Illinois with less than 250 population were coded on the grid in the approximate centroid of the county. Instead of coding OD data to civil zones such as townships or counties, this method loads them on to a specific coordinate, thus simplifying a system with a possible infinitum of trip origins and destinations. Using this system, zones still have to be established which include the loaded coordinates so that socio-economic data can be collected and applied to the trips.

Figure II-8 illustrates a grid system utilized by Connecticut in assigning trips to zones.

Wyoming also used a grid coordinate system consisting of zones which were ten miles square. The state was thereby divided into 999 zones. Trip terminals within each zone were assigned the number of that zone. It was found in Wyoming that for the purposes of travel analysis, all of the individual 999 zones were not required, hence they were aggregated into "traffic analysis zones," varying in character and size, according to the following criteria:

1. Recreational areas of prime significance
2. County seats
3. Towns and cities that accounted and/or would account for a significant share of trip ends within each county.
4. Known natural resource development areas
5. Similar geographic regions without distinguishable differences in socio-economic characteristics
6. County boundaries were not to be crossed by traffic analysis zones.

Using this method, a set of zones was developed which was composed of 220 internal zones and 23 external zones.



The final method of zone development is derived from the case in which a state is attempting to correlate older multiple screenline data to a finer zonal system. Such an example is the State of Wisconsin. The coding system for the Mississippi Valley Origin and Destination Survey utilized both civil units and geographic data. Therefore the zone system developed for analysis of highway travel between all of the zones had to correlate to this data. Furthermore, all available existing socio-economic data and anticipated projections of such data are by civil subdivisions. Thus incorporated cities, villages and civil towns became the building blocks for larger zones. The larger zones were then established based on civil subdivision boundaries and the MVOD screenlines. This resulted in a double zone system where there is a base of smaller zones (a maximum of 699) and a set of 24 larger zones termed "cells" which correspond to the screenlines of the original survey. Only with this type of zone system could the screenline data be directly used as a basis for traffic analysis.

Figures II-9a and II-9b show the locations of "cells" and zones in Wisconsin conforming to the MVOD screenlines.

In 1972, Creighton, Hamburg, Inc., Consultants, prepared a report for the Pennsylvania Department of Transportation dealing with the merits of using a system of both large and small zones and correspondingly coarse and fine networks (25). The paper described two alternative approaches to statewide transportation assignment. One technique calculates and assigns long trips to a system of very large zones. Then, in the second pass, the shorter trips which have not been assigned in the first stage are calculated and assigned to a finer network of zones, and finally, if

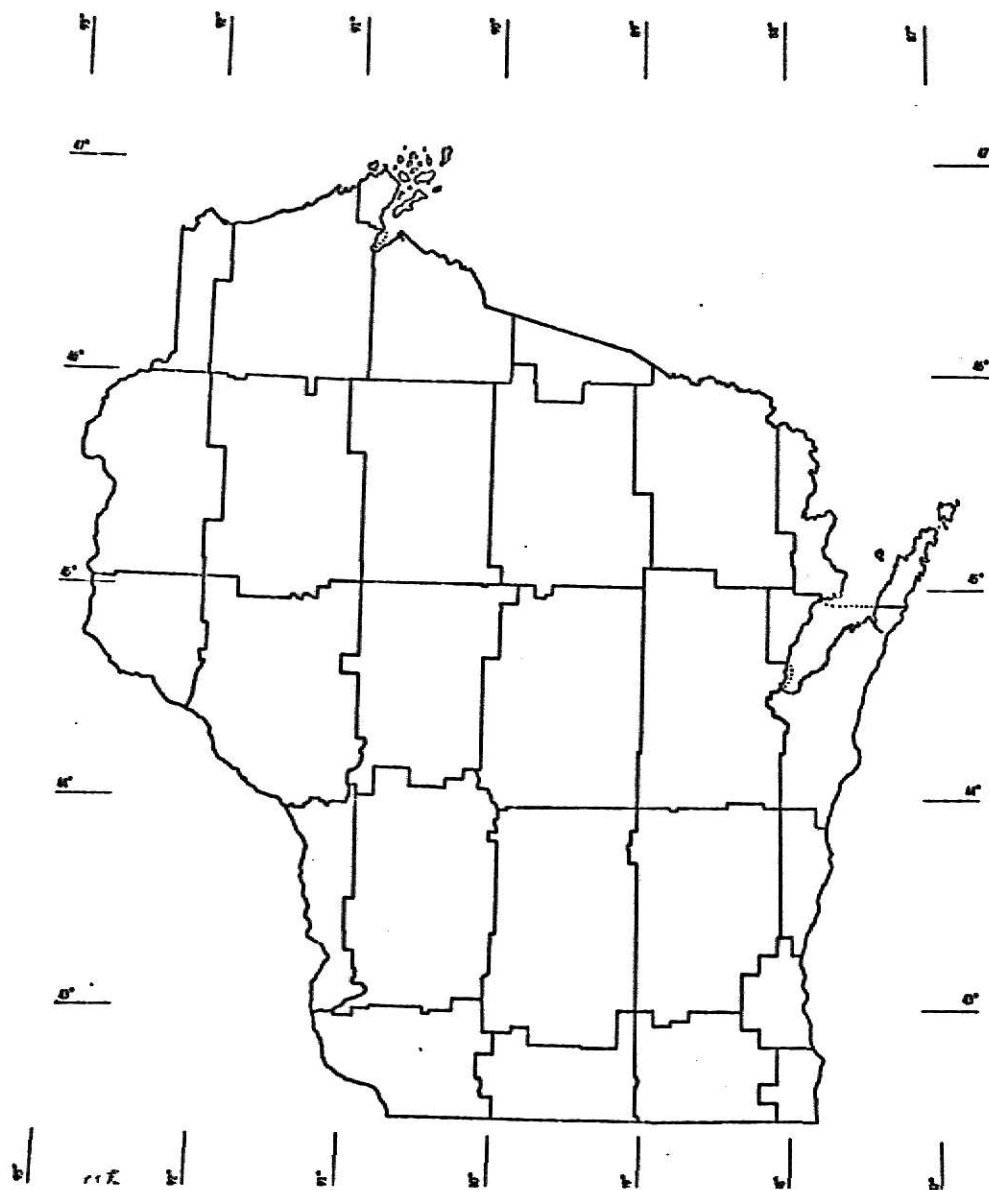


FIGURE II-9a

LOCATION OF "CELL" BOUNDARIES IN
WISCONSIN CONFORMING TO MVCD LINES

TRAFFIC ANALYSIS ZONES

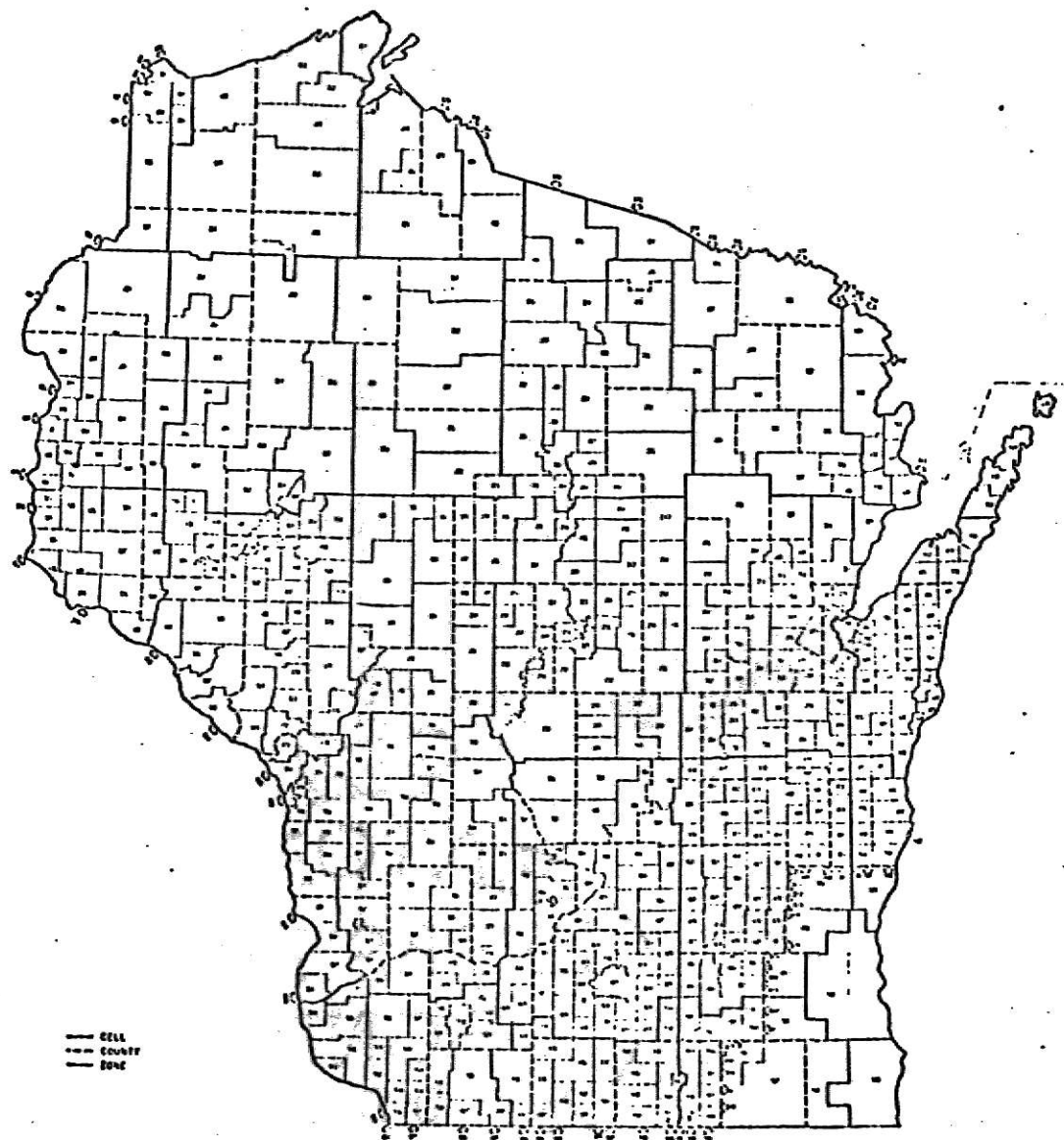


FIGURE II-9b

LOCATION OF TRAFFIC ANALYSIS ZONES WITHIN
CELLS FOR THE STATE OF WISCONSIN

necessary, there is a third stage in which short trips are assigned to a very fine zone system. In the alternative approach, a subregion or corridor is delineated within the state and trips are simulated and assigned to the network within the subregion. In this second approach the size of the zone and coarseness of the network are directly related to the length of travel and are automatically selected by the computer programs.

In both approaches the obvious advantage is the same. The method permits the use of whatever degree of fineness or coarseness needed to simulate traffic patterns. It permits the use of fine grained detail in geography and network for the representation of those trips whose synthesis requires a detailed network but does not require that a fine zone system in one part of the state interact with a coarse zone system in another area. The present methods of network and interzone trip analysis could be used as a basis for either approach.

Obviously a "superzone" or regional highway system will conform well to this proposed approach with no additional data requirements from methods presently in use other than perhaps a system of identifying a hierarchy of routes between locations.

Computer Technology

Perhaps the largest boost to efforts in developing Statewide Transportation Assignment Models in recent years is the battery of computer programs available from the Federal Highways Administration, U.S. Department of Transportation. Since these programs have become an invaluable tool in modeling traffic patterns, this section of the report will be devoted to a brief summary of the available programs and a look at some of the methods developed for their use.

The FHWA published a listing of their programs in a user's manual (26) intended to assist transportation agencies in building and maintaining computer program libraries and to show where the battery of programs can be used as a transportation planning tool. The following is a list of programs which have been found invaluable to statewide transportation planning efforts:

BUILDHR - Build Traditional Historical Record. This program reads link data cards, edits them, and unless errors are too numerous, prepares a historical record containing descriptive print records, a link parameter record and one historical record for each node in the network.

BLDSPTR - Build Spiderweb Network. This program reads coordinates of nodes and constructs a network.

BUILDVN - Build Minimum Impedance Paths. This program reads the historical record created by BUILDHR and prepares designated outputs.

CAPRES - Apply Capacity Restraint. This program reads in link capacities and loadings from traditional historical records and then adjusts link travel times according to a predetermined relationship of volume to capacity on the links to achieve a balanced assignment.

COMPARE - Compare Network Assignments. This program is set up to generate statistical data indicating the amount of similarity between two sets of data. It has proved most valuable in comparing loaded networks, loads to counts, loads to capacities, and one load to another load.

FORMAT - Variable Formats of Historical Record. This program formats traditional or spiderweb historical records. By use of appropriate control cards, the program can be instructed to print detailed information on a link by link basis or accumulate selected values from the network.

FRAT - Fratar Program. This program adjusts and outputs given trip tables according to the Fratar formula.

GEALPHA - Annotate Network Nodes for Plotting.

GEGBWP - Plot Bandwidth Displays of Link Information. Figure II-10 shows a bandwidth plot showing traffic volumes on links.

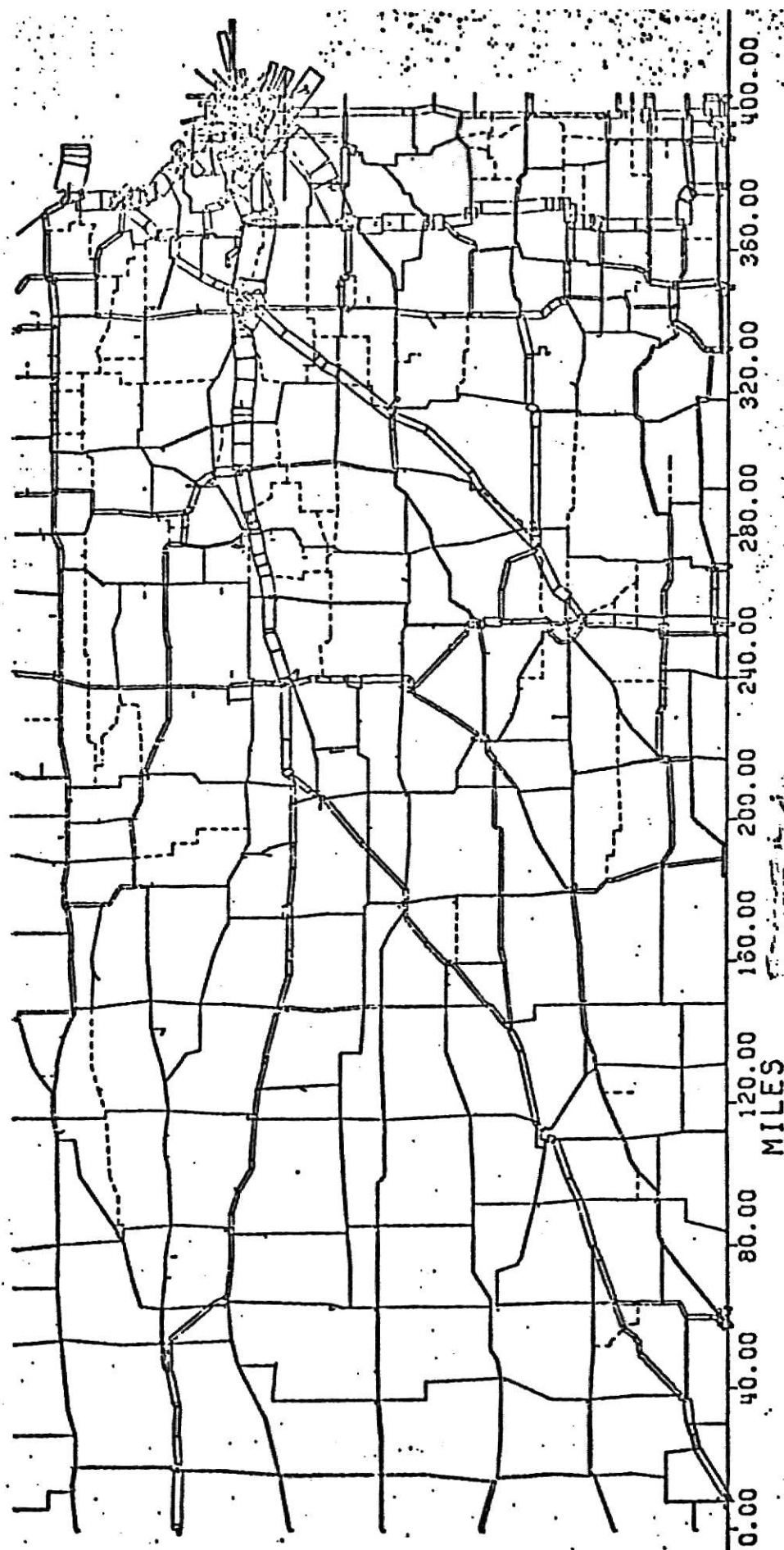


FIGURE II-10

PLOT OF TRAFFIC VOLUME ASSIGNED TO HIGHWAY
LINKS USING A BANDWIDTH PLOTTING PROGRAM FOR
THE KANSAS STATEWIDE TRANSPORTATION STUDY

GEPlot - Prepare Single Line Plots of Network. The output of this program is a tape to be used as an off-line input to a CALCOMP plotter (see Figure II-11).

GEPREP - Prepare Network for Plotting.

GESERT - Insert Node Coordinates in Historical Record.

GM - Gravity Model Program. This program distributes zonal productions and attractions according to the gravity model formula, outputting resultant trip tables and printable reports summarizing total attractions and trip length distributions.

LNKCOST - Compute Link Travel Cost. This program reads speed-cost curve data cards, edits them and updates the HR by addition of link cost words.

LOADVN - Load Trips on Network Links. This program reads the PATHSI data set created by BUILDVN and loads specified trips from a TRIPSI data set. An HRI data set is read and updated and output as a Loaded Historical Record.

PRINTHR - Format Historical Record. This program prepares a printout of selected data from the traditional network historical record file.

PRINTLD - Format Historical Record Link Volumes. This program prepares a printout of the data from a loaded traditional historical record. Among the data which can be printed are counts, capacities, turning movements and link loads.

PRINTVN - Format Zone to Zone Paths. This program formats for printing, traces to selected destination zones from selected origin zones. Traces may be nondestructive or iteratively destructive.

TRPTAB - Trip Table Builder. This program will use a variety of inputs to form trip tables.

UPDTHR - Update Historical Record. This program is a dual purpose program for either building or updating traditional historical record files. In "update" mode it will add/delete/change links and data in existing HR files. In "build" mode, it may be used as an alternative to BUILDVN under certain circumstances.

BEHMLE - Obtain Vehicle Miles of Travel. This is a general purpose program capable of reading single or merged trip tables on one TRIPSI data set and up to eight IMPEDI data sets and preparing single or merged vehicle mile trip tables on one TRIPSO data set.



FIGURE II-11
SPIDERWEB NETWORK PLOTTED FOR
CHARLESTON, WEST VIRGINIA

VOLAVG - Average Volume, Speeds and Times. This program is used to develop weighted averages for time, speed, turning movements and directional volumes for each link in the historical record. VOLAVG uses the loaded link records from up to 15 iterations of data.

Figure II-12 illustrates a flow diagram which is typical of ones used as a basis for putting a statewide transportation system on computer. With attachments, this basic process may then be used to test the results of various trip distribution models. Figure II-13 shows the form that was used by the Wisconsin State Highway Commission to code link data into the system.

EXAMPLE OF CODED LINK

STATE HIGHWAY COMMISSION OF WISCONSIN
 PLANNING AND RESEARCH DIVISION
 ALTERNATIVE A NETWORK NET WORK DESCRIPTION FOR TRAFFIC ASSIGNMENT
 NODE-LINK DATA
 METROPOLITAN AREA TRANSPORTATION STUDY

JURISDICTION	"A" NODE	"B" NODE	SIGN (+/-)	FLAG (YES)	DISTANCE (MILES)	T OR S	TIME OR SPEED		T OR S	CHANGED LINK TO BE "B" NODE OF	CAPACITY	TRAFFIC VOLUME (A.D.T.)	CITY CODE	CARD NO.	STREET NAME
							A FIELD 1 (TIME IN 0.01 M.P.H.)	B FIELD 2 (SPEED IN 0.1 M.P.H.)							
2	35.66	36.08	1.1	07.6	S	570	570	S	001600	002	STH 29				

FIGURE II-13

NETWORK LINK DATA CODING CHART

SECTION III

SELECTED ABSTRACTS OF STATEWIDE TRANSPORTATION STUDIES

The previous section provided a large spectrum of mathematical formulations and techniques which have been found to be of significance in analyzing and describing intercity travel patterns. This section will extend the previous discussion by summarizing many of the existing practices in comprehensive analytical statewide planning. The purpose of this section is to provide a cross section of information pertaining to statewide studies, networks and models which may be of value to agencies which are contemplating the development of a statewide planning system or are, in fact, in the initial development phases.

The result of the questionnaires sent to planning agencies, consulting firms, universities and other research agencies revealed that out of responses from 45 states, 30 of the states were working on a statewide transportation planning system similar to the one being developed in Kansas. Of these 30, the states of Minnesota, Pennsylvania, Massachusetts, Wisconsin, California, Connecticut, Nebraska, and Rhode Island have completed development of traffic models. Texas, New Hampshire and Delaware have limited capability models and the State of Virginia has replaced the statewide type of study with a comprehensive plan of urban studies in all areas of 3500 population or more. The Canadian Transport Commission has also responded with the report that most of the present effort being spent in transportation system analysis in Canada is directed at intercity public transport. There were only 11 states that reported no work in the field of statewide transportation studies or assignment models. Four

states reported that work had been started on development of a statewide traffic analysis and planning procedure but had been stopped for various reasons. South Dakota, Missouri and Oklahoma could not obtain sufficient results with their initial work.

In order to present a desirable cross section of the studies which have been performed and to give as much insight as possible into the techniques involved in statewide traffic modeling the following abstracts from studies conducted in 12 states are presented.

California (1966)

The State of California completed a multimodal passenger movement study within a central corridor connecting 20 of the state's major cities (23). The following socio-economic variables were tested in a regression analysis of the surveyed traffic patterns. A major consideration in determining the variables is that they must be truly independent of the effects of traffic volume.

Population Product (X_1). In a relatively homogeneous economic area, one of the variables likely to be the most important in determining the amount of intercity travel between the two cities is the number of people in each city available to visit or be visited. This may be thought of in terms of the number of possible pairs of individuals, one in each city, who might have occasion to communicate. The number of pairs for any given city pair can be measured by the product of the populations of the two cities. This product became X_1 .

Intercity Distance (X_2). The distance between two cities can be thought of as a limiting factor or deterrent for travel in determining

the traffic between them. The intercity distance variable also can serve as a substitute for time and cost variables with little loss of accuracy thereby limiting the number of variables in the demand equation. The direct air distance from city center to city center is used as X_2 in this model.

Weighted Travel Time (X_2'). This variable was introduced to help reflect future effects of technology on travel deterrents between cities. The variable is the average total trip time required to travel between each city pair by each of the four modes of travel. The average is weighted by multiplying the travel time on each mode by the percent share of the total traffic accounted for by that mode.

Income (X_3). The personal income per capita was found to show a measure of the ability of the potential travel market to make intercity trips. The personal income per capita variable (X_3) is derived for each city pair by adding the combined personal incomes of the two cities and dividing by the combined population. An alternate income variable (X_3') is the median of the combined incomes of the two cities and yet another alternative variable (X_3'') is just the combined personal incomes of the two cities.

Industry of Employment (X_4). A final variable was derived to reflect the pattern of business and commercial travel between the two cities in the pair. It had been found earlier that employees of the different industries had different propensities to travel. The following index numbers were derived to reflect this: wholesale and retail trade (1.47); manufacturing (0.63); Agriculture (0.45). From the combined employment of these industries, the variables (X_4) is obtained by multiplying each index by the percent employment in that particular industry and then adding all three weighted factors.

The demand model took the form:

$$\text{Log } Y = b_0 + b_1 \text{ Log}X_1 + b_2 \text{ Log}X_2 + b_3 \text{ Log}X_3 + b_4 \text{ Log}X_4$$

where: Y = total intercity traffic expressed in thousands of passengers

X_1, X_2, \dots = various independent variables

b_1, b_2, \dots = respective coefficient assigned to logarithms

b_0 = constant

The following equations achieved very good results (Y_e = estimated traffic produced by each equation).

$$(1) \text{ Log } Y_e = +5.45772 + 1.09733 \text{ Log}X_1 - 2.57510 \text{ Log}X_2$$

$$(2) \text{ Log } Y_e = +1.65502 + 1.04782 \text{ Log}X_1 - 2.86064 \text{ Log}X_2'$$

$$(3) \text{ Log } Y_e = -7.17021 + 0.96040 \text{ Log } X_1 - 2.46169 \text{ Log}X_2 + 3.72306 \text{ Log}X_3$$

$$(4) \text{ Log } Y_e = -13.82646 + 1.03359 \text{ Log}X_1 - 2.48166 \text{ Log}X_2 + 5.02282 \text{ Log}X_3'$$

$$(5) \text{ Log } Y_e = -24.62032 + 1.06277 \text{ Log}X_1 - 2.50507 \text{ Log}X_2 + 4.52065 \text{ Log}X_3' \\ + 6.37492 \text{ Log}X_4 .$$

The final equation included the industry of employment variable and was the best of the models tested with $R^2 = 0.984$.

The sources of data for this study were numerous. Automobile travel data was obtained for the most part from a large regional origin-destination study conducted in the Los Angeles area and was supplemented by smaller studies done by individual communities. In order to mesh this data for automobiles with data sets from other modes of transportation, the sizes of the origin and destination zones usually had to be modified. For example,

in work done at the Stanford Research Institute dealing only with air traffic, it was found that it is necessary to define "cities" as areas larger than covered by the city limits in order to account for the broad areas served by major airports. Also, other common carrier data commonly assigns to a city of carrier origin or destination, all of the traffic moving through its terminal, even though partly drawn from many surrounding communities. In order to establish growth rates for automobile travel, data was obtained from continuous traffic counters and compared over a number of years. Data from common carriers was obtained from samplings of tickets or drivers' passenger manifests (in the case of bus travel.) The airline and rail carriers summarized their sample data for an entire year while it was sufficient to obtain bus data for only one month.

Along with this data collection, methods were devised which would place a specific cost per passenger mile for each mode of transportation. This information would provide an alternative impedance variable in the distribution model if required.

Pennsylvania (1966-67)

Two unique traffic assignment models can be found for the State of Pennsylvania. The first was devised by the Pennsylvania Department of Transportation in 1966 (27) and the second was formulated by Villanova University in 1967 (28).

The first model was the result of a statewide origin -- destination study conducted in 1963. The study consisted of 500,000 roadside interview stations and ten screenlines: three to intercept east-west traffic, two lines to intercept north-south traffic, lines at all four state boundaries and a line which represented the Pennsylvania Turnpike.

The state was divided into 149 geographic zones taking county boundaries as the primary zone division with additional county subdivision being carried out as a function of the location of significant population centers. Out-of-state area was divided into 14 adjacent zones based on the criteria that each out-of-state zone contain a city with population of at least 30,000 - 100,000 located within 40 miles of the state border, and 19 regional zones that did not contact the state border.

Eleven cities were selected for detailed analysis as to their state-wide trip generating characteristics. Trip production and attraction equations were developed for each of three vehicle types: auto, light truck, and heavy truck. An example of the results are these equations derived for automobile travel:

$$TP = -1.68.2 + 2.2V/A^{0.4}$$

$$TA = 0.4(1.9TE + P)/A^{0.4}$$

where: TP = trip productions
 TA = trip attractions
 V = auto registration
 TE = total employment
 P = population
 A = zone area

The trips were then distributed using an intervening opportunities model of the form:

$$T_{ij} = P_i (e^{-L \sum A} - e^{-L(\sum A + A_j)})$$

where: ΣA = summations of attractions considered prior to reaching zone j

P_i = total trips produced by zone i

A_j = derived factor to express the probability of trip acceptance

e = base of natural logarithm.

The model was calibrated to give acceptable results. Since small rural communities did not fit the general equation for trip generation, their attraction and production factors were determined independently. Comparison of outputs from the trip-length frequency distribution revealed that net travel characteristics were within 11 percent of the surveyed trips. The final assignment resulted in an accuracy with average weighted errors of 28 percent for passenger traffic and 50 percent for commercial traffic.

The second statewide traffic survey which was conducted by Villanova University involved only a 45 county area (less than half the state) which constituted the rural or non-metropolitan area. The intention of this survey was to simulate rural traffic patterns. The study area was divided into a grid network comprised of units approximately 7.8 miles long and 4.8 miles wide. Trip data from the 1963 OD survey was coded into this network.

For the development of the trip generation and distribution model, 12 socio-economic variables were originally selected. However, due to problems in applying all variables to the grid, only four independent variables were finally used:

No. of automobiles (A)	=	118 + 0.02837 (Residential Population)
Employment by Residence (E)	=	-59 + 0.03576 (Residential Population)
Housing Units (H)	=	-73 + 0.3128 (Residential Population)
Daytime population (D)	=	-704 + 1.195 (Residential Population)

In order to develop a distribution model, the trip information was stratified by type of origin and destination and trip purpose. From both linear and non-linear relationships it was found that the non-linear trip characteristics were best suited for trip distribution. For rural-to-rural areas, then, the following generation and distribution models were derived:

$$\text{Work Trips} = -129.8 + \frac{45.75 - 117.8E + 812.0H + 2.78R - 61.04D + 511.1A}{d^{0.2}}$$

$$\text{Shopping Trips} = -25.9 + \frac{31.59 - 144.3E + 71.8H + 16.46R - 1.51D + 70.75A}{d^{0.2}}$$

$$\text{Other Trips} = -106.9 + \frac{40.78 - 604.7E + 66.6H + 36.75R - 37.68D + 558.6A}{d^{0.2}}$$

where: E, H, R, and A are defined above and d is the trip length.

Checks were performed by comparing actual versus estimated trips at internal stations and by screenline analysis. Comparing at interview stations, this model yielded a correlation of 0.71. Using small screenlines, the highest percent error obtained was 37.6. Finally, a comparison on the large statewide screenlines revealed a highest percent error of 12.3.

Wisconsin (1968)

In developing a Statewide Traffic Assignment Model, the State of Wisconsin tackled the two biggest problems facing most state highway planners today (2). First, as a method of pointing out a need to be able to predict future transportation requirements and as a mechanism for putting to use the output from the statewide traffic assignment model, the State Highway Commission of Wisconsin developed a process of "priority planning."

By 1967, according to a study conducted by Wisconsin, less than half of the states had a method of priority determination for highway improvements. To date, establishing priorities has been based to a large extent on intuitive engineering judgement. It was noticed, then as today, that exercising this judgement to provide planning for the transportation system required now, and the system required twenty years in the future, is becoming increasingly complex and demanding on those who must make these decisions. Because of the complexity and the magnitude of the highway and transportation systems of most states, it was envisioned that in order to meet the needs of the future, improvements in program management must be made.

The program of priority planning developed by Wisconsin involves four basic steps;

1. developing a functional classification plan for the state highway system,
2. determining the future transportation needs and improvement requirements based upon that plan,
3. determining future revenues based on projected transportation systems, and
4. relating future transportation needs to future revenues.

Notice that the first two steps of this program can be adequately met by the Statewide Traffic Assignment model. It was recognized by the State of Wisconsin that the parallel development of priority planning method and the statewide traffic assignment model would greatly benefit its future highway and transportation program.

The second large problem, then, which Wisconsin chose to tackle was the reclassification and development of the state's arterial highway system.

A close inspection of the system was necessary because the trip distribution model was based on sufficiency of routes and travel time and these two factors depended largely on the functional classification of the route. It was recognized that the completion of planned facilities would modify the use of certain other routes and therefore change their functional class and sufficiency.

One of the early attempts to conceptualize functional highway systems on a statewide basis was the development of intuitive, limited, single purpose highway planning schemes. The planning staff was interested in studying the differences and similarities which would emerge when socio-economic, land use and other long range planning factors were used independently as a basis for developing functional arterial system schemes. Schemes that were tried linked urban centers via existing or planned arterials on the basis of population (connecting cities and towns of lower population to nearest communities with higher population), trade center activity (wholesale and retail activity), recreation activity, directional travel patterns, population distribution and even the volume of long distance telephone calls.

A final arterial network was arrived at for both the 1960 and 1990 travel patterns. Collector and local highways were then added to comprise the entire network. Local highways with an ADT of less than 300 were not included in the network.

The main source of data utilized in developing the assignment model in Wisconsin was the Mississippi Valley Origin and Destination (MVOD) study that was conducted in 1960. Since all available and anticipated projections

of socio-economic data were by civil subdivisions, incorporated cities, villages and townships became the building blocks for larger zones. Since the MVID produced data for rather large zones, Wisconsin developed a system of two level zone analysis. (Refer to Figure II-9). "Cells" were introduced which were approximately equal to or larger than the MVID zones. It was decided to first devise a traffic model for intracell travel and then expand to include the rest of the zones and cells in the state.

Out of a total of 24 cells in the statewide system, one "test" cell was selected for a detailed analysis. In the report, it was not stated exactly what basis was used to select the test cell. An auto trip generation curve was developed by computing and plotting for 27 study areas within the cell, the external auto trip ends per one thousand population. The auto trip generation curve was then applied to all 43 zones within the cell to obtain a complete listing of trip ends. A net generation curve was then developed eliminating intrazonal trips and accounting for special traffic generators such as state parks and recreational areas. The formula devised to eliminate intrazonal trips within the cell was as obtained from the following linear relationship:

$$y = 87.38 + 0.0749 X_1 - 1.1491 X_2$$

where: y = % of gross trips generated which are intrazonal.

X_1 = % of total zonal population living outside the urban area.

X_2 = ratio of total zonal perimeter to the total zonal area
expressed as a percent

The net trips generated were distributed using a gravity model of the form:

$$T_{ij} = E_i P_{ij} \frac{E_j F_{ij}}{\sum_x E_x F_{ix}}$$

where: E_i, E_j are the number of trip ends in zones i and j

P_{ij} is a factor indicating the proportion of trip ends at zone i which are associated with the type of exchange connecting zone i to zone j

F_{ij} is a "friction" factor associated with travel time between zones. This factor was found to decrease with increasing travel time and generally approximates an inverse exponential relationship

$\sum_x E_x F_{ix}$ is the sum of the products of the trip ends in all other zones in the considered land use exchange and their respective friction factors

To verify the results of the model, a comparison of assigned traffic volumes to base year ground counts was made. In the test cell, it was found that assigned ADT was less than 1.5% higher than ground counts and assigned vehicle miles were less than 3% higher than the actual vehicle miles for all rural links. The average assigned volume was 1.46% greater than the average existing volume and the total weighted average error was 58.98%.

The process as described above was applied to all cells within the state with less promising results. The weighted average error for all cells was 106.61% and a comparison of plotted values showed trip ends in large cities were underestimated, and if there were two or more large cities within a cell, the trip distribution was poor. A technique based on the Fratar model was devised for adjusting these errors, and also for forecasting future travel using growth factors.

Oklahoma (1968)

Research at the University of Oklahoma led to a unique traffic model developed from the basic gravity model (29). This model which was applied

to highway traffic in the state of Oklahoma was of the form

$$T = \frac{a_0 (SM \times SM)^{a_1}}{D^{a_2}}$$

where: SM = Social Mass

D = Distances between study areas

T = Number of trips

$a_0 a_1 a_2$ = Regression constants

The term "social mass" was an attempt to break down population into its resulting activities. The problem became one of isolating and analyzing the constituent parts of a community of population center and applying them to a combination trip generation and distribution model. The individual elements which were considered a part of social mass effect were retail sales, number of retail establishments, number of service establishments, and number of hotels, motels, and tourist camps.

It was decided to use a Gaussian Least Squares Technique of regression analysis to study each socio-economic parameter as well as its corresponding regression constants a_0, a_1, a_2 . To reduce the computer time required for the analysis, the logarithm of both sides of the equation was taken, rendering it linear. The following model results:

$$\log T_{ij} = \log a_0 + a_1 \log (SM_i \times SM_j) - a_2 \log D_{ij}$$

Rounding off the distance to the nearest mile and calculating the regression constants for each parameter separately, the original formula assumed the form indicated below for each of the separate independent parameters or variables:

Population (P) - Distance (D)

$$T_{ij} = \frac{6.372(P_i \cdot P_j)^{0.608}}{D_{ij}^{2.372}}$$

Retail Sales (RS) - Distance (D)

$$T_{ij} = \frac{7.537(RS_i \cdot RS_j)^{0.562}}{D_{ij}^{2.386}}$$

Number of retail establishments (NR) - Distance (D)

$$T_{ij} = \frac{1448.114(NR_i \cdot NR_j)^{0.675}}{D_{ij}^{2.401}}$$

Number of service establishments (N) - Distance (D)

$$T_{ij} = \frac{279.177(NS_i \cdot NS_j)^{0.789}}{D_{ij}^{2.457}}$$

Number of hotels, motels, and tourist camps (H) - Distance (D)

$$T_{ij} = \frac{18867.046(H_i \cdot H_j)^{0.746}}{D_{ij}^{2.334}}$$

The program output used by Oklahoma also listed the statistical characteristics of the models. Analysis showed that the parameters studied have nearly the same estimating power. All of the regression constants were significantly different from zero and the standard errors of the estimates were nearly all the same, ranging from 0.847 to 0.865. It was obvious from this that all of the parameters were stating the same

things; hence the next test was to see which parameter had the most significance. To accomplish this, an "overall" model was assembled using all of the parameters.

$$\begin{aligned}\log T_{ij} = \log a_0 = & a_1 \log(P_i P_j) + a_2 \log(RS_i RS_j) \\ & + a_3 \log(NR_i NR_j) + a_4 \log(NS_i NS_j) \\ & + a_5 \log(H_i H_j) + a_6 \log D_{ij}\end{aligned}$$

This model yielded the following statistical results:

standard error of estimate $s = 0.802$

$$R^2 = 0.768$$

$$F = 33.297$$

Therefore the F ratio tests indicate that the constants are significantly different from zero. A "T" test on the parameters showed that distance was the most significant with $t = 153.9674$, followed by service establishments ($t = 2.2969$), and then, in order, lodging ($t = 1.5108$), population ($t = 0.2623$), retail establishments ($t = 0.0993$), and retail sales ($t = 0.0529$).

Minnesota (1971)

Minnesota combined some interesting techniques in arriving at their statewide model (30). First, in collecting origin - destination data, even though travel analysis zones were sized with a minimum population of 2500, only urban areas with more than 5,000 population, with a few exceptions, were included in the study. In addition, one major recreational area and all major highways crossing the state line were scheduled for roadside interviews (see Figure III-1). Population data were collected to relate the number of trips observed to and from an urban area to the

CITIES, METRO AREAS & STATE-LINE CROSSINGS SCHEDULED FOR INTERVIEWING

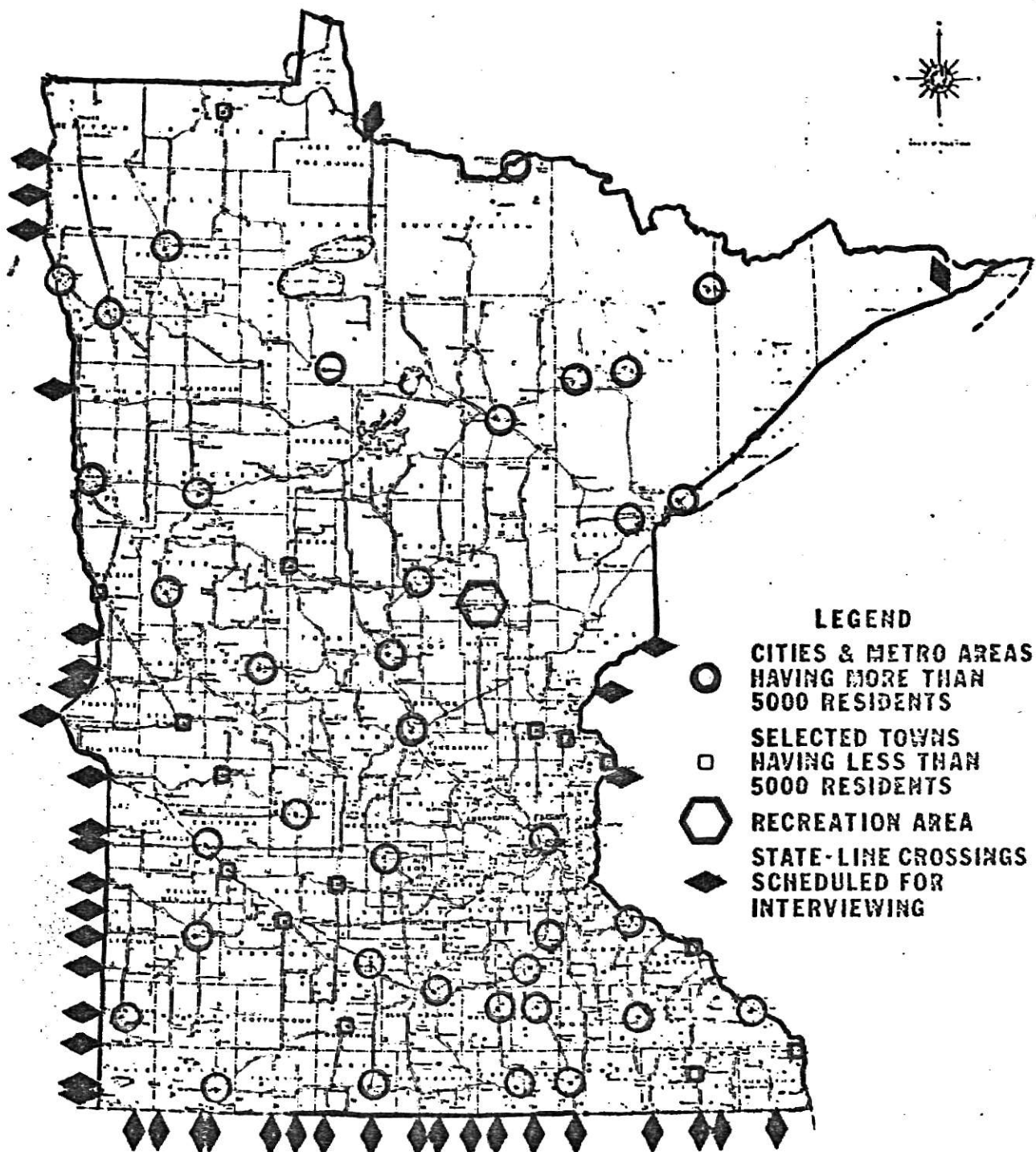


FIGURE III-1

**AREAS SELECTED FOR OBTAINING ORIGIN-DESTINATION
DATA FOR MINNESOTA'S STATEWIDE MODEL**

number of persons residing various distances from the town. Four different measures of population were used as a measure of the independent variable:

1. 1960 population
2. 1966 population estimate
3. 1960 population adjusted for seasonal variations
4. 1966 population adjusted for seasonal variations

Population adjustments were based on seasonal variation of traffic flow on highways serving urban areas.

A curve was first established relating generated travel to population. The equation for this curve was:

$$Y_c = \text{Anti-log } (1.587 + 0.604858 \log X)$$

where: Y_c = trips

X = population

Further analysis indicated that when trip length frequencies and populations were compared, there was a trend showing more trips per person in the studied area as the area population increased. The small cities, where this trend was more apparent, were split into four population groups. The data from trip length frequency tables were then plotted as length of trip versus trips per person (see Figure III-2). The line values from these curves would be used to distribute the trips generated by the final model.

Of interest to the developers of this model were the observed fluctuations in the traffic in certain highways during summer months. In order to look at these variations more closely, the state was divided into areas

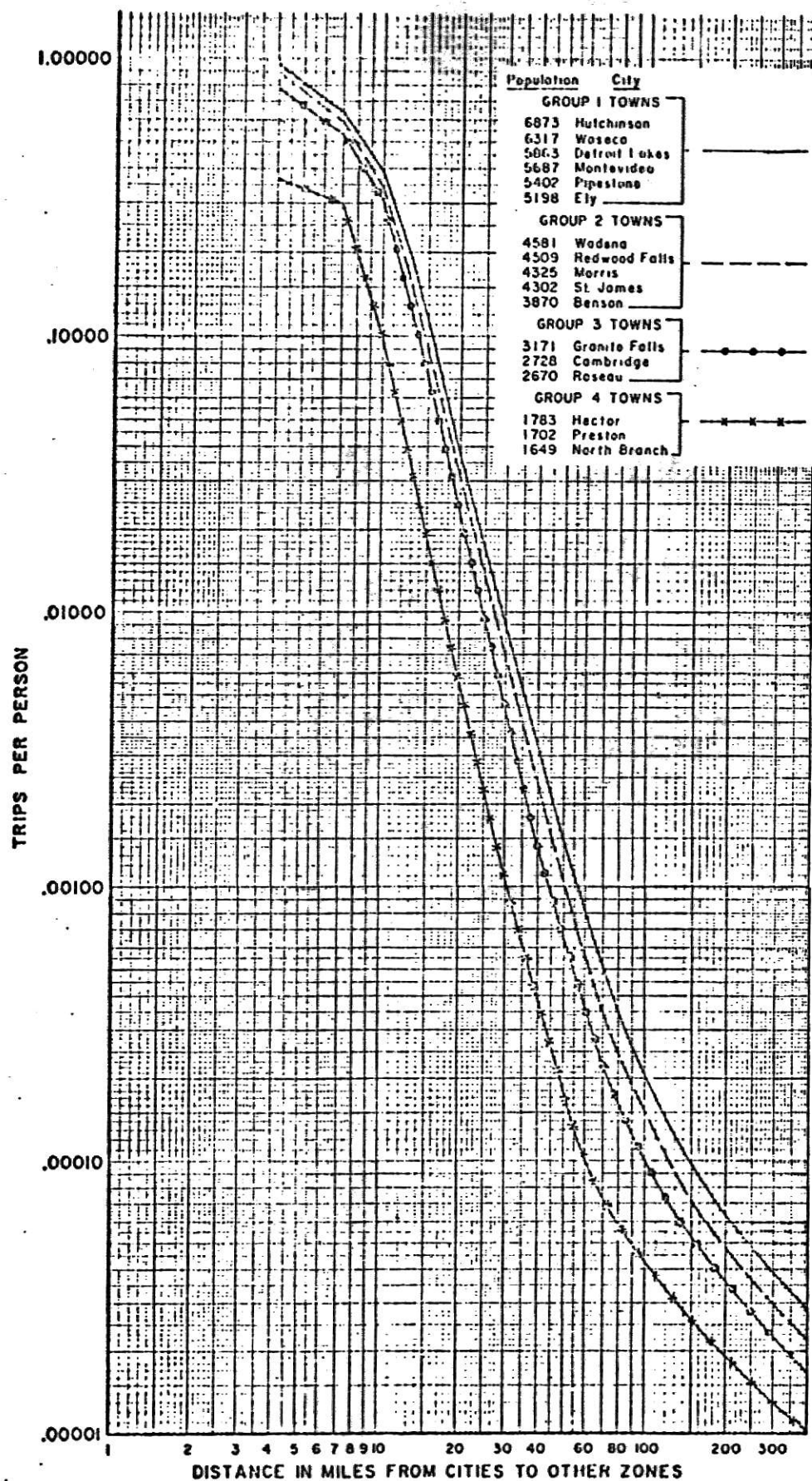


FIGURE III-2
 PLOT OF TRIPS PER PERSON AGAINST TRIP LENGTH
 FOR GROUPS OF TOWNS IN MINNESOTA

according to travel purpose and the ratio between volume observed in separate summer months and the average summer monthly volume for each category as listed below was studied for significance.

	<u>June</u>	<u>July</u>	<u>August</u>	<u>Summer Average</u>
1. farm to market	110	112	116	113
2. some recreational	118	129	127	125
3. highly recreational	125	142	142	136
4. very highly recreational	139	182	166	162

From these observations, expansion factors were developed and applied to urban populations within these areas. Also, an index was derived for use in the trip generation model which could make final adjustments related to trip purpose.

By regression analysis it was found that both a straight line and a curvilinear model could represent the associated population and travel.

The results are listed here:

Straight line models:

$$T = 4914 + 0.516 (1960 \text{ pop.}) + 3192 (\text{Index})$$

$$T = 4533 + 0.550 (1966 \text{ pop.}) + 3166 (\text{Index})$$

$$T = 4732 + 0.418 (1960 \text{ adj. pop.}) + 2980 (\text{Index})$$

$$T = 4354 + 0.445 (1966 \text{ adj. pop.}) + 2929 (\text{Index})$$

Curvilinear models:

$$T = 42.84 (1960 \text{ pop.})^{0.600} \times (1.422)^{\text{Index}}$$

where: T = total trips generated.

The choice of index was based primarily on geographical considerations and land use. It was found that many areas located in the lake areas of north and west-central Minnesota (areas associated with high tourism)

required a "+1" index. Some areas in the predominantly agricultural area of southern Minnesota required a "-1" index with the remainder of the areas in the state requiring no adjustment of a "0" index. The actual assignment of index values to different zones was based on an analysis of the traffic volumes and the model being used to estimate traffic.

Michigan (1972-1975)

In the early 1970's, the State of Michigan Highway Department, Transportation Planning Division (31), began work with statewide transportation assignment models. In the introduction to one of the several publications released by Michigan on the subject of statewide models, the following comment sums up the trend toward statewide planning:

"In order to more efficiently allocate the public resources available, some highway agencies have turned to analysis of transportation at the statewide system level. States which have developed a statewide traffic forecasting model have recognized that effective planning must take into account the comprehensive review of many interrelated factors. To this end, selected highway planning agencies have modeled the entire transportation system, complete with social, economic and environmental aspects of travel (32)."

Michigan has currently completed work on models for automobile trip assignment and multi-modal trip distribution and is presently working with a commodity flow model.

The first model set up by the state was for highway travel only. The state was divided into 480 internal zones, and 30 external zones were established outside the state. With the exception of Detroit, zones were based on individual townships or combinations of townships because population information and forecasts were available on this basis. It was found also that the townships were sufficiently large to provide the

necessary degree of homogeneity within the zones. The highway network connecting the zone system was comprised of all state trunk highways and a selected portion of county roads. This network included 30-35% of the entire road network of the state.

Various independent factors were studied as to their applicability to the assignment model. In a statewide model, when zones have been established as nearly homogeneous areas, population and economic factors become indistinguishable in most cases and tend to merge into a single measure of traffic movement potential. It was established that throughout the state, at any given point in time, car ownership appears to be dependent on population. Other data collected indicated that total intercity, motor-vehicle travel is quite constant and independent of location of auto registration. Accordingly, it was decided to use only population as a factor in trip generation.

Time, distance, or cost factors serve as a measurable deterrent to travel. The deterrence is not based solely on distance; the quality and capacity of roads as they influence travel times, costs and aesthetic values will also influence the allocation.

The highway trip assignment and distribution model developed by Michigan was capable of allocating traffic to individual highway links. With modifications, it also could be used to distribute traffic on a series of roads or road combinations such as might be observed when traffic is redistributed because of an overloaded route.

The trip generation equation developed from regression analysis was as follows:

$$\text{(general trips)} \quad N = 1.04 P_c^{0.89} \frac{P_c + P_e^{0.19}}{P}$$

$$\text{(heavy truck trips)} \quad N = 0.062 P_c^{0.89} \frac{P_c + P_e^{0.11}}{P}$$

where: P_c = zone population

P_e = external ring population (within 30 miles from zone center)

N = interzonal trips generated in each direction

$P = P_c + P_e$

Certain limitations were noted on these early models shown above because of data from various surveys not "mixing" very well. It was also noted that the "tune up" or calibration procedures used were crude.

In 1974, Michigan published a report on work with multi-modal assignments. The work of developing traffic assignment in this report is handled entirely by computer programs. Three major programs, PATH, MODAL SPLIT, and NET LOAD combine to give good results for transportation planners. This new modeling system holds the "potential for addressing many questions which are currently at issue, such as branch line abandonments, avoidable costs, subsidy tradeoffs between modes, and induced revenues generated by improvements in frequencies of service (33)."

Tennessee (1973)

Tennessee has recently completed the initial phases of development of a statewide multi-modal transportation model (34). Based on limited origin-destination data which was already available for trips originating in 7 of the 95 counties in the state, the following model was formulated:

$$\begin{aligned} \text{Trips}(ij)_h + \text{trips}(ij)_a = & \beta_0 (\beta_i \beta_j P_i P_j)^{\beta_1} [(\text{time}_h)^{\alpha_4} (\text{cost}_h)^{\alpha_5} \\ & + \alpha_a (\text{time}_a)^{\alpha_1} (\text{cost}_a)^{\alpha_2} (1 - e^{-K \text{ freq.}})^{\alpha_3}]^{0.9} \end{aligned}$$

where: subscript h refers to highway variables

subscript a refers to airline variables

k = 0.12 from earlier work

$$\left. \begin{array}{l} \beta_0, \beta_1, \beta_i, \beta_j \\ \alpha_0, \alpha_1, \alpha_2, \alpha_3, \\ \alpha_4, \alpha_5 \end{array} \right\} = \text{calibration constants}$$

Analysis produced the following values for these constants:

$$\beta_0 = 0.1$$

$$\beta_1 = 1.76$$

$$\beta_i \text{ ranges from } 0.08 \text{ to } 1.35 \text{ depending on the county}$$

$$\alpha_4 = \alpha_5 = -1.46$$

$$\alpha_1 = \alpha_2 = -0.72$$

$$\alpha_3 = -1.13$$

$$\alpha_a = 6.2 \times 10^{-4}$$

The results showed (34) "an acceptable degree of accuracy as measured by overall averages" but the report pointed out that there were large differences in volume between certain city pairs.

The data collected for this first trip model included; automobile trip data from 7 county origins to all other counties, scheduled airline volumes between 9 counties within the state collected from a 10 percent sampling of tickets taken by the Civil Aeronautics Board in 1967, highway travel times and distances on the statewide network, scheduled airline travel times, costs and frequency, 1970 county populations and the fraction of families with incomes greater than \$10,000 as taken from census records.

A more extensive transportation need survey was being planned in 1973 with the objectives of determining the number of trips taken over a one year period on all modes of transportation. The survey was to be conducted using a combination of Home Interviews (mailed questionnaires) and roadside interviews. Actual interviews were to be conducted on stations along low volume roads while license numbers only would be recorded on freeways and other high volume routes and questionnaires would be sent to the owner of the vehicle. General aviation traffic would be surveyed by questionnaires mailed to owners registered through the FAA, and bus companies would be asked to summarize their passenger manifests over all routes.

The State of Tennessee decided to use four screenlines across the state and a cordon around the state border primarily to separate local travel from intercity or interstate travel.

Rhode Island (1975)

In 1961 the State of Rhode Island conducted the Providence Metropolitan Area Transportation study which obtained travel data in an area containing 89 percent of the 859,488 state population. With only a small percentage of the state travel data remaining, it was a minor task to gather data for rural travel simulation.

The state was divided into 497 internal zones, and 53 external zones were formed outside the state based on census tracts. Based on social and economic data available for all of the zones, the following two sets of generation equations were developed:

$$\text{Work Trips} = 66.95 + 0.81 \text{ LF}$$

$$\text{Shopping Trips} = 20.07 + 0.66 \text{ A}$$

$$\text{Social-Recreation} = -27.12 + 1.10 \text{ A}$$

$$\text{Non-Home based} = 44.08 + 0.09\text{P} + 0.1\text{ME} + 0.4\text{TE} + 0.61\text{SE}$$

$$\text{Miscellaneous Trips} = 55.47 + 0.76\text{A}$$

$$\text{Work Trips} = 179.19 + 0.62\text{E}$$

$$\text{Shopping Trips} = 158.10 + 1.32\text{TE}$$

$$\text{Social-Recreational} = 205.39 + 0.18\text{P}$$

$$\text{Non-Home Based} = 46.71 + 0.9\text{P} + 0.8\text{ME} + 0.43\text{TE} + 0.34\text{SE}$$

$$\text{Miscellaneous Trips} = 80.70 + 0.9\text{P} + 0.55\text{TE} + 0.89\text{SE}$$

where: LF = labor force

A = automobile registration

P = population

ME,TE,SE = manufacturing, trade and service employment

E = total employment.

The gravity model was used to simulate trip interchange.

In 1971 Rhode Island conducted another extensive O-D survey to update their statewide traffic assignment model (5). Rhode Island's unique method of using cameras and videotapes in conducting the external survey has been previously discussed. In addition to this form of roadside interview, a home interview survey was conducted by telephone over a random sample of 1420 units over the state. Questionnaire surveys were also developed for airline passengers, taxi drivers, mass transit riders, airport employees, and trucking companies. A sample of some of these forms can be seen in Figure III-3a, III-3b and III-3c.

**Rhode Island
Department of Transportation
Division of Planning
In Cooperation with U.S.D.O.T.
Federal Highway Administration**

ON BOARD SURVEY QUESTIONNAIRE
AIRPORT TRAVEL SURVEY
Rhode Island Statewide O-D Update Study
0000 INBOUND 0000

ALLINSON INC.
Warwick, R. I.

Form Air 3A

Serial No. Nº 270 Travel Day _____

1. At what airport did you begin your trip?

Airport State or Country

2. To what address (or nearest street intersection or building) will you go after leaving this plane?

Street Address or Nearest Street Intersection or Building

City State Zip

3. How will you travel to this address? (circle one)
a. Auto: (1) private (2) rented or leased (3) courtesy (4) company
b. Taxi
c. Limousine
d. Bus
e. Other Specify _____

4. Do you live in either Massachusetts, Rhode Island or Connecticut?
YES NO (circle one)

5. If YES, what is your home address (or nearest street intersection) If this is not the same address as given in question number 2?

Street Address or Nearest Street Intersection

City State Zip

6. What is the purpose of your trip? (circle one)
a. Work or Business
b. Vacation or Recreation
c. Personal Affairs
d. School
e. Military Orders
f. Other (Specify) _____

7. What is your occupation? _____
(example: Salesman, Engineer, Doctor, Carpenter, etc.)

8. What type of industry are you working in? _____
(example: Jewelry manufacturing, Jewelry wholesale, Jewelry retail, city government, state government, federal government, self-employed, etc.)

9. Are you a MALE or FEMALE? (circle one)

10. What is your age? (circle one)
a. 0 — 16
b. 17 — 21
c. 22 — 34
d. 35 — 44
e. 45 — 54
f. 55 — 59
g. 60 and over

11. Please circle the last year of school you have completed.
a. Elementary: 0 1 2 3 4 5 6 7 8
b. High School: 9 10 11 12
c. College: 1 2 3 4
d. Graduate School: 1 2 3 4

Rhode Island
Department of Transportation
Division of Planning
In Cooperation with U.S.D.O.T.
Federal Highway Administration

ON BOARD SURVEY QUESTIONNAIRE
AIRPORT TRAVEL SURVEY
Rhode Island Statewide O D Update Study
and OUTBOUND TRIP



ALLINSON INC.
Warwick, R. I.
Form Air 30

Serial No. **N^o 2521**

Travel Day _____

8

9 10 11 12

1. From what address (or nearest street intersection or building) did you begin your ground trip to the airport?

13 14

(and)
Street Address or Nearest Street Intersection or Building

City State Zip

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

2. How did you travel to the airport today? (circle one)

- a. Auto: (1) private (2) rented or leased (3) courtesy (4) company
b. Taxi
c. Limousine
d. Bus
e. Other Specify _____

53

3. How long did it take you to get from that address to the airport?

Hours Minutes

54 55 56 57

4. How much did it cost you to get from that address to the airport, if you paid a fare?

\$ _____

58 59 60 61

62

5. Do you live in either Massachusetts, Rhode Island or Connecticut?

YES NO (circle one)

63

6. If YES, what is your home address (or nearest street intersection) if this is not the same address as given in question number 1?

(and)
Street Address or Nearest Street Intersection

City State Zip

32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65

7. What is your final destination?

City State or Country

66 67 68 69

8. Will it be necessary to change planes to reach this destination?

YES NO (circle one)

70

9. What is the purpose of your trip? (Circle One)

- a. Work or Business d. School
b. Vacation or Recreation e. Military Orders
c. Personal Affairs f. Other (Specify) _____

71

10. What is your occupation?

(example: Salesman, Engineer, Doctor, Carpenter, etc.)

72

11. What type of industry are you working in?

(example: Jewelry manufacturing, Jewelry wholesale, Jewelry retail, city government, state government, federal government, self-employed, etc.)

73

12. Are you a MALE or FEMALE? (circle one)

74

13. What is your age? (circle one)

- a. 0 — 16 e. 45 — 54
b. 17 — 21 f. 55 — 59
c. 22 — 34 g. 60 and over
d. 35 — 44

75

76

14. Please circle the last year of school you have completed.

- a. Elementary: 0 1 2 3 4 5 6 7 8
b. High School: 9 10 11 12
c. College: 1 2 3 4
d. Graduate School: 1 2 3 4

77 78

79

FIGURE III-3b

QUESTIONNAIRE DISTRIBUTED TO OUTBOUND AIRLINE
PASSENGERS IN RHODE ISLAND'S SURVEY

Rhode Island
Department of Transportation
Division of Planning
In Cooperation with the DOT
Federal Highway Administration

This information will be held in strictest confidence

Nº 20550



ALLINSON INC.
Form M.T. 1

MASS TRANSIT SURVEY

Dear Bus Rider:

This survey of bus riding is being conducted in order to plan better transportation for the State. Your assistance will provide essential information for this planning. A survey card should be filled out for each passenger five years of age or older.

Completed questionnaires received before the end of this week will be eligible for prize drawings. There will be five \$20.00 prizes and thirty \$10.00 prizes. We hope that you take advantage of this opportunity to help improve transportation in the State, and to perhaps win a cash prize. Please complete the questionnaire and return it to the driver, or mail it today — postage free.

Your cooperation in this important survey is appreciated.

Thank you

PLEASE PRINT

1 MY HOME ADDRESS IS:
(Street No.) (Street Name) (City or Town Name — Not Post Office)

2 I GOT ON THIS BUS AT (Nearest Street Intersection) (City or Town)

3 THE TIME OF DAY WAS
AM
PM
(Record Time of Day & Circle AM or PM)

4 I GOT TO THIS BUS BY (Check One)
☐ Walking ☐ "Park and Ride" ☐ Other (If other, specify)
☐ Auto-Passenger ☐ Bus

5 I CAME FROM (Check One)
☐ Home ☐ Shopping ☐ A Recreational Activity
☐ Work ☐ A Social Activity ☐ School ☐ Conducting Personal Business

6 THE PLACE I CAME FROM IS LOCATED:
(Street Number & Name or Building Name) City or Town

7 I WILL GET OFF THIS BUS AT:
(Nearest Major Building Name or Nearest Street Corner) (City or Town Name)

8 I AM GOING TO (Check One)
☐ Home ☐ Shopping ☐ A Recreational Activity
☐ Work ☐ A Social Activity ☐ School ☐ Conducting Personal Business

9 THE PLACE I AM GOING TO IS LOCATED AT (Record final Destination)
(Street Number & Name or Building Name) (City or Town Name)

10 AFTER LEAVING THIS BUS I WILL GET TO MY DESTINATION BY (Check One)
☐ Walking ☐ Auto ☐ Train
☐ Taxi ☐ Bus ☐ Other (If Other, Specify)

11 IS THIS TRIP PART OF A ROUND TRIP BY BUS TODAY? (Check one) ☐ Yes ☐ No
If "Yes", record the starting time of the trip in the opposite direction: AM
PM
(Record Time of Day & Circle AM or PM)

12 PLEASE ANSWER THE FOLLOWING THREE QUESTIONS ABOUT AUTOMOBILES IN YOUR FAMILY.
a. Are you a licensed driver (check one) ☐ Yes ☐ No
b. How many other persons in your family are licensed drivers? _____
c. How many automobiles do you have in the family? _____

13 WHAT IS YOUR OCCUPATION? (example: Salesperson, Machine Operator, Student, Retired, etc.) _____

14 WHAT TYPE OF INDUSTRY ARE YOU WORKING IN? (example: Jewelry, Manufacturing, Jewelry Wholesale, Jewelry Retail, City Government, State Government, Federal Government, Self-Employed, etc.) _____

15 ARE YOU MALE OR FEMALE? (Circle One)

16 WHAT IS YOUR AGE? (Circle One)
a. 5—16 c. 22—34 e. 45—54 g. 60—64
b. 17—21 d. 35—44 f. 55—59 h. 65 and over

17 HOW MUCH INCOME DID YOUR FAMILY RECEIVE IN 1971 FROM ALL SOURCES?
(Circle) a. 0—999 c. 3,000—4,999 e. 8,000—9,999 g. 15,000—19,999
(range) b. 1,000—2,999 d. 5,000—7,999 f. 10,000—14,999 h. 20,000 and above

18 PLEASE RECORD YOUR HOME TELEPHONE NUMBER. YOU WILL BE CALLED IF YOU ARE A PRIZE WINNER OR IF ADDITIONAL INFORMATION IS NECESSARY. _____

AFTER COMPLETING THIS CARD, PLEASE GIVE IT TO THE DRIVER OR DROP IT IN ANY U.S. MAIL BOX.

THANK YOU

FIGURE III-3c

QUESTIONNAIRE DISTRIBUTED TO MASS TRANSIT
PASSENGERS IN RHODE ISLAND'S SURVEY

The main reason for this second study conducted by Rhode Island was to update statewide data and computerize the 1966 synthetic trip distribution system.

West Virginia (1975)

The West Virginia Department of Highways, in 1975 was in the last phase of developing a statewide traffic assignment model (35). They have established the traffic study zones, a base network, socio-economic growth factors, and have developed several traffic assignment models based on different socio-economic parameters.

The traffic zone system was established on a given criteria of developability. Consideration was given to population, land use, potential trip generation, barrier to travel, geometric shape and accommodation for traffic assignment. Centroids were identified for trip loading with special attention paid to the prospect that future development might create the need for additional zones. The instate zone system was comprised of 909 zones; there were 134 external zones established outside the state borders with the majority of these being in the surrounding five states.

The base year highway network included all major rural and urban roadways which presently carry statewide and interstate travel. It was believed that a network of this magnitude is of sufficient size so that 80 to 90 percent of all intercity travel in the state could be simulated. With the inclusion of major highways and interstates which lie outside the boundaries of West Virginia, the network is also extensive enough to provide proper assignment to interstate trips passing through or near the state.

Within the State of West Virginia, the initial basis for the network was the facilities open to traffic in 1969 on the Legal Functional System of Highways and the National Functional Classification Study. For the base network, these systems included the "expressway," "trunkline," and "feeder" systems also known as "principal arterial", "minor arterial," and "major collector" systems depending on what classification system is referred to. These systems in general provide for most trips over 10 miles in length and interconnection of population centers of over 200 population.

With the development of the highway network, centroids were established for each zone. All trips that began or ended in a traffic zone were assumed to be loaded on the network at the centroid. The location of zone centroids was then based on a judgement as to the distribution of trip ends within each zone. The density of development in each zone and the type of development, i.e., commercial, residential, were used to locate centroids.

With the network established, such information was obtainable on link distance, link speed, traffic content geometrics, etc., so as to determine a sufficiency rating over all routes.

The initial step in the development of a trip generation and distribution model for the State of West Virginia was to conduct a study of intercity travel between 18 urban centers. A functional relationship between trip volumes and socio-economic characteristics of their origins and destinations was established by use of regression analysis. A summary of the results of that initial study are as follows:

1. A set of trip generation equations was developed for total trips, home based, shopping, work, social and recreational, and non-home based purposes. These are listed on Figure III-4.
2. Interaction type models involved populations and travel time functions were developed to describe the trip distribution relationships*.
3. A competing gravity model was tested for twelve cities of this study. The results obtained from this model suggest that this method can be efficiently used to describe intercity trips throughout the state*.
4. Characteristics of the trips underlying travel between communities were analyzed through correlation, regression and trip length frequency distributions. These results were in general agreement with those of other states of this type*.
5. The findings of the study indicate that it is also feasible to predict trip generation and distribution relationships for travel between small communities based upon the same approach and techniques*.

Nebraska (1975)

Nebraska's objective in the development of a statewide traffic assignment model was for research to fill several other needs related to future traffic assignment (36). The model is intended for use as an aid in forecasting traffic on the state highway system and major feeder roads, in forecasting traffic on a proposed freeway-expressway system and evaluating these facilities in terms of probable traffic diversion, in evaluating future highway needs on a statewide basis, in assigning functional classifications, in assigning project priorities, in programming stage construction plans, in supporting requests for federal aid funds, and for other similar purposes.

*Details of these findings are published in a report entitled, West Virginia Intercity Trip Generation and Trip Distribution Relationships, by Plummer and King, Civil Engineering Department, West Virginia University.

RECOMMENDED REGRESSION EQUATIONS FOR ALL CITIES

Trip Type	Equation	R ²
Total Trips - (T ₁)	2236+5.74 WREMP	0.82
Home Based - (T ₃)	1769+1.33 AUTO+4.26 WREMP	0.85
Home Based Work - (T ₄)	554+0.39 HH	0.87
Home Based Shop - (T ₅)	265+0.71 INC 4,000-0.36 EDU	0.69
Home Based Social & Recreation - (T ₆)	142+0.38 AUTO-0.28 EDU	0.73
Non-Home Based - (T ₈)	301+0.80 WREMP	0.78

WREMP = Wholesale and retail trade employment

HH = Number of households in the community

EDU = Number of people with at least 4 years of high school

INC = 4,000 = Number of people with incomes greater than \$4,000/yr.

TABLE 3-4

REGRESSION EQUATIONS BASED ON CITY SIZE

City Size Group	Dependent Variable	Equation	R ²
1. POP 5,000 * N = 5	Total Trips, T ₁	-923+7.78 HE-465 EDU	0.92
	Home Based, T ₃	85.75+2.76 HH	0.70
	Non-home Based, T ₈	705+.624 AGE 14-.58 PCAP	0.76
2. 5000 POP 10,000 N = 4	Total Trips, T ₁	1.57 POP+0.36	0.925
	Home Based, T ₃	.389 AUTO+310 MEDSCH	0.95
	Non-Home Based, T ₈	0.43 ENPL-0.034 POP	0.90
3. POP 10,000 N = 5	Total Trips, T ₁	1.07 AUTO+.132 PCP	0.91
	Home Based, T ₃	2.59 HH+1181 MEDSCH -.286 AUTO	0.98
	Non-Home Based, T ₈	0.10 ENPL+0.03 POP	0.92

* N = Number of cities in group

R² = Coefficient of determination

Source: West Virginia Trip Generation and Trip Distribution Relationships Final Report, November, 1973

Pgs. 64, 65, 67, 68 and 69

FIGURE III-4

REGRESSION EQUATIONS FOR TRIPS DEVELOPED FOR THE
WEST VIRGINIA STATEWIDE ASSIGNMENT MODEL

An example of this diversified intent was the use of the data collected in the initial O-D survey. Besides being used in the development of the assignment model, the data served an immediate need to provide required input to pending corridor and bypass studies.

For the O-D survey, roadside interviews were conducted in a fashion similar to that used by Minnesota. A total of 49 stations were set on a stateline cordon. Urban cordon lines were established around larger Nebraska towns. Existing external cordon line information from urban transportation studies for three large cities was used in connection with the data being collected. Initially it was felt that sufficient data could be collected by cordon lines set only around towns of population 3500 or more, but it was later decided that in order to develop the capability for subsequent refinement and periodic updating of the model, external cordon lines would also be set around a 12.5% sample of the 152 Nebraska communities between 500 and 2500 persons. It was noted that the exclusion from the sample of the 335 or so towns with fewer than 500 inhabitants was based on the hypothesis that these towns generated a negligible percentage of the average summer weekday traffic on the assignment network since their residents constituted only 5% of the state's population.

It is of particular interest to note the method Nebraska used in developing between zones in the trip generating equations. The state was divided into 882 zones of which 70 were classified as "full zones" because they had a full cordon of O&D stations. The remaining 811 zones were classified as "non-full zones" since most of them contained only towns with population of less than 1,000. It was decided to aggregate

groups of zones with similar population densities within certain areas so the sample populations would be large enough for statistical calculations during the development of the generation equations. This aggregation gave a sample of 36 zones to be used as base data. Zones with populations greater than 5,000 were excluded from the sample because all such zones were full study zones and there was no need to generate trips for them (see Figure III-5).

Two groupings of sample zones were tried in an effort to improve the accuracy of generation equations. One grouping separated zones by population with one subgroup of populations of 2,500 or less and the other for over 2,500. The other grouping was based on the population density in which the zones were located. All zones in counties with densities of 10.5 persons per square mile or less were included in a subgroup called the western zones and the remaining zones were in the other subgroup called eastern zones (see Figure III-5). The best fit to the base data was obtained using the population density grouping. The resulting regression equations were:

$$T_i = -1.38 + 1.24P_i \quad \text{for eastern zones, and}$$

$$T_i = 149.13 + 0.855 P_i \quad \text{for western zones}$$

where: T_i = production and attraction for zone i

P_i = population of zone i

The root mean square error of the estimate for the generated trips was 0.26 trips per person for both eastern and western zones. This represented an error of 27% of the mean for the western zones and 21% for the eastern zones. The greater relative error for the western zones

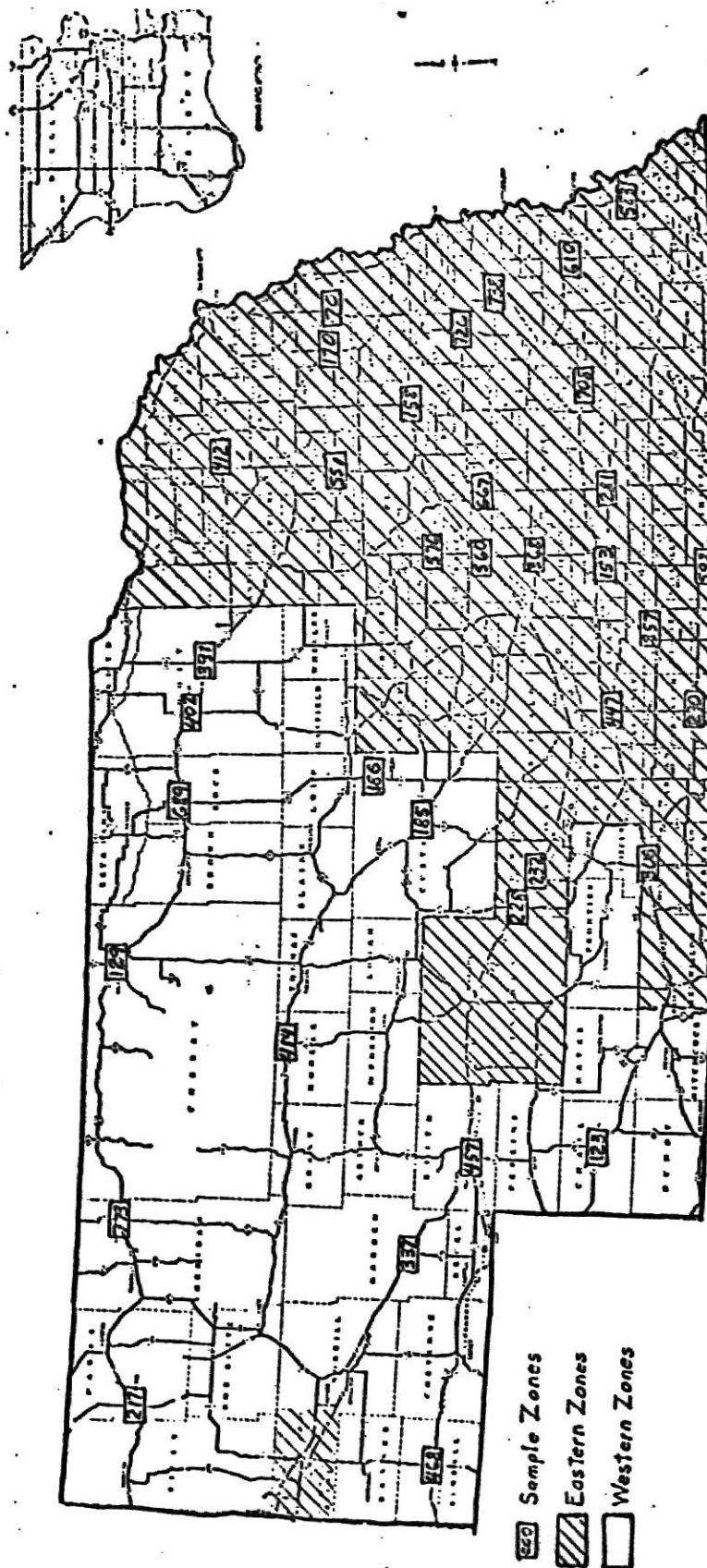


FIGURE III-5
NEBRASKA'S TRAFFIC ANALYSIS ZONES SHOWING
DIVISION BY POPULATION DENSITIES IN COUNTIES

was probably due to smaller sample size and greater disparity between zones within sample. While these errors were larger than desired, they were considered acceptable at the 80% confidence level.

Wyoming (1975)

Wyoming, in conducting their statewide traffic survey, used two mathematical simulation techniques not found very often in statewide traffic assignment (6).

The first of these simulation methods was used to distribution trips entering the state from surrounding areas. This simulation was necessary because Wyoming conducted their primary Origin-Destination survey by questionnaires distributed to residents only. With this approach it is possible to use Origin-Destination data collected at the entry point to distribute "foreign" trips throughout the state since there were no internal stations set up which could pick up these trips. The method considered two types of foreign trips: 1) trips passing through the state, termed "bridge trips," and 2) trips having destinations within the state, termed "non-bridge" or "external" trips. The end result of this was a distribution of bridge and non-bridge interchanges over all the possible exists or destinations within the state based on a seasonal input of incoming foreign ADT at each of the 38 roads crossing the state's borders.

The simulation model operated on one vehicle at a time using a Monte Carlo procedure to determine whether the vehicle was on an external-internal or a bridge trip. The process was repeated until the number of vehicles processed was equivalent to sixty days traffic on each of the roads leading into the state. The model is mathematically formulated as described below:

$$T_{ij} = \sum_{n=1}^{N_i} \sum_{j=0}^{38} K_j \quad i = 1, 2, 111, 38$$

where T_{ij} = the number of trips from entry point i to exit point j if $j > 0$; if $j = 0$, T_{ij} is the number of external-internal trips from entry point i to destinations within the state

k_j = a dummy variable, assuming a value of 0 or 1 under the following conditions: If $P_j < R_n < P_j + 1$ then $k_j = 1$, otherwise $k_j = 0$.

R_n = a uniformly distributed random number in the interval (0,1)

P_j, P_{j+1} = lower and upper end points, respectively. The P_j 's correspond to a particular value of i and thus can represent the probability distribution governing destination at those trips entering at i .

A similar model was developed for bridge trips which had a short stopover at a particular community, recreational area or lodging facility.

The empirical trip distribution model developed to distribute trip productions for the three types of travel studied within the state (non-commercial resident, lightweight commercial and heavy commercial travel) was a modified competing opportunity model.

$$T_{ij} = (P_i D_{ik}) A_{jk}$$

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

P_i = estimated trip productions in zone i that are attracted to zones in distance band k

$$A_{jk} = \frac{\text{estimated attractions in zone } j \text{ (in band } k\text{)}}{\text{total estimated attraction in band } k}$$

The model used by Wyoming had two important differences compared to the traditional competing opportunity model. First, the traditional model stipulates that every opportunity (destination) within a given time or distance band from the zone of origin has an equal probability based on

the zones' total attractiveness to all other zones of being selected Wyoming's model uses uniform probabilities based on the zones' attractiveness to the origin zone rather than equal ones. Second, the competing opportunity model is calibrated by varying bandwidths until trip-length frequencies match. Wyoming's model assumes the band widths to be constant and is calibrated by adjusting the synthesized trip ends for each band. A further modification was made to permit more extensive use of sample data. This change incorporated trip length frequencies to trips attracted to each zone as follows:

$$A_{jk} = \frac{\text{estimated number of attractions of trips of length } L \text{ to zone } j}{\text{total estimated number of attractions of trips of length } L \text{ to all zones in distance band } k}$$

Kentucky (1976)

The Kentucky Department of Transportation is in the process of developing a comprehensive statewide traffic model (4). Perhaps the most interesting research completed at this time on the project is the Home Travel Survey which was used to collect socio-economic data across the state for comparison with the base year 1970. This was the largest and most time-consuming of the data collecting activities, and in terms of model development, the most important.

The household travel survey (HTS) was designed to collect information on weekday and Sunday travel in order to maximize efficiency from the survey process. Only weekday information will be processed into the model format at the time of the survey, the weekend information being checked only for accuracy as it is intended for use later in a weekend travel model. The survey procedure included selecting a 1 percent random sample

from automobile registrations for each county. A self-administered questionnaire was mailed to each person selected for the sample. Residents receiving the questionnaire were asked to record information about the household and about all vehicle trips made on one designated weekday and one Sunday. Telephone and personal interview follow-ups were used to verify or clarify responses from a subsample of 30 households per county. Based on a FHWA recommendation, a minimum of 30 responses per county were obtained. The sample size was adjusted based on a pilot survey.

The HTS questionnaire and associated material were mailed third class so as to reach the sampled households one or two days before the survey day. The economy of the third class mail service, however, was overshadowed by the low priority and resultant situation where the questionnaire would arrive at the household after the survey day and sometimes even after the first reminder letter. Two reminder letters were mailed. The first reminder was mailed first class so as to arrive three days after the survey day and was sent to all the sampled households. Mailings were accompanied by news releases on local TV and radio stations and in local newspapers. The second reminder letter was accompanied by all the material included in the initial mailing and was mailed if no response had been received 12 days after the survey day. If no response was obtained from the second reminder, no further effort was tried unless the household was one of sub-sample elements. In that case, a home interview survey was done 21 days after the second mailing.

Using this system of surveying, the statewide response rate to the mailed surveys was 40% with a high of 53% and a low of 22%. Total response rate after telephone and home interviews was 45% with a high

of 65% and a low of 37%. Figures III-6a-c show the format for the mailed household survey used in Kentucky.

A truck travel survey was conducted in a manner similar to the HTS. Information was collected for specific registered vehicles. The same sample elements were selected as 2% of the trucks with gross weight less than 26,000 lb. and 5% of the larger vehicles. A state-wide sub-sample of 2,500 was selected for telephone and personal follow-up interviews.

Field O-D surveys were also conducted to check information obtained through the household and truck surveys. The surveys were conducted at about 20 locations in the state on selected main rural roads, including principal and minor arterial highways.

A stratification scheme relating certain geographic and economic variables was devised. The scheme was based on research reported in Highway Research Record 240 to correct for non-response bias.

At the present time Kentucky plans to use a gravity type trip distribution model which will be calibrated using zonal trip end data synthesized from trip generation equations. Factors will be used to adjust the model until the model trip lengths distributions match those produced from factored survey data. The model will be internally iterated to balance trip attractions. Separate distribution models will be developed for each trip purpose used in trip generation analysis. As an additional check, the network will be loaded and model volumes checked on specific screenlines, and cutlines will be compared to ground counts.

APPENDIX B-3

**KENTUCKY STATEWIDE TRAVEL SURVEY
HOUSEHOLD TRAVEL SURVEY QUESTIONNAIRE**

Household Data

1. Please record the date of your Survey Day. (See upper right hand corner of TRAVEL DATA sheet for Survey Day)

Mo. Day Yr.

2. Where is your household located?

- a. If it is in a town or city, please record the house number, street name and city.
b. If it is in a rural area, please record the name of the nearest place or community (no matter how small) or the nearest road intersection. If an intersection is used, please give the name or number of both roads. A RURAL MAIL DELIVERY ADDRESS IS NOT USEABLE IN OUR SURVEY.

Location: _____

3. How many persons live in this household? (Do not count those who are generally away to school and room away from home.)

Number _____

4. What is the age of the head of the household? Check appropriate blank.

- a. If husband-wife family:
1. Under 25 _____ 4. 35-44 _____
2. 25-29 _____ 5. 45-64 _____
3. 30-34 _____ 6. 65 and over _____
b. If other than husband-wife family:
7. Under 65 _____ 8. Over 65 _____

5. Please indicate the sum of the gross annual income of all persons living in this household. Check the appropriate blank.

1. Under \$2,000 _____ 6. \$10,000 - \$11,999 _____
2. \$2,000 - \$3,999 _____ 7. \$12,000 - \$14,999 _____
3. \$4,000 - \$5,999 _____ 8. \$15,000 - \$24,999 _____
4. \$6,000 - \$7,999 _____ 9. \$25,000 and over _____
5. \$8,000 - \$9,999 _____

6. For each of the vehicle types listed below, please record the number that are normally available for personal use by the members of this household.

<u>TYPE</u>	<u>NUMBER</u>
Passenger Cars or Station Wagons	_____
Pick-up or Panel (Example: Ford Econoline)	_____
Other Single Unit Trucks	_____
Tractor-Trailer Combination	_____

PLEASE DO NOT WRITE
IN THIS SPACE

CARD NO.:

1

SAMPLE NO.:

3 4 5 6 7

9 10 11 12 13 14

15 16 17 18 19 20

21 22

23

24

25

26

27

FIGURE III-6a

FIRST PAGE OF MAILED QUESTIONNAIRE
USED IN KENTUCKY'S STATEWIDE STUDY

7. Please estimate the miles driven last year in each of the vehicles mentioned above:

Vehicle #1 _____ miles
 Vehicle #2 _____ miles
 Vehicle #3 _____ miles
 Vehicle #4 _____ miles

8. a. Please assign a Person Number to each person living in this household who is 16 years of age or older; and

b. Indicate with a check mark in the appropriate column those who are licensed drivers and those who drove on Survey Day.

Person Number	Relationship to Head of Household or Initials	Licensed Driver	Drove On Survey Day
1	Head of Household	_____	_____
2	_____	_____	_____
3	_____	_____	_____
4	_____	_____	_____
5	_____	_____	_____

9. For each person employed full-time and living at this household, please list the location of his job. Refer to Question 2 for instructions on the type of location information that is desired.

Person Number	Location of Job
1	_____
2	_____
3	_____
4	_____

10. Telephone Number _____

We may need to call you to make sure we understand all your answers.
 What would be a convenient time? _____

11. Please continue by filling out the TRAVEL DATA portion of the questionnaire

PLEASE DO NOT WRITE
 IN THIS SPACE

☐
☐
☐
☐
☐
☐
☐
☐
☐
☐
☐

FIGURE III-6b

CONTINUATION OF MAILED QUESTIONNAIRE
 USED IN KENTUCKY'S STATEWIDE STUDY

TRAVEL DATA
(Please Do Not Write In The Small, Numbered Blocks)

Survey Days

CARD NO. ☐ SAMPLE NO. ☐ EXPANSION FACTOR ☐

DAY OF WEEK ☐ RESIDENCE ZONE ☐ DATE ☐

FROM			ORIGIN ADDRESS (Please write complete address)										DESTINATION ADDRESS (Please write complete address)										TO				
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
1	1	2	Peake Mill, Ky (home)										Second Street & New Street, Frankfort, Ky (service garage)										1	0	8		
1	2	2	Second Street & New Street, Frankfort (service garage)										419 Linn Street Frankfort, Ky (work)										2	8	1		
1	3	2	419 Linn Street Frankfort, Ky (work)										Devils Hollow Road & Taylor Ave, Frankfort, Ky (feed mill)										1	1	2		
1	4	2	Devils Hollow Road & Taylor Avenue, Frankfort (feed mill)										Peake Mill, Ky (home)										1	2	0		
2	1	1	Peake Mill, Ky (home)										Stamping Grounds, Ky (bank)										1	0	3		
2	2	1	Stamping Grounds, Ky (bank)										215 Antak Drive Frankfort, Ky (feed mill)										1	3	5		
2	3	1	215 Antak Drive Frankfort, Ky (feed mill)										Peake Mill, Ky (home)										1	5	0		

"EXAMPLE"

CODE

1. PERSONNEL IN OR OUT OF VEHICLE

2. PICKUP OF PASSENGER, ISOLATED FROM COMMUNITY

3. GROUP LOADING AND UNLOADING

4. MOTORIST-TRUCKER COMBINATION

CODE

1. HOME

2. WORK

3. SHOPPING

4. RECREATION

5. BUSINESS

6. OUTDOOR RECREATION

FIGURE III-6c

SAMPLE OF COMPLETED "TRAVEL
DATA" SECTION OF KENTUCKY'S
MAILED QUESTIONNAIRE.

SECTION IV

SUMMARY AND CONCLUSIONS

The previous sections of this report covered in some detail a few of the most important topics relating to the study and synthesis of travel on a statewide or regional basis. Several hypotheses have been advanced for intercity travel both in a theoretical sense and in current studies. In all, the results of nearly 30 independent studies dealing with the characteristics of intercity travel have been reviewed taking in a time span of some 90 years. The most significant findings and conclusions gained from this review are listed below.

1. A review of hypotheses advanced for intercity travel revealed that the following concepts should be included in future mathematical models simulating intercity travel:
 - a. Travel demand as related to socio-economic factors
 - b. Travel impedance function which may be related to other factors in addition to distance such as travel time, sufficiency of route, travel cost, mode of transportation, etc.
 - c. Attraction between "social masses" as well as the concept of intervening opportunities to account for attractions outside the pair of cities being considered
 - d. Vehicular versus other forms of transportation (modal split)
2. The law of attraction between physical masses (usually taken here to be groups of population) has been the most widely used basis for the mathematical formulation of intercity highway travel; however as more states move toward analysis of multi-modal transportation systems, this model becomes very complex. The Gravity Model is still the most widely used format for trip distribution, but with more requirements for flexibility, the Fratar Model and the Intervening Opportunities Model are assuming a more important role in statewide trip simulation. Also, in some of the more recent studies there is shown a trend toward the classical Multiple Linear Regression Model of the following form:

$$y=k+b_1X_1+b_2X_2+\dots+b_nX_n$$

Where: X_1 to X_n are independent variables relating for example to zonal land use, and socio-economic characteristics, and

b_1 to b_n are the coefficients of the respective independent variable and k is a constant

3. Current studies reveal no completely new mathematical theory for use in intercity travel simulation with the exception, perhaps of certain mathematical techniques advanced to define Modal Splits. They do, however, show a very wide range of innovations and offer several approaches in developing a state-wide model. Many possible alternatives along each step of the development of a transportation simulation model have been shown.
4. The most frequently observed variations in intercity travel have been due to trip purpose, socio-economic factors at the origin (reflecting characteristics of the traveler), and geographic locality. These factors should be considered when collecting data and selecting a model type or the variables to be used.
5. The report has described three techniques of constructing internal statewide traffic analysis zones. These were: Zones based solely on demographic boundaries; zones based on a statewide grid-coordinate system; and zones based on state-wide multiple screenlines. In the work reported on, there has been considerable variation in both civil and geographic divisions between states depending on the available traffic data. Zone sizes have varied widely from census tracts of a few square miles to counties or "super zones" of several hundred square miles. While this variation is present, it is important that the size of the zone selected should be commensurate with the level of travel analysis desired, and that socio-economic data be available for each zone in the system.
6. The treatment of external zones also has been varied. One commonly used approach is to continue the internal zone system into neighboring states, increasing their size as they become farther away from the state's border until the whole of the United States has been considered. Another approach has been to consider entrance or exit points around the state border as external zones and through a process of iteration, assign trips from these zones to other zones within the state.
7. A highway network interconnecting all of the analysis zones and representative of the roads carrying trips of a non-local nature has been the most suitable for analysis. For most studies reviewed here, this network has consisted of a system of most state highways, some major county or township roads,

and all U.S. and Interstate highways. Obviously, in considering air, rail or water transport, the networks would have to correspond to whatever routes they operate on.

8. The most widely used sources of trip data are the external surveys of existing urban studies, screenline surveys, and roadside interviews; however, with requirements for better data, more extensive surveys are being planned and have been conducted in the past few years. Many of these recent surveys, as has been shown in this report, have combined the use of roadside interviews with mailed or telephone surveys and have developed special questionnaires to be distributed to users of various modes of transportation. Considerable planning is required in these later types of surveys to insure the proper data is collected in sufficient quantities.
9. Computer technology has greatly aided transportation research with its ability to perform rapid analysis and regression and handle complex traffic assignments over large networks. A complete battery of computer programs is available for transportation researchers through the Federal Highway Administration, U.S. Department of Transportation.
10. Many of the statewide studies being started in the past few years have been closely tied in with long range state planning programs with definite goals and objectives as to how to utilize the completed analysis. This is a marked improvement, it seems, over many of the early transportation studies.
11. The advent of multi-modal transportation systems has brought with it a tremendous increase in data requirements describing both traffic and social groups. As has been described in abstracts of states using or developing multi-modal transportation models, the methods of collecting the data required for such models will take increased cooperation between transportation agencies, regional planning agencies and all common carriers of both people and commodities. In addition, it has been pointed out that these models require extensive study of the social and economic factors in the areas where they are to be applied. In order to arrive at a "complete" transportation model, then, many different types of surveys will have to be conducted and perhaps a composite model derived from the analysis of several different modeling techniques.

LIST OF REFERENCES

1. Rodger Borg, Intercity Travel Synthesized from Multiple Screenline Origin and Destination Surveys. (Iowa State Highway Commission: Ames, Iowa) November 1964.
2. Wisconsin Highway Plan, Technical Reports Number 1, 2, 3, 4. (Wisconsin State Highway Commission: Madison, Wisconsin) Undated.
3. Intercity Traffic Models and Statewide Origin-Destination Travel Information - Review of Literature. (Illinois Division of Highways) November 1965.
4. Kentucky Statewide Traffic Model Study, Technical Reports Number 1, 2, 3, 4. (Commonwealth of Kentucky Department of Transportation) 1974, 1975, 1976.
5. Rhode Island Department of Transportation Statewide Travel Pattern Update Study. (Allinson, Inc., Consultants) Not dated.
6. Babcock, Ronald D. and Morgan, William E., An Analysis of Highway Travel in Wyoming, An Origin-Destination Study. (College of Commerce and Industry, University of Wyoming) January 1975.
7. Waltz, Eugene W. and Grecco, W. L., "Evaluation of a Mailed Planning Survey." Highway Research Record No. 472 (Highway Research Board) 1973.
8. Tittmore, Lawrence H., Analysis of Regional Travel Patterns for a Medium-Sized Community. (Civil Engineering Department, Purdue University) September 1965.
9. Olsson, Gunnar, Distance and Human Interaction - A Review and Bibliography. (Regional Science Research Institute: Philadelphia) 1964.
10. Carrothers, Gerald A. P., "A Historical Review of the Gravity and Potential Concept of Human Interaction." Journal of the American Institute of Planners, Vol. 22, 1956.
11. Zipf, G. K., "The P_1P_2/D Hypothesis: On the Intercity Movement of People." American Sociological Review, Vol. 2, 1946.
12. Dodd, S. C., "The Interaction Hypothesis: A Gravity Model Fitting Physical Masses and Human Groups." American Sociological Review, Vol. 15, 1950.
13. Cavanaugh, J. A., "Formulation, Analysis and Testing of the Interaction Hypothesis." American Sociological Review, Vol. 15, 1950.
14. Ickle, F. C., "Sociological Relationship of Traffic to Population and Distance." Traffic Quarterly, Vol. 8, 1954.

15. Anderson, T. R., "Intermetropolitan Migration: A Comparison of the Hypothesis of Ziph and Stouffer." American Sociological Review, Vol. 20, 1955.
16. Mylroie, W. A., "Evaluation of Intercity-Travel Desire." Highway Research Board Bulletin No. 119, 1956.
17. State Interest in Highways. (Washington State Council for Highway Research: Pulman, Washington) 1952.
18. Schmidt, R. E. and Campbell, M. E., Highway Traffic Estimation. (The Eno Foundation: Saugatuck, Connecticut) 1956.
19. Busch, J. S., "Traffic Interaction Between Cities." Highway Research Board Bulletin No. 297, 1961.
20. Report on the Origin-Destination Survey at Five City Crescent Area. (North Carolina State Highway Commission) 1959.
21. Bruton, M. J., Introduction to Transportation Planning. Hutchinson Educational Ltd., London, 1970.
22. Urban Transportation Planning, General Information. (U.S. Department of Transportation, Federal Highway Administration) March 1972.
23. An Analysis of Intercity Passenger Traffic Movement Within the California Corridor Through 1980. (Stanford Research Institute) April 1966.
24. Hosford, John E., Development of a Statewide Traffic Model for the State of Missouri. (Midwest Research Institute) 1966.
25. Improvements in Statewide Highway Traffic Assignment. (Creighton, Hamburg, Inc. Consultants)
26. FHWA Computer Programs for Urban Transportation Planning. (U.S. Department of Transportation, Federal Highway Administration) July 1974.
27. Statewide Origin and Destination Study. (Commonwealth of Pennsylvania, Department of Highways, Edwards and Kelcey) 1966.
28. Development of Traffic Prediction Techniques in Non-Metropolitan Areas of Pennsylvania. (Institute for Transportation Studies, Villanova University) 1967.
29. Sikkink, R., Ried, G., Laguros, J. G., Influence of Socio-Economic Parameters on a Highway Traffic Model. (University of Oklahoma) January 1968.
30. Minnesota Statewide Travel Model Report. (Minnesota Department of Highways) April 1971.

31. Statewide Transportation Analysis and Research. (Michigan Department of State Highways and Transportation) Reports dated 1972-1975.
32. A Statewide Transportation System Effectively Meets the Transportation Challenge of the 70's. (Michigan Department of State Highways and Transportation) June 1973.
33. Michigan Goes Multi-Modal. (Michigan Department of State Highways and Transportation) July 1974.
34. A Study Design for Statewide, Multimodal Transportation Systems Planning. (Stanford Research Institute for the Tennessee Department of Transportation) March 1973.
35. West Virginia Statewide Traffic Assignment Model, Statewide and Regional Transportation Forecasting Models. (West Virginia Department of Highways) January 1975.
36. Nebraska Statewide Traffic Assignment Model (four reports). (State of Nebraska Department of Roads, Program and Planning Division) Not dated.

A STATE OF THE ART REPORT ON STATEWIDE
TRAFFIC ASSIGNMENT MODELS

by

JAMES HENRY JATKO

B.S., Rensselaer Polytechnic Institute, 1972

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

ABSTRACT

A state-of-the-art literature review on statewide traffic assignment models is presented. Various approaches for conducting transportation need studies and for collecting data required for the analysis and synthesis of travel patterns are reviewed for their advantages and disadvantages under different conditions, and conclusions are drawn as to their individual merits. Theories and hypotheses advanced for the description of intercity travel are listed as they were developed over time and are examined for their application in forming a basis for a statewide traffic simulation model. Specific developments in the use of certain independent variables in these equations are noted if the variable has been found later to be of major importance in traffic simulation. In all, a historical development of intercity travel models covering a period of over 80 years in 15 major studies is included. Selected abstracts of recent statewide transportation analysis projects completed or being conducted in 13 states are then presented. The abstracts deal with study procedures, models used, results, and are suggestive of present trends in statewide traffic assignment.

Key Words: Transportation Analysis, Statewide, Intercity Travel Model.