

1. Report No. FHWA/TX-91/1235-4	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle FEASIBILITY OF DEVELOPING A STATEWIDE MODELING SYSTEM FOR FORECASTING INTERCITY HIGHWAY VOLUMES IN TEXAS, INFO. REPORT #7		5. Report Date Jan. 1991/Oct. 1991 Revised	6. Performing Organization Code
7. Author(s) Jim D. Benson, James A. Mullins III, and George B. Dresser		8. Performing Organization Report No. Research Report 1235-4	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, TX 77843-3135		10. Work Unit No.	11. Contract or Grant No. 2-10-90-1235
12. Sponsoring Agency Name and Address Texas Department of Transportation Transportation Planning Division P. O. Box 5051, Austin, TX 78763		13. Type of Report and Period Covered Interim - September 1989 - August 1990	
15. Supplementary Notes Study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Research Study Title: Improving Transportation Planning Techniques.		14. Sponsoring Agency Code	
16. Abstract <p>In the urban transportation studies in Texas, computerized network based models (i.e., the urban travel forecasting models) are used to forecast future traffic volumes on the planned urban freeways and arterials to evaluate the capability of the proposed system to handle the forecast demand. Comparable statewide models (i.e., computerized network-based models) for forecasting intercity highway volumes on the rural segments of the proposed Texas Highway Trunk System are not currently available in Texas. If such a set of models could be implemented for Texas, they would be useful in reviewing and updating the Texas Highway Trunk System Plan every five years. The feasibility of developing and implementing such a statewide modeling system was investigated as a part of the first year program under Study 2-10-90-1235. The objectives of this first year effort were:</p> <ol style="list-style-type: none"> 1. To review and evaluate the current state of the practice for statewide models which focus on forecasting highway volumes on the rural sections of a statewide system such as the Texas Highway Trunk System; and, 2. Based on these investigations, to recommend a set of statewide network-based modeling techniques that could be considered for implementation in Texas. <p>This report presents the findings and recommendations from this investigation.</p>			
17. Key Words Statewide Highway Travel Forecasting Statewide Highway Traffic Assignment		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 73	22. Price

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

in ²	square inches	645.2	centimetres squared	cm ²
ft ²	square feet	0.0929	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
mi ²	square miles	2.59	kilometres squared	km ²
ac	acres	0.395	hectares	ha

MASS (weight)

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft ³	cubic feet	0.0328	metres cubed	m ³
yd ³	cubic yards	0.0765	metres cubed	m ³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
km ²	kilometres squared	0.39	square miles	mi ²
ha	hectares (10 000 m ²)	2.53	acres	ac

MASS (weight)

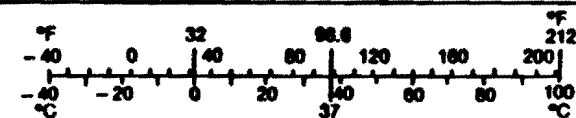
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

**FEASIBILITY OF DEVELOPING A STATEWIDE MODELING SYSTEM FOR
FORECASTING INTERCITY HIGHWAY VOLUMES IN TEXAS**

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**Research Study No. 2-10-90-1235
Improving Transportation Planning Techniques**

Sponsored by

Texas Department of Transportation

**in cooperation with the
U.S. Department of Transportation
Federal Highway Administration**

**Texas Transportation Institute
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College Station, TX 77843-3135**

**January 1991
October 1991/Revised**

ABSTRACT

In the urban transportation studies in Texas, computerized network based models (i.e., the urban travel forecasting models) are used to forecast future traffic volumes on the planned urban freeways and arterials to evaluate the capability of the proposed system to handle the forecast demand. Comparable statewide models (i.e., computerized network-based models) for forecasting intercity highway volumes on the rural segments of the proposed Texas Highway Trunk System are not currently available in Texas. If such a set of models could be implemented for Texas, they would be useful in reviewing and updating the Texas Highway Trunk System Plan every five years. The feasibility of developing and implementing such a statewide modeling system was investigated as a part of the first year program under Study 2-10-90-1235. The objectives of this first year effort were:

1. To review and evaluate the current state of the practice for statewide models which focus on forecasting highway volumes on the rural sections of a statewide system such as the Texas Highway Trunk System; and,
2. Based on these investigations, to recommend a set of statewide network-based modeling techniques that could be considered for implementation in Texas.

This report presents the findings and recommendations from this investigation.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Jimmie D. Benson, P.E., #45900, was responsible for this project.

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I. INTRODUCTION

The recently adopted Texas Highway Trunk System is a planned future intercity highway system which provides for a minimum four-lane divided cross-section for all highway facilities included in the plan. The Texas Highway Trunk System includes all interstate highway facilities, all U.S. highways, and other key highways. The system was developed to assure that a high quality intercity highway system is provided to link all major population centers in Texas. It is anticipated that this plan will be reviewed and updated every five years.

The current procedures used by the Department for forecasting intercity highway volumes are essentially manual procedures which rely heavily on historical trends observed in counted volumes. In the urban transportation studies in Texas, computerized network based models (i.e., the urban travel forecasting models) are used to forecast future volumes on the planned freeways and arterial system to evaluate the capability of the system to handle the forecasted demand. Comparable statewide models (i.e., computerized network-based models) for forecasting intercity highway volumes on the rural segments of the proposed Texas Highway Trunk System are not currently available in Texas. If such a set of models could be implemented, they would likely improve the quality of the intercity highway volume forecasts which would be useful in reviewing and updating the plan every five years. The feasibility of implementing such a statewide modeling system was investigated as a part of the first year effort under Study 2-10-90-1235. The basic goals of the first year efforts were essentially:

- to review and evaluate the current state of the practice for statewide models which focus on the forecasting of the highway volumes on the rural sections of the major highway arterial system; and,
- based on these investigations, to recommend a set of statewide network-based modeling techniques that could be considered for implementation in Texas.

This report presents the findings and recommendations from this investigation.

II. REVIEW OF CURRENT STATEWIDE MODELS

The initial efforts under this study focused on a review of the state of the practice in statewide network-based models directed toward forecasting intercity highway volumes. It was hoped that this review would provide the basis for recommending the procedures for use in Texas for forecasting intercity volumes on the Texas Highway Trunk System. The following highlights some of the pertinent findings from the state-of-the-practice review and discusses some of the key concerns raised from this review.

STATE OF THE PRACTICE

In the late 1960's and early 1970's, there was substantial optimism that the urban travel demand modeling procedures (used in estimating and forecasting urban highway volumes on major facilities) could also be adapted and used to forecast intercity highway travel. While many states announced plans to develop statewide models similar to the urban travel demand models, few were ever implemented. Currently the two most commonly cited statewide network-based modeling procedures directed toward forecasting intercity highway volumes (and probably the only two states currently using such procedures) are the Michigan and Kentucky modeling systems.

In recent years, substantial interest and efforts have been directed toward more macroscopic intercity modeling efforts which focus on modal choice issues (i.e., air versus rail versus highway) for intercity travel between major destinations. While these multi-modal modeling systems have a highway component, they are not directed toward forecasting highway volumes on a detailed highway network such as the Texas Highway Trunk System. The Florida statewide multi-modal travel models are a good example of this type of statewide modeling system. In the Florida models, the entire United States is included in their zone structure. Florida's 67 counties are treated as individual zones. Groups of counties in Alabama and Georgia along the Florida border are aggregated into zones. The remainder of Alabama and Georgia, the other 47 states, and the District of Columbia are designated as zones. This level of detail is certainly appropriate for multi-modal analyses which focus primarily on longer intercity trips having mode-choice options.

In contrast to the Florida system which uses 67 in-state zones, the Michigan models currently use 508 in-state zones; and the Kentucky models use 663 in-state zones. The Michigan DOT reports that they are currently developing a 2,300-zone system for use in some of their highway analyses. The use of a county level zone structure in Texas (i.e., 254 in-state zones) was judged to be too macroscopic dealing with a relatively detailed highway network needed to represent the Texas Highway Trunk System. It was also felt that the inclusion of a mode-choice step would not significantly improve the quality of the highway forecasts on a detailed highway networks and would make the modeling system more difficult to develop and apply.

Since the basic objective of this study is to investigate network-based modeling systems for estimating volumes on detailed highway network, the state-of-the-practice review under this study focused on the Michigan and Kentucky statewide modeling procedures. The following discussion presents brief overviews of these two systems. More detailed descriptions of these two systems are provided in the Appendices of this report. It should be noted that these model descriptions are based on a review of a number of reports obtained regarding these two models and not from detailed first-hand knowledge and experience with the models.

Michigan Statewide Highway Network Model

The Michigan Statewide Highway Network Model is a modeling system which uses a basic three-step modeling process: trip generation, trip distribution, and traffic assignment. The modeling process is directed toward estimating intercity highway volumes on the major highway facilities in the state.

The early Michigan models used approximately 480 zones within the state and a set of 29 out-of-state zones. Zones generally have a population of 2,500 or more except where such zones would be unusually large in area. The in-state zones generally consist of an aggregation of one or more contiguous townships and/or cities. All cities with a population exceeding 10,000, with the exception of Detroit, are designated as a zone (Detroit is split into three zones). The highway facilities represented in the statewide network included all interstate, U.S., and Michigan (state) routes as well as "significant" county roads. In the

1975 model update, 508 in-state zones and 39 out-of-state zones were used. Michigan is currently developing a 2,300-zone system for use in some of their analyses.

The Michigan models generate, distribute, and assign only interzonal vehicle trips. Three trip purposes are used: general intercity trips, heavy truck intercity trips, and vacation intercity trips.

The trip generation models for the general intercity trips and the heavy truck intercity trips are used to estimate trip origins and destinations by zone (rather than trip productions and attractions by zone). These are regression models developed to reflect the following characteristics:

- As the zonal population increases, the interzonal trips will increase less rapidly provided the external environment for the zone remains unchanged. (In other words, all other things taken as equal, a 20 percent increase in a zone's population should result in less than a 20 percent increase in the number of interzonal trips estimated by the model.)
- As the external population near a zone increases, an increased number of interzonal trips should be generated for the zone even though the zone's population remains constant.

In effect, the Michigan models recognize that the number of interzonal trips generated for a zone is not only a function of the activity within a zone but also a function of activity in the nearby zones. The Michigan intercity trip generation models, therefore, basically use two independent variables: (1) the population within the zone, and (2) an external population variable computed to include 100 percent of the external population of zones within 20 minutes of the zone plus 50 percent of the population of zone within 20 to 30 minutes of the zone plus 25 percent of the population of zones within 30 to 40 minutes of the zone. These models were developed using origin-destination (O-D) external cordon survey data from ten cities in Michigan.

The trip distributions for both the general intercity trips and the heavy truck intercity trips are performed using a gravity model. The "deterrence function" (i.e., essentially the gravity model F-factors) was developed using the observed trip length frequency data from the ten urban external cordon O-D surveys.

The estimation of Vacation Intercity trips relied on data from four sources: a tourist survey conducted for the state, the Mackinac Bridge Study, Highway Department Statistics and the ten urban external cordon O-D surveys. Three categories of Vacation Intercity trips are used: Michigan residents vacationing within the state, Michigan residents vacationing out of state, and Out-of-state residents vacationing in Michigan. Trip generation estimates for these three categories are initially estimated at the state level (not the zonal level) and are used as control totals.

The trip generation process for two of the categories (i.e., the Michigan residents vacationing within the state and the out-of-state residents vacationing within Michigan) might be described as a "top-down allocation process." The vacation attractions within the state for each category (i.e., the vacation destinations) are allocated from the state level to the zonal level based on indices developed using the tourist survey. The productions by category are allocated from the state level to the zonal level based on population indices.

The trip distributions for two of the categories (i.e., the Michigan residents vacationing within the state and the out-of-state residents vacationing within Michigan) are performed using a gravity model. These gravity model applications are somewhat unique in that the scaling is performed relative to attractions rather than productions (i.e., in effect, the attractions are distributed to productions rather than the more conventional production-to-attraction approach). The Mackinac Bridge Study data were used as a means for establishing a "relative deterrence function."

For the third category of vacation trips (i.e., the Michigan residents destined to out-of-state vacation attractions), the statewide control total is allocated directly to the zonal interchange level based on the product of the zonal populations. In effect, no deterrence function due to spatial separation is employed in the distribution process.

The final step in the modeling chain is traffic assignment. The resulting five trip tables are combined to obtain the trip table for assignment. The early applications of the model chain were complicated due to software constraints of the old BPR Package (implemented for the old IBM 7090 computer). These early traffic assignment were performed using a conventional iterative capacity restraint assignment model for the large interchange volumes and an all-or-nothing assignment for the small interchange volumes.

Today's software packages do not have the software limitations of the old packages so that the assignment can be performed using the combined trip table.

The initial 1965 base year assignment results were compared with counted volumes on 30 links with permanent count stations. These comparisons indicated an average over-assignment of approximately 57 percent (or an average absolute error of approximately 76 percent). To correct for this bias, the assignment results were simply scaled by a factor of 0.64. The use of the scaling factor resulted in an average absolute percent error of approximately 40 percent for the 30 links. Before applying the 0.64 scaling factor, only six of the 30 links had assigned volumes within ± 25 percent of the counted volumes; 13 of the 30 were within ± 50 percent and 22 of the 30 were within ± 100 percent. Eight of the 30 links had unscaled assignment volumes which exceeded the counted volume by more than 100 percent. After applying the 0.64 scaling factor, 10 of the 30 links had assigned volumes within ± 25 percent of the counted volumes, 22 of the 30 were within ± 50 percent and 29 of the 30 were within ± 100 percent. Table II-1 presents the root-mean-square (RMS) error and the percent RMS error for these 30 links by volume group.

In the late 1970's, the Michigan Statewide Models were updated to a new base year of 1975. One of the main objectives of this update was to recalibrate the models so that a majority of the assigned link volumes would be within ± 10 percent of the counted ADT. To achieve this objective, the trip generation and distribution models had to be adjusted on an area-specific or zone-specific basis to better reflect the observed travel patterns. The 1975 model update results for 29 count stations are provided in Table A-1 of Appendix A.

The updated Michigan models were subsequently applied to forecast the year 2000 intercity highway volumes. These forecasted volumes were graphically compared to observed trends from 1966 through 1977 at 32 permanent count stations located throughout the state. This graphical comparison indicated that the model was producing forecasted volumes that were very consistent with observed trends. Based on these comparisons and the calibration results, the Michigan report concludes:

... If the assumptions and limitations are clearly understood, the model can be used for future year forecasts. Additionally, general consensus by users of the model to

date have, for the most part, found future year forecasts reasonable relative to other forecasts derived by manual forecasting methods.(1)

A more detailed description of the Michigan models is provided in Appendix A of this report.

Table II-1

**SUMMARY OF MICHIGAN BASE YEAR ASSIGNMENT RESULTS
FOR THIRTY PERMANENT COUNT LOCATIONS
(Scaling Factor Applied to Assigned Volumes = 0.64)**

Volume Groups	Links	Average Count	Unscaled Assignment		Scaled Assignment	
			RMS	Percent RMS	RMS	Percent RMS
Less than 1,500 vpd	5	1,030	1,714.32	166%	992.52	96%
1,500 - 3,000 vpd	12	2,179	2,014.76	92%	897.17	41%
3,000 - 5,000 vpd	6	3,731	4,104.04	110%	2,159.87	58%
5,000 - 10,000 vpd	3	8,059	6,717.70	83%	2,769.68	34%
10,000 - 23,000 vpd	4	17,665	17,299.74	98%	6,183.85	35%
ALL	30	4,951	6,238.70	126%	2,393.83	34%

Kentucky Statewide Traffic Model

The Kentucky Statewide Traffic Model (developed in the 1970's) is a modeling system that uses a basic three-step modeling process: trip generation, trip distribution, and traffic assignment. The modeling process is directed toward estimating average daily volumes on major intercity highway facilities.

The Kentucky model's zone structure uses 663 in-state zones and 118 out-of-state zones. The 663 in-state zones were formed to correspond to the census county divisions and aggregation of traffic analysis units in urban and rural areas, respectively. Major recreational areas within the state were treated as independent zones. The 118 out-of-state zones are used to represent the remainder of the continental U.S., Canada, and Mexico. These 118 zones were developed by taking a single county or a combination of two or more counties in the adjacent states and a single state or combination of states for the remainder of the nation. Canada and Mexico are each represented by a single zone.

The in-state network contains about 11,000 miles of highway system (represented using 6,000 links). The highway network includes essentially all of the Interstate facilities, toll roads, and the state primary facilities. The network also includes about 70 percent of the state secondary facilities and about 11 percent of the rural secondary facilities.

One of the major differences between the Michigan and Kentucky models is that the Kentucky models generate and distribute all vehicle trips (not just the interzonal or intercity vehicle trips). Three types of surveys were conducted for use in developing the Kentucky models:

- (1) **Household Travel Survey:** The household travel survey was conducted by mailing questionnaires to a sample of the in-state auto-owning households. The nominal sampling rate used in the sample selection was approximately 1.5 percent with a minimum sample size requirement of 60 households in each county (i.e., a sample size of 14,979 households). The usable response rate was approximately 45 percent (i.e., 6,713 total usable responses).
- (2) **Roadside O-D Surveys:** roadside O-D surveys were conducted on the cordon line and at certain internal locations.
- (3) **Truck Travel Survey:** The truck travel survey was conducted along with the FHWA-sponsored National Truck Commodity Flow Survey by sending questionnaires to a 2 percent sample of truck registrants.

The Kentucky Models essentially use three trip purposes: "short" vehicle trips (i.e., trips less than or equal to 35 minutes); "long" vehicle trips (i.e., trips over 35 minutes); and, truck trips. The following briefly highlights some of the more interesting aspects of the models for each of these trip purposes.

The Kentucky trip generation models utilize a cross-classification technique of households by population density and auto ownership to estimate total zonal productions. The trip rate corresponding to the auto ownership level and population density strata designation is used with the household data to compute total trips produced in each zone. Trips are then split into long and short trips based on trip length. Following a county-level comparison of observed and assigned VMT in which the modeled or assigned VMT was found to be greater than the observed VMT, the trip rates were "adjusted" on a county basis.

Therefore, trip rates vary not only by zonal population density and auto ownership but also by trip length as well as by county throughout the state. Trip attractions are calculated for Short trips based on "analysis units" which are aggregations of zones. Due to the unique manner in which the distribution of long trips is performed, it was not necessary to estimate attractions for long trips.

Short trips were separated into intrastate and interstate trips for purposes of trip distribution. Distribution of intrastate short trips was performed with a gravity model with a set of F-factors calibrated using the household travel survey. Base year modeling of short interstate trips was accomplished by expanding an external cordon survey trip table. For future year traffic, a FRATAR technique was used to growth-factor this short interstate trip table.

The developers of the Kentucky model did not feel that a gravity model was a suitable technique to be used in the distribution of long trips. A new and unique trip distribution process referred to as the "Long Trip Distribution Model" was developed to carry out the distribution of long trips. According to the model's developers, the model is based on the theory that:

... trip interchanges between a set of two areas of given population sizes and spatial separation will demonstrate a stable "production/attraction" ratio which is characteristic of all sets of areas with the same population sizes and spatial separation characteristics.(2)

The expanded statewide travel survey trip table was used to develop these ratios for the long trips. A more detailed explanation of the theory and application of the Long Trip Distribution Model is provided in Appendix B of this report.

In the early stages of the development of the Kentucky model, truck trips were not directly modeled. Instead, the assigned volumes from the other two trip purposes were simply factored to estimate truck trips. Later, it was found that the use of a "calibrated" truck trip table yielded better assignment results. However, the available documentation does not describe the process used to develop the calibrated trip table.

The assignment of trips to the Kentucky statewide network was performed using a simple all-or-nothing minimum travel time path procedure. Observed speeds are used in the calculation of the minimum time paths. Table II-2 summarizes the base year assignment

results for nine screenlines and the external cordon links. It should be noted that this was the final base year assignment which was performed after the trip generation rates were adjusted by county based on a comparison of the assigned and counted VMT.

A more detailed description of the Kentucky Statewide Traffic Model is provided in Appendix B of this report. It might be noted that subsequent to the initial preparation of this report, the Kentucky Transportation Cabinet has hired a consultant to update their statewide model. The approach being used in updating the Kentucky model is briefly outlined in an addendum to Appendix B.

**TABLE II-2
SUMMARY OF FINAL BASE YEAR ASSIGNMENT RESULTS
KENTUCKY STATEWIDE TRAFFIC MODEL**

Screenlines	Links	Count	Assigned	Percent Difference	RMS	Percent RMS
Tennessee River	3	14,992	15,795	5.36	863.87	18
Kentucky Dam - Nortonville	6	15,800	25,301	60.13	2504.77	96
Henderson - Hopkinsville	9	15,500	23,711	52.97	2254.19	135
Green River E-W	17	55,598	51,525	-7.33	1337.00	34
Brandenburg - Scottsville	11	30,872	34,791	12.69	1521.00	55
Kentucky River - Rocastle River	14	69,044	64,703	-6.29	2624.00	56
Berea - Frenchburg	5	20,367	22,316	9.57	1228.32	30
Licking River - Jenkins	16	23,484	29,345	24.96	1009.01	64
No. Morgan - Johnson - Martin	5	4,200	4,317	2.79	191.06	20
All Screenlines	86	249,857	271,804	8.78	1745.00	60
External Cordon Links by Volume Group	Links	Count	Assigned	Percent Difference	RMS	Percent RMS
0 - 999 vpd	21	10,456	14,302	37	473.39	95
1,000 - 2,999 vpd	19	34,164	36,327	6	988.91	55
3,000 - 7,999 vpd	12	73,394	74,010	1	1315.58	22
8,000 vpd and above	14	226,914	251,887	11	3054.02	14
All External Cordon Links	66	344,928	376,526	9	2263.50	45

III. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

FINDINGS

The Michigan and Kentucky statewide models are essentially adaption of the three-step urban travel demand models (i.e., vehicle trip generation, trip distribution, and traffic assignment). By comparing these models to their urban counterparts, some key differences were noted which highlight some of the fundamental problems in adapting the urban travel modeling techniques for statewide applications.

Zone Structures and Networks

Perhaps the most fundamental problem in statewide modeling is the level of detail used in the zone structure. In urban applications, it is generally agreed that the quality of the highway assignment results will generally improve with greater levels of detail in the zone structure and network. Historically, Texas has led the nation in the level of detail used in zone structures and networks.

Statewide applications of the three-step travel demand modeling approach will generally use considerably less detailed zone structures and networks than urban applications. Hence, all other things taken as equal, it is only reasonable to expect that the quality of the highway assignment results (i.e., comparison of the base year assignments to counted volumes) will generally decrease as the level of detail decreases. The reasons for this should become more apparent as some of the basic problems related to statewide modeling versus urban modeling are examined.

Intrazonal Trips

In urban travel models employing a large number of relatively small zones, the portion of vehicle trips which are intrazonal trips (i.e., trips with both the trip origin and trip destination within the zone) is normally very small. For example, in the Houston-Galveston regional transportation models employing 2,600 zones, less than 5 percent of the total trips are estimated to be intrazonal trips. Even though the percent of intrazonal trips are typically very low in urban models, it is one of the trip distribution model results which is

routinely checked to assure the quality of the model results.

Since statewide models typically use much larger zones, the problems of accurately handling intrazonal trips change from a relatively minor problem to a very major problem. In statewide models, it is not unusual for a small city or town to be represented by a single zone. In such instances, a very large majority of the daily vehicle trips would be intrazonal trips. The split between intrazonal and interzonal trips is extremely important in statewide models. Since only interzonal trips are assigned to the network, one of the key factors influencing the success of a statewide model is, in effect, its ability to accurately estimate the number interzonal trips for each zone. Certainly, location of the zone relative to other travel opportunities influence the split between intrazonal and interzonal trips. Indeed, the portion of the trips that would be intrazonal trips is, at least in part and perhaps largely, a function of the intrazonal versus interzonal travel opportunities. For example, a small city or town (represented by a single zone) within, say, 20 to 40 minutes of a large metropolitan area would likely have a smaller percentage of intrazonal trips than a similar small city or town (also represented by a single zone) located in a relatively remote area where there are few nearby travel opportunities.

In the Michigan statewide model, this problem is taken on in a very direct manner. The Michigan trip generation models directly generate only interzonal trips. Indeed, the Michigan trip generation models are regression models developed to reflect the following two characteristics:

1. As the zonal population increases, the interzonal trips will increase less rapidly, provided the external environment for the zone remains unchanged; and
2. As the external population near a zone increases, an increased number of interzonal trips should be generated even though the zone's population remains constant.

These two desirable characteristics could be restated in terms of total trips, interzonal trips, and intrazonal trips as follows:

1. As a zone's population increases, the total trips generated in the zone will increase. Also, as the zone's population increases and the external

environment for the zone remains unchanged, both the percent of intrazonal trips will increase and the number of interzonal trips will increase. Hence, the number of interzonal trips will increase less rapidly than the population.

2. As the external population near a zone increases and the zone's population remains constant, the percent of intrazonal trips will decrease and the number of interzonal trips will increase.

Typically, in urban transportation studies, the application of the trip distribution model (i.e., the conventional gravity model, the Atomistic model or the Texas model) will reflect these two characteristics. To some extent, the Michigan trip generation model's weighting of the external population by time periods might be considered a coarse way of reflecting the impedance to travel due to spatial separation (which is represented in the gravity model analogy by F-factors).

In contrast, the Kentucky Statewide Models actually generate total trip productions. The total trip production rates are split into two groups: short trips (i.e., trips with an expected trip length of 35 minutes or less) and long trips. The short trips generally account for roughly 80 percent to over 95 percent of the total trips (depending on the zone's population density strata and stratification of households by auto ownership). Short trip attractions are also generated based on the zone's population and employment estimates. The gravity model is then applied to distribute the short trips. The long trips (i.e., the trips over 35 minutes) are distributed using a special trip distribution model developed specifically for the Kentucky applications. In effect, the gravity model application determines what portion of the short trips are intrazonal trips. On the surface, this is very appealing. However, it should be recalled the Kentucky model developers found it was necessary to adjust the short trip production rates for each county based on comparisons of counted versus assigned VMT. In essence, it was assumed that the differences in the assigned and counted volumes were due to weaknesses in the short trip production rates. It is likely that the problems being observed were not totally trip generation problems but were at least in part a trip distribution problem related to intrazonal trips. For example, if a zone should have retained 85 percent of its trips as intrazonals but the distribution model is producing an estimate of 80 percent intrazonals, then the zone would, in effect, be producing 25

percent too many interzonal trips for assignment. If this were the problem, it can often be corrected in conventional gravity model applications by simply changing the user-supplied intrazonal time estimate by 1 or 2 minutes (thereby changing the gravity model F-factor used in the intrazonal trip estimate). Again, the problem in dealing with the very large zones used in statewide models where a majority of the trips produced should be intrazonal trips is that the assignment can be very sensitive to relatively small variations in the intrazonal trip estimates.

In urban travel modeling, a similar problem is encountered in sketch planning applications which use substantially larger than normal zone sizes. Although sketch planning zones are substantially larger than the normal zone size used in urban studies, they would generally be much smaller than the zones used in statewide model applications. Indeed the problems of reasonably estimating the intrazonal trips in sketch planning applications was one of the problems which lead to the development of the Atomistic trip distribution model.

Centroid Loadings

In urban transportation studies, the placement of zonal centroids and centroid connectors is generally given substantial attention in the network development to attempt to assure that the trips to and from a zone are loaded on the network properly. By using a large number of relatively small zones, the centroid loading problems are reduced but not eliminated. With the very large zones used in statewide models, centroid loading problems can create substantial "noise" in the assignment results.

Trip Length Frequency

In urban travel modeling, trip length frequency estimates by trip purpose are used either directly in the trip distribution modeling process or indirectly as the criteria for calibrating gravity model F-factors (i.e., factors which reflect the impedance to travel due to spatial separation). Urban travel survey data generally provide a very good estimate of the average trip length of trips by purpose and a reasonably good estimate of the shape of the trip length frequency distribution. The shape of the trip length frequency distribution for longer trips (e.g., trips over 40 network minutes measured using 24-hour network speeds)

is probably the weakest part of the trip length frequency estimates. However, since the vast majority of the urban trips are short to medium length trips (e.g., trips under 40 network minutes), urban traffic assignment results are generally not very sensitive to the trip length frequency distribution of the longer trips so long as overall trip length frequency distribution provides a good estimate of the average trip length.

Statewide models, by their very nature, will be more sensitive to the trip length frequency estimates for the longer trips than the urban models. Although this is a more difficult problem to deal with in statewide studies, it is not insurmountable. Indeed, with good urban external cordon survey data from a number of urban areas within the state, there are probably sufficient data to develop a reasonable set of F-factors for use in statewide gravity model applications.

Demographic Data and Trip Generation Models

Urban travel models generally require relatively detailed estimates of demographic variables at the zonal level. For example, the Houston-Galveston travel models use zonal household estimates (cross-stratified by five household income groups and five household size groups) and zonal employment estimates (stratified by six employment types). In sharp contrast, the Michigan statewide models essentially use zonal population as their basic demographic data input. The Kentucky statewide models use zonal estimates of car-owning households (stratified by 1 car, 2 car and 3+ car households), zonal population, and zonal employment as their basic demographic data inputs. For statewide modeling, it is desirable to keep the demographic data requirements as simple as possible due to the costs associated with developing zonal level demographic data forecasts on a statewide basis. This is certainly consistent with the more macroscopic nature of statewide modeling. Indeed, with the large zones used in statewide models, there are probably less differences in the trips per household between zones than can be observed for the small zones in urban transportation studies.

Evaluation Objectives

The urban travel demand models were developed to evaluate and compare the implications

of different land-use and transportation system alternatives from a travel demand perspective. For a given land-use and transportation system alternative, the urban travel models provide useful insight on the ability of the proposed transportation system to serve the proposed urban form. Typically, these analyses focus primarily on the major elements of the transportation system and its ability (i.e., capacity) to handle the anticipated travel demands. Indeed, the capacity restraint assignment techniques are essentially tools to obtain a multiple path assignment based on capacity restraints to facilitate the subsequent system capacity analyses. At the statewide level, the issues are really not the same. Since there are no comparable tools for managing statewide growth (i.e., tools comparable to zoning and other land-use controls which can impact the urban form), it would be very unusual for statewide models to be directed toward evaluating different "statewide forms." Also, the daily volumes on intercity highway facilities are usually much lower than those experienced on congested segments of urban freeways and principal arterials. With these lower intercity volumes, the levels of congestion experienced on segments of the urban systems would rarely (if ever) be encountered; and, hence, system capacities would rarely be at issue in statewide studies. Indeed, because of these lower volumes, the justification of improvements to statewide systems, such as the Texas Highway Trunk System, must focus on more qualitative and safety related issues.

Assignment Accuracy

In the calibration of urban travel demand models, the assigned volumes on higher volume facilities (such as freeways) are typically more accurate than the lower volume facilities (such as secondary arterials and major collectors). This is reflected in summaries which present the root-mean-square (RMS) error and the percent RMS error by volume ranges. The summaries of the Michigan and Kentucky assignment results show a similar trend with regard to the percent RMS errors observed. In urban transportation studies, these lower volume facilities are really not the focus of the analyses and evaluation. Unfortunately, in statewide systems, the highways are typically lower volume facilities which have the greatest variance of estimate. With the more macroscopic level of application of the travel models at the statewide level, it is really only reasonable to expect that the

variance of estimates on lower volume facilities will be greater in statewide studies than in urban studies.

Use of Assignment Results for Project Planning and Design

Nearly all computerized system-level assignments require that further refinement take place prior to their use in highway project planning and design. NCHRP Report 255 describes various techniques for refining assignment results. Texas uses similar procedures for refining urban traffic assignment results. It is certainly reasonable to expect that statewide assignment results will likely require even more refinement than urban assignment volumes before they could be used for project planning and design.

CONCLUSIONS

Based on the detailed review of the Kentucky and Michigan statewide models and the basic problems identified in applying the three-step modeling techniques statewide to estimate highway volumes, the following conclusions were drawn:

1. The Michigan and Kentucky statewide models represent two very different adaptations of the three-step modeling approach. Neither approach emerged as being clearly superior in terms of the quality of the results.
2. Neither the Kentucky nor the Michigan statewide models are portable in the sense that they could be obtained and applied in Texas without major recalibration to estimate highway volumes on the Texas Highway Trunk System. Indeed, Kentucky is considering a major update and revision of their statewide models.
3. Both the Kentucky and Michigan statewide trip generation models were initially developed using travel survey data. The principal data base for the Michigan models was the external cordon surveys from 10 urban areas. The principal data base for the Kentucky models was the statewide household travel survey with 6,713 usable responses. In both states, it was found that the use of a single set of statewide trip generation models did not produce desirable traffic assignment results. Both required substantial local

adjustments to produce acceptable assignment results. Indeed, the Kentucky models were adjusted on a county by county basis based on comparisons of the assigned and counted VMT. The Michigan report on the 1975 update of their models (1), indicates that some zonal level trip generation adjustments and some zonal interchange level adjustments were necessary to achieve the desired results. With this level of localized adjustments, it is felt that a simple set of synthesized rates would probably have provided as good a starting point as those developed using the statewide travel survey. Indeed, based on the experiences of these two states, it would be difficult to recommend an extensive travel survey for use in developing trip generation models.

4. The Michigan Model was judged to be the more desirable approach. The following outlines some of the key reasons:
 - a. The basic demographic data used by the model are population. From a statewide modeling perspective, it is certainly desirable to keep the demographic data requirements as simple as possible. The Kentucky model requires zonal estimates of households by auto ownership, population, and employment. It does not appear that these additional data requirements really improved the model's performance.
 - b. The intrazonal problems of statewide modeling are lessened by directly generating interzonal trips based on the zone's population and the population of nearby zones. The Kentucky approach of generating total trips and splitting them into long and short trips based on trip generation variables rather than considering the location of the zone relative to other travel opportunities was judged to be less desirable.
 - c. A gravity model is used in the trip distribution.
 - d. The year 2000 forecasts using the 1975 update of the Michigan model compared very favorably with the observed trends at the 32 permanent count locations.
5. Michigan's comparisons of the modeled results with observed trends at their

32 permanent count locations has some interesting implications:

- a. Extrapolation of observed traffic growth trends would have produced forecasts which would be very comparable to the Michigan statewide model forecasts which use population as the principal independent variable. If the modeled results are consistent with observed traffic growth trends, then it would seem the forecasts based on the observed trends would also be reasonable.
- b. The consistency of the results is really not surprising. By and large, population forecasts are based on observed trends in population growth. If intercity traffic growth is principally a function of population growth (an underlying assumption in the Michigan models), then it would seem reasonable to expect that the modeled results would be consistent with the observed trends in the count data.

RECOMMENDATIONS

Based on the review of current practice for statewide models directed toward estimating highway volumes on intercity highway facilities, such as the Texas Trunk System, the following recommendations are offered:

1. The primary recommendation is that the Department not undertake the development and implementation of a detailed set of statewide models (like those used in Michigan and Kentucky) at this time. The available data simply did not indicate that the implementation of such statewide models will improve the quality of the intercity travel forecasts.
2. If it is determined that a detailed set of statewide models is needed, it is recommended that a pivot or shift approach be used to estimate the expected percent increase in traffic on a detailed network. The expected percent change can be applied to the base year count data to forecast the future year volume. Using this approach, it is recommended that the Michigan general trip and truck trip models be adapted for use in estimating the expected percent change. Chapter IV describes this approach.

3. It is recommended that the Department investigate the feasibility of less detailed (i.e., more macroscopic level models) for the development of intercity travel demand estimates. Models such as the Florida statewide models and the models used by consultants in the recent investigations of the feasibility of high speed rail in the Texas triangle should be considered in this investigation. The inclusion of multi-modal considerations in such a model set could be beneficial as the Department assumes a broader responsibility as a Department of Transportation.

IV. PROPOSED INVESTIGATION OF A NEW APPROACH

Rather than recommending the implementation of a modeling system using one of the more traditional approaches, it is proposed that a simpler and less costly alternative be investigated. Some of the advantages of the proposed new approach include:

1. No new O-D travel surveys would be required for the proposed approach. Instead, the approach would take advantage of the extensive count data available.
2. Since the new approach would focus on estimating the expected percent change in traffic volumes rather than directly estimating the volumes, the calibration phase of the implementation process would be much less intensive.
3. The demographic data requirements for the model would be zonal population estimates and forecasts.
4. The validation phase would provide a good indication of the expected accuracy of the model's forecasts.

The following describes the proposed new approach, the proposed calibration phase, and the validation phase.

GENERAL APPROACH

The proposed new approach would be directed toward forecasting the expected percent change or "shift" in intercity travel demand rather than attempting to directly forecast intercity travel volumes as is done with the more traditional modeling systems. This type of model is sometimes referred to as a "pivot" model in which the estimation of change is applied to the measure of the base condition. In this case, base year counted volumes would serve as the measure of the base condition and would be the item which is "pivoted" or to which the shift (percent change) is applied. A three-step modeling procedure would be used to estimate the percent changes or growth factors. While this is apparently a new approach for statewide forecasting, it is not a truly new approach. It is similar in many respects to the conceptual approach utilized in the FHWA's Simplified Project Forecasting (SPF) procedures.

Current forecasting procedures for estimating intercity highway volumes are generally extrapolations based on historical trends. Although extrapolation is a useful and very quick tool requiring relatively minimal data, it does not directly consider the population changes and network changes.

The following outlines the basic modeling elements of the proposed new approach:

- **Zones and Network:** The network should include all major intercity highway facilities (e.g., facilities which would be included in the Texas Highway Trunk System) and other facilities (as needed) to fairly represent the intercity travel opportunities. The speeds on the system should represent the average daily speeds (i.e., the typical 24-hour type speeds). The zone structure should be similar to the zone structure used in the Michigan Statewide Modeling System (the criteria used in delineating the Michigan zone system is summarized in Appendix A). It is suggested that the very large metropolitan areas be represented using multiple zones so that population accessibility can be reasonably represented in the models. For example, it is likely that five to ten zones might be used to represent Houston and Harris County. It should be noted that since Harris County and its surrounding seven counties are already included in the regional transportation study, the statewide models are not directed toward estimating highway volumes within such urban and regional study areas but rather are directed toward including them at sufficient macroscopic detail so that their impact on facilities outside the region can be fairly accounted for.

As currently envisioned, the Texas state line will be used as the external cordon for the study area. Depending on data availability, it would be desirable to extend the cordon line roughly 30 to 50 miles into adjacent states or even to include the entire states in the modeled area. If the cordon can be extended into adjacent states, a gradually less detailed network and zone structure could be used (essentially analogous to the transition ring concept in subarea focusing). Texas' international border with Mexico probably can be best handled by using the border as the external cordon.

- **Demographic Data:** The proposed model structure will use zonal population data as its basic demographic input. Zonal population estimates for both the base year and for the forecast year will be needed to apply the models.
- **Trip Generation:** It is recommended that the Michigan trip generation equations (i.e., models) for general trips and heavy truck trips be used as the initial internal trip generation models. It is proposed that available information on Texas tourism be used to estimate a simple set of vacation models. Major vacation attractors will need to be handled as special generators. Since vacation travel is included in the base year ADT counts (which will be growth-factored for the forecast) and since vacation travel generally accounts for a relatively small portion of ADT volumes, it is anticipated that a fairly simplistic method of accounting for these trips in the modeling process should be adequate. The initial trip generation models (borrows from Michigan) will be adjusted in the subsequent calibration phase to represent Texas travel. Trip generation estimates at external stations would continue to be estimated using historical trends in count data.

Since the zonal trip generation equations require both zonal population estimates and weighted estimates of the population within 40 minutes of the zone, software will need to be developed to accumulate the surrounding population estimates for each zone. This software will also apply the models to estimate the zonal trip ends.

- **Trip Distribution:** It is proposed that an Atomistic version of the traditional gravity model be employed for trip distribution. Texas' Atomistic model is the only known model which considers zone size in the distribution of interzonal trips. Since the current version of the ATOM2 routine in the Texas Trip Distribution Package limits the zonal radii values to a maximum of 10.2 minutes, a special version of the ATOM2 routine will need to be developed for statewide modeling that allows for substantially larger radii values. Since the trip generation models estimate interzonal trips, intrazonal trips will need to be prohibited in the trip distribution process. This option to prohibit

intrazonal trips is already available in the ATOM2 software.

The ATOM2 trip distribution model allows the direct input of the traditional gravity model F-factors rather than trip length frequency estimates. As with the traditional gravity model, the F-factors will be held constant in the iterative process. The F-factors are used to represent the relative impedance to travel due to spatial separation. Since Michigan has already calibrated sets of F-factors for both general trips and heavy truck trips, it is proposed that these F-factors be borrowed and used in the Texas application.

- **Traffic Assignment:** It is proposed that the traffic assignment be performed using the Texas Large Network Package. Since the focus of the models is the estimation of growth factors on rural facilities which do not experience major congestion problems, it is recommended that all-or-nothing assignments be used. Urban congestion, of course, will be represented in the speeds used on links passing through urban areas. If a capacity restraint assignment is desired, it is suggested that capacities be coded only on the rural links to avoid the potential distortions on urban links due to the large zones.

The following outlines the proposed calibration and validation phases for implementing and testing the proposed new approach.

MODEL CALIBRATION

Since the 1990 census will be available soon, it is recommended that the statewide models be calibrated for a 1990 base year. A relatively simplistic model calibration procedure is proposed. As may be recalled from the discussion of the original Michigan models, following their initial application the assigned volumes at 30 permanent count locations were compared to the observed ADT counts. These comparisons were used to estimate an assignment correction factor to account for model biases. A similar approach is proposed to calibrate the models for application in Texas. It is recommended that 1990 ADT estimates be developed for all rural links which would be considered in the statewide forecasting. Using only these rural links (i.e., avoiding the links within cities and urban study areas), the assigned volumes will be compared to the "observed" 1990 ADT volumes

to estimate the desired adjustment factor (i.e., the ratio of the average counted ADT volume to the modeled assigned volume). Rather than applying the adjustment factor to the assigned volumes, it is proposed that the factor be applied to the coefficients of the trip generation equations thereby "calibrating" the equations for Texas applications. Using the models with the adjusted coefficients, the final base year model application would be performed.

MODEL VALIDATION

Since this is a new approach, a good validation procedure is felt to be highly desirable. To validate the proposed model approach, it is proposed that the 1990 calibrated model be applied to "backcast" the growth factors for the 1980 to 1990 time period. The 1980 zonal population data needed should be readily available from the 1980 census. The largest task for the validation will probably be the development of the 1980 network.

It is suggested that 50 to 100 geographically dispersed rural links (more if available) be selected where good 1980 ADT estimates are available. For these selected links, the 1990 forecasted volume will be estimated by applying the growth factors estimated from the 1980 and 1990 modeled assignment results. The modeled 1990 volume estimates for these selected links can be compared to the "observed" 1990 ADT volumes on the 1990 network. The root-mean-square (RMS) error and percent RMS error by volume group are the traditional measures used to compare the modeled and observed results. Conversely, the reciprocal of the growth factors for the selected links could also be applied to the "observed" 1990 ADT volumes to "backcast" the 1980 volumes for comparison to the "observed" 1980 volumes.

In addition, the 1990 assigned volumes on the selected links can be directly compared to the 1990 "observed" ADT's. Similarly, the 1980 assigned volumes on the selected links can be compared to the 1980 "observed" ADT's. It is expected that the percent RMS errors will be substantially smaller for the growth factored results than for the direct comparison of assigned volumes to the "observed" ADT's.

The comparisons of the RMS errors and percent RMS errors by volume groups are probably the minimal recommended comparisons for validating the models. As in urban

transportation studies, there are many other interesting and useful comparisons which can be made depending on the availability of 1980 ADT's. It is anticipated that the proposed new approach will provide as good (and hopefully better) forecasts as the old traditional direct link volume estimation procedures would provide.

APPENDIX A

MICHIGAN STATEWIDE HIGHWAY NETWORK MODEL

MICHIGAN STATEWIDE HIGHWAY NETWORK MODEL

In the mid-1960's the state of Michigan, with assistance of a consultant, undertook an effort to develop and calibrate a model capable of estimating intercity highway volumes on a statewide basis. Subsequent to the development of the statewide model, utilization of the model in various applications such as traffic studies and regional system plans increased. By the late 1970's, with use of the statewide model becoming widespread, the state felt that the time had come to recalibrate the model. The year 1975 was chosen as the base year for this recalibration effort. Since the 1975 update, the Michigan models are reported to have been used in over 1,800 applications related to transportation decisions.

The Michigan Statewide Model uses a basic three-step process of trip generation, trip distribution, and traffic assignment to estimate intercity highway volumes on the major highway facilities in the state. Summaries of the zonal and network development, trip generation and trip distribution models as well as the traffic assignment model from the original model calibration effort (base year 1960) are presented in this appendix. Additionally, information regarding these same areas from the 1979 recalibration effort (base year 1975) is presented along with results of the original base year application and recalibration of the statewide model.

Zones and Network

As it was the purpose of the statewide model to estimate interzonal highway volumes, intrazonal trips would be ignored. Therefore, zone size had to be small enough in terms of size so that interzonal trips would effectively portray major highway traffic volumes. The criteria employed in choosing the zones within the state were as follows (3):

- Zones should consist of an aggregation of one or more townships and/or cities which are contiguous.
- A zone should lie entirely within one county.

- All cities except Detroit with populations exceeding 10,000 should form a single zone (Detroit was split into three "arbitrary" zones, each containing roughly 710,000 population).
- Any township or city with a population of 2,500 or less should be combined with one or more adjacent townships or cities to form a zone.
- Zones should have a population of 2,500 or more except where such zones would be unusually large in area.

On this basis, a total of approximately 480 zones within the state were selected. In order to account for those trips entering and leaving the state, a set of 29 out-of-state zones were developed. The in-state zone selection criteria was not applied to the out-of-state zones, and they were considerably larger in size.

The zone structure utilized in the recalibration of the model to a 1975 base year was slightly different to the one used in the original calibration effort. The number of in-state zones increased to 508, and the amount of out-of-state zones increased to 39, bringing the total number of zones to 547 (4). Figures A-1 and A-2 present the in-state and out-state zone structure used in the recalibration of the statewide model.

The facilities which were represented in the statewide highway network included all interstate, U.S., and Michigan (state) routes as well as "significant" county roads. In addition, a highway route around Lake Michigan through Wisconsin, Illinois, and Indiana was included in order that traffic between the upper and lower peninsula would have an alternate route to the Mackinac Bridge. The resulting network contained approximately 2,100 links (3). For the 1975 recalibration effort, the original network was updated to include state trunklines which were not in existence at the time of the original calibration effort.

It should also be noted that Michigan is in the process of developing a more detailed network and zone structure. This new system will use approximately 2,300 zones.

Travel Surveys

Two sources of travel data existed upon which the models could have been based.

The first and larger of the two in terms of observations were from various Mississippi Valley Screen Line surveys while the second set of data were from origin-destination studies made at ten cities in the state of Michigan. Technically speaking, a model could have been constructed using either or both sources in a complimentary fashion. However, it became evident that the available resources allowed a detailed analysis of only one set of data. Therefore, a decision as to which of the two data sources would serve as the primary data source had to be made. The screenline data provided detailed information regarding the route selection of cars which passed through the screenlines but were incomplete relative to the origins and destinations of the cars. The metropolitan O-D data provide relatively complete information on the origins and destinations of cars passing through a cordon but give little information concerning the route over which the traffic traveled (3).

After examination of the data, a decision was made to use the metropolitan O-D data as the basis for the statewide model. This decision was made on the consideration that the screenline data lacked the completeness for studying trip generation characteristics as well as the feeling that screenline data were less compatible with the adopted network model (BPR network model). In the course of the data analysis, it was necessary to eliminate data from one city due to "a number of discrepancies." Additionally, because the O-D data did not include information on areas with large populations, aggregated data from a Detroit traffic study were used along with the O-D data.

Despite its selection as the data source upon which the model would be based, the metropolitan O-D data contained deficiencies of its own. The available data on external trips to and from Detroit were inadequate and treated the city as a whole, rather than splitting it into zones as was necessary for use in the network model. There was very limited data on small towns and rural areas where productions generally exceeded attractions. In nine of the ten cities for which data were available, the cities' trip attractions were greater than their trip productions. If these characteristics were applied to the whole state, it would result in an impossible and unbalanced situation (3).

After performing various analyses and tabulations of the O-D data, it became clear that total trips (excluding through trips, which had been removed from the O-D data early in the analysis) could be better estimated than trip productions and attractions. Therefore,

the trip generation models would estimate origins and destinations instead of productions and attractions.

The 1979 recalibration effort made use of some 60 major and minor O-D surveys taken throughout the state over the preceding 20 years in the development of an "actual" trip length distribution (TLD) curve. The actual TLD curve was used in evaluating the results of the recalibration effort.

Trip Generation

Through an analysis of average trip length by trip purpose from the metropolitan O-D data, it was felt that in terms of variation in trip length, the original nine trip purposes from the O-D data could be reduced to three purposes for trip generation and distribution. The resulting trip purpose breakdown was vacation, heavy truck (trucks other than light trucks), and general (all non-vacation auto trips and light truck trip types) (3). The trip generation models for general trips and heavy truck trips were used to estimate trip origins and destinations rather than trip productions and attractions by zone.

An analysis of the relationship between population and vehicle ownership indicated that throughout the state, car ownership appeared to depend almost solely on population. It was established that correlations between county car and truck ownership and population were consistently .98 or higher (3). Therefore, it was felt to be reasonable to attempt to forecast interzonal vehicular trips directly from forecasts of population. To take account of the time dependent effects of economic factors, highway conditions, etc., on the per capita level of car ownership, an additional item was necessary. For this reason, the ratio of forecast vehicle miles per capita traveled during the year under study to vehicle miles per capita traveled during the base year of 1960 was used. The Michigan Highway Department had already made estimates of the values necessary to derive this ratio. However, there were factors other than internal population of a zone which influenced its potential for interzonal trips.

This can be seen by considering what would happen to a city if it grew in population while its surrounding environment (i.e., other cities and towns) did not change. As this growth occurred, one would expect that the attractions available within the zone boundary

would increase. As this process occurred, one would also expect a smaller fraction of the trips taken by inhabitants of the growing city to be attracted to destinations outside the zonal boundaries. Similarly, if a town or city remains constant in size while its external environment grows in population and sources of attractions, one would expect an increasing number of trips to be made through the interzonal boundary.

As a result of these observations, it was determined that the trip generation function should have the following characteristics (3):

- As zonal population increases, interzonal trips should increase less rapidly provided the external environment remains unchanged.
- As the external population near a zone increases, an increased number of interzonal trips would arise even though the zone population remains constant.

Several functions with these characteristics were examined in an effort to develop the best regression relationship for implementation in the model. Central to the development of this relationship was the need to strike a balance between simplicity and accuracy. After a series of investigations, it was determined that an adequate measure of interzonal trip generation could be based on a combination of internal zone population plus a function of the external population within a limited distance of the zone's center. All of the potential models which were subsequently tested made use of two demographic parameters: the internal population of the zone and a measure of the population of its surrounding environment. This surrounding population variable is critical in the statewide demand estimation process. Initially, the external population was defined as the population outside the zone boundary but within 35 miles of the zone center. This definition was revised for the final regression to a travel time rather than distance based variable and the external population was defined to be all residents of other zones within 20 minutes, half of the residents in zones between 20 and 30 minutes, and one-fourth of the residents in zones between 30 and 40 minutes travel time (3).

The trip generation and distribution models assumed symmetry in the sense that for every trip from one place to another there was also a return trip in the reverse direction. Therefore, the number of trips could be specified as either trips in each direction or trips

in both directions (3). Both of these definitions were utilized in the regression analysis.

After statistically testing the ability of the regression relationships to estimate the trip generation of a number of regression relationships, the following was selected as the final model for the generation of general trips and heavy truck trips:

$$N = 1.04 P_c^{0.89} \left(\frac{P_c + P_e}{P_c} \right)^{0.19}, \quad \text{General trips (3)}$$

$$N = 0.062 P_c^{0.89} \left(\frac{P_c + P_e}{P_c} \right)^{0.11}, \quad \text{Heavy truck trips (3)}$$

where:

- N = interzonal trips generated in each direction
- P_c = zonal population
- P_e = external population - 100 percent of population of zones within 20 minutes plus 50 percent of the population of zones between 20 and 30 minutes plus 25 percent of the population of zones between 30 and 40 minutes

As previously mentioned, the number of trips could be expressed either in terms of trips in each direction or trips in both directions. In the early analysis, the latter definition was utilized. However, each way trip data were used in performing the regressions to obtain the final traffic generation models.

The network model was initially run to develop data on the external population and to develop the skim trees (used to produce a table of interzonal travel times) for use in the trip generation process.

The results of the regression analysis showed that the relationship used for generating general trips accounted for 99 percent of the variance in general trips and that the

relationship used for heavy truck trips accounted for 95 percent of the variance in heavy truck trips (3).

From the documentation, it appears that the same trip generation models developed for the original calibration effort were used in the 1975 model recalibration.

Trip Distribution

A gravity model was used to perform the distribution of the interzonal vehicular general and heavy truck trips estimated by the trip generation models. In the early gravity model and deterrence function (F-factor) analysis, a single exponent of distance was employed for deterrence. This led to a deterrence function proportional to time or distance approximately cubed. However, when this function was plotted against data from the ten external cordon O-D surveys, departures from linearity were observed at very short and very long separations, where there is a tendency for deterrence to fall off more slowly than in the inverse cube (3).

The previously mentioned assumption of trip symmetry (i.e., for every trip from one place to another there is a return trip in the reverse direction) resulted in the consideration of a "symmetrical" gravity model. Rather than perform the more traditional step of scaling trip table entries to a row (production) total, a symmetrical type of scaling was required. This resulted in the development of an "extended" gravity model (3).

The extended gravity model is of the form (3):

$$N_{ij} = \sqrt{\alpha_i \alpha_j} \sqrt{N_i N_j} g(t_{ij})$$

With the "extended" gravity model, the use of adjustment factors, α_i , can be anticipated in performing regression with the O-D data to obtain the deterrence function. Unfortunately, the deterrence function regressions could not be performed directly because $g(t_{ij})$ is a function of α_i and α_j (3).

A two-step process was employed to transform the O-D data from the ten urban area cordon studies into a form suitable for developing the final deterrence function. First, the

O-D data from each of the nine O-D study cities were grouped into travel time intervals according to the location of the external trip end, and trips were accumulated over these time bands. In addition, the traffic generated by the zones belonging in each of these bands was accumulated by summing the N_j for each zone in the band (3).

A preliminary deterrence function was obtained which then allowed the computation of preliminary adjustment factors for each zone. Once these preliminary adjustment factors had been obtained the value of $\sqrt{\alpha_j N_j}$ for all zones in each band was accumulated. This permitted the final deterrence function to be hand fitted to the data points (3). Deterrence curves which describe deterrence as a function of distance were derived for the general and heavy truck trip purposes. They are as follows (3):

General trips:

$$t \leq 8.0 \text{ minutes, } g(t) = 2.0$$

$$8.0 \leq t \leq 25 \text{ minutes, } g(t) = (198) t^{-2.21}$$

$$25 \leq t \leq 45 \text{ minutes, } g(t) = (8.5 \times 10^3) t^{-3.38}$$

$$45 \leq t \leq 70 \text{ minutes, } g(t) = (1.43 \times 10^7) t^{-5.33}$$

$$70 \leq t \leq 150 \text{ minutes, } g(t) = (5.08 \times 10^3) t^{-3.46}$$

$$150 \leq t \leq 300 \text{ minutes, } g(t) = (16.75) t^{-2.32}$$

$$t > 300 \text{ minutes, } g(t) = 3 \times 10^{-5}$$

Heavy truck trips:

$$t \leq 8.0 \text{ minutes, } g(t) = 1.6$$

$$8.0 \leq t \leq 15 \text{ minutes, } g(t) = (75) t^{-1.85}$$

$$15 \leq t \leq 35 \text{ minutes, } g(t) = (2.68 \times 10^2) t^{-2.32}$$

$$t > 35 \text{ minutes, } g(t) = (6.35 \times 10^3) t^{-3.21}$$

The deterrence function for general trips was somewhat arbitrarily set equal to a constant for travel times less than 8 minutes. Because the travel time across a zone could be on the order of 5 to 10 minutes and, thus, travel between adjacent zones could vary from seconds to as much as 15 or 20 minutes, it made little sense to differentiate between interzonal travel times of 5 and 8 minutes. Also, the O-D data suggested that as t approached zero, $g(t)$ approached a constant (3).

Speculation could only be made as to why the deterrence function flattened out at very long travel times. Because of the small number of O-D trip interviews involving such long trips, the data base was not large enough to support the conclusion that $g(t)$ approached a constant for large t . It was sufficient, however, to support the conclusion that $g(t)$ flattened out considerably (3).

It should be noted that only intrastate trips were included in the deterrence function analysis. It was the analysts' feeling that trips over 5 hours (300 minutes) length within the state of Michigan invariably had an origin or destination located outside of major metropolitan areas. Therefore, the tendency to shift to air transportation was reduced. If interstate trips were considered, a continual drop in $g(t)$ as t increased beyond 300 minutes due to the increasing attractiveness of air travel might have been found. In Michigan, it was felt that this was somewhat immaterial, as beyond 300 minutes, $g(t)$ was so small that general trips between such distant points was fairly insignificant (3).

The documentation on the recalibration effort indicates that the trip distribution model made use of a "gravity principal" in determining the trip interchanges between zones.

Vacation Travel Analysis

As noted earlier, an analysis of trip length by purpose led to the decision to generate and distribute intercity vehicular trips by three trip purposes, one of which was vacation trips. Due to its uniqueness, an analysis of vacation travel was conducted separate from that for the other trip purposes, general and heavy truck travel. The following summarizes the procedure used to model vacation travel in the state of Michigan.

A number of factors complicated the analysis of vacation travel. They were as follows (3):

Definition

The definition of vacation travel posed difficulties; it was not always clear how well distinguished this category was from some of the other travel categories such as social and recreational travel. For example, O-D studies indicated an appreciable fraction of vacation travel as having destinations only 5 to 10 miles outside the cordon established around a node within which the vacation-bound cars are registered. Trips of this type did not correspond to what might most usefully be considered as travel for vacation purposes, and these results suggested that certain travel categories have overlapping definitions.

Cause of Attraction

While for most forms of travel the attraction of a node can be considered a function of its population and various economic indicators, in the case of vacations it was clear that this was not the case. There was, in fact, obvious evidence that vacation travel was attracted to just those areas where other people are not, provided these areas have certain characteristics desirable for purposes of recreation and relaxation. Under these conditions two difficulties were met: first, it is difficult to find some factor other than a sample of vacationers to determine exactly which nodes will prove attractive for vacations; and second, it becomes very difficult to forecast the attractiveness of various locales for vacations in the future.

Categories of Vacationers

A careful analysis of vacation travel in Michigan distinguished at least four categories of travelers: Michigan vacationers staying within Michigan; Michigan vacationers traveling through Michigan to an out-of-state destination; out-of-state visitors vacationing in Michigan; and out-of-state vacationers traveling through Michigan to another vacation spot. The large number of categories compounded the difficulties of analyzing vacation travel, and this last category of vacation travel was excluded from the model.

The estimation of vacation intercity trips utilized data from the following sources: (1) a survey of in-state and out-of-state tourists in Michigan, (2) Mackinac Bridge Study, (3) Highway Department statistics and (4) O-D data from the urban cordon surveys. In an analysis of the tourist survey data, it was apparent that both out-of-state and Michigan vacationers tended to choose the same counties for vacation destinations, with the exception of Detroit, which was an important tourist center for out-of-state vacations but not for

residents of Michigan. If Detroit and some of the border counties were removed from the transit survey, there was a relatively high degree of correlation between vacation preferences among in-state and out-of-state vacationers. Additionally, the ratio of in-state and out-of-state vacationers from the tourist survey and the bridge study were very consistent, even when the Detroit visitors were removed from the tourist survey data (3).

Given the fact that the population of the Upper Peninsula was so small that the number of vacations generated in the Lower Peninsula would be few, it was assumed that the bridge data applied entirely to the residents of southern Michigan vacationing in the Upper Peninsula. From the tourist data, a scaling factor was developed by which the bridge data were multiplied to obtain a trip generation estimate at the state level of the total native Michigan tourist travel. Since the tourist survey indicated similar destination preferences among out-of-state and Michigan tourists and the ratio of Michigan to out-of-state tourists was the same in the Upper and Lower Peninsula, the same scaling factor was applied to obtain a statewide trip generation estimate of out-of-state tourists (3). The estimates of statewide travel for the three categories of vacation travel function as control totals and are used in the allocation to the zonal level.

The trip generation process for in-state vacation travel by Michigan residents and out-of-state residents can be described as a "top-down" allocation of the respective control total. Vacation attraction indices for each county were developed from the tourist survey data. The county level attraction indices were then allocated to the zonal level within each county in proportion to zonal population. At this point, the vacation attractions (i.e., vacation destinations) were allocated from the state level to the zonal level based on the attraction indices. Vacation productions for the two categories were allocated from the state level to the zonal level based on population indices equal to zonal population.

The trip distribution for these two categories of vacation travel (i.e., Michigan residents vacationing within the state and out-of-state residents vacationing within Michigan) are performed using a gravity model. This model is as follows (3):

$$v_{ij} = \frac{P_i A_j^i g(t_{ij})}{\sum_{k=1}^Y P_k g(t_{ij})} \quad 1 \leq i, j \leq Y$$

These gravity model applications are unique in that the scaling is performed relative to attractions rather than to productions as would be done in a more conventional approach. In effect, the attractions are being distributed to productions instead of the productions to attractions approach. Data from the Mackinac Bridge Study was used in establishing a "relative deterrence" function to be used in the distribution of the vacation attractions (distributions) (3).

The deterrence function was obtained by first grouping the counties in the Lower Peninsula into five tiers running north to south, with the uppermost tier containing those counties closest to the Mackinac Bridge and the lowest tier containing those farthest away. For each of these tiers, the average distance from the group of counties to the bridge was determined; and the number of trips made across the bridge by residents of counties in each tier was totaled. The average trips for a tier were divided by the total population of counties represented in that tier. A relatively good fit to the points was obtained with a deterrence function proportional to the square of the travel distance (3).

The third category of vacation trips, Michigan residents destined to out-of-state vacation attractions, was handled somewhat differently than the other two vacation trip categories. The statewide control total was directly allocated to the zonal level based on the product of the home (in-state) and vacation (out-of-state) zonal populations (3).

$$N_{ij} = N_{ji} = \frac{3400^*}{P_T^i P_T^o} P_i P_j \quad (13)$$

*: control total

In effect, no deterrence function was employed in the distribution of these trips. With the 2,300-zone system currently being developed, the Michigan DOT staff expect that both the trip generation and trip distribution process will be sensitive to socioeconomic change.

Trip Assignment

The network model used for assignment of the interzonal trip tables was the BPR network model. Because of a limitation imposed by the methodology with which the software handled small volume trip interchanges, which were very common in the statewide trip table, some modifications to the method of assigning trips were made. This basically involved the splitting the trip tables for each trip purpose into two different trip tables: a "major trip table" which contained (with minor round-off effects) all of the major interzonal trips (i.e., predominantly those between neighboring zone pairs) and a "minor trip table" which contained many small interzonal trip volumes between distant zone pairs plus the round-off remainders from the major trips. These trip tables were then combined to an overall major and overall minor trip table.

At this point, the trip tables were separately assigned to the network using an iterative capacity restraint procedure for the large interchange volumes and an all-or-nothing procedure for the small interchange volumes. The volume for a link was the sum of that obtained with the major trip table and 0.01 of that obtained with the minor trip table. Since these two trip tables were assigned separately, capacity restraint could not be performed using combined trips. However, this was not felt to be a severe limitation because the major trips between neighboring zones were the ones which had the predominant effect on congestion (3).

Model Results

As a means of checking the performance of the model, a limited error check on a set of links having permanent count stations was carried out. For the 30 links checked, the average value of the ratio of the assigned to observed link volume was 1.57 (i.e., a 57 percent over-assignment). It was felt that the O-D data used to calibrate the distribution models and collected on summer weekdays, were not adjusted to account for the summer

bias. The tendency to assign volumes larger than the year round ADT could have been due to the fact that the assigned volumes represented an average summer weekday volume (3).

For this reason, a simple scaling adjustment which was the reciprocal of the assigned to counted ratio (1.57) was used. This particular scaling approach focuses on minimizing the percent error as opposed to focusing on the numerical error. Table A-1 presents both the scaled and unscaled assignment results for the 30 links along with the corresponding observed count. The use of the scaling adjustment resulted in an average assignment error of approximately 40 percent over link volumes ranging from under 1,000 ADT to 30,000 ADT (3).

Table A-1
COMPARISON BETWEEN OBSERVED AND ASSIGNED VOLUMES
(With Scaling Adjustment - $k = 0.64$)

STATION	OBSERVED 1965 COUNT	UNSCALED ASSIGNMENT	UNSCALED ASSIGNMENT/ OBSERVED	SCALED ASSIGNMENT	SCALED ASSIGNMENT/ OBSERVED
101	2,430	5,075	2.09	3,250	1.34
103	924	895	0.97	573	0.62
105	1,077	4,298	3.99	2,750	2.55
107	2,048	4,828	2.36	3,090	1.51
201	1,991	1,247	0.63	798	0.40
203/4	2,763	6,752	2.44	4,320	1.56
205	1,066	883	0.83	565	0.53
207/8	3,641	10,891	2.99	6,910	1.90
301	2,275	3,678	1.62	2,355	1.04
305	1,691	1,801	1.07	1,153	0.68
307	968	1,906	1.97	1,220	1.26
309	3,065	3,981	1.30	2,550	0.83

**Table A-1 (cont.)
COMPARISON BETWEEN OBSERVED AND ASSIGNED VOLUMES**

STATION	OBSERVED 1965 COUNT	UNSCALED ASSIGNMENT	UNSCALED ASSIGNMENT/ OBSERVED	SCALED ASSIGNMENT	SCALED ASSIGNMENT/ OBSERVED
405	3,635	1,927	0.53	1,233	0.34
407	1,939	2,823	1.46	1,810	0.93
411/12	6,559	6,883	1.05	4,410	0.67
501/2	9,695	12,767	1.32	8,170	0.84
509	1,117	434	0.39	278	0.25
511	2,910	4,997	1.72	3,200	1.10
513	4,499	3,677	0.82	2,350	0.52
515	1,663	73	0.04	47	0.03
521/2	7,922	16,906	2.13	10,820	1.37
601	1,815	3,233	1.78	2,135	1.18
603	1,668	2,229	1.34	1,430	0.86
607	3,131	5,790	1.85	3,705	1.18
611/2	18,927	32,253	1.70	20,650	1.09
705	2,960	4,181	1.41	2,675	0.90
815/6	4,413	8,902	2.02	5,700	1.29
817/8	17,415	16,199	0.93	10,700	0.61
819/2	22,455	44,513	1.98	28,500	1.27
821/2	11,862	27,101	2.28	17,350	1.46

Source: (3)

It is important to note that these results represent the first development stage of the statewide model. Following this initial application, several recommendations were made regarding a number of adjustments and improvements which could be made. It was felt that the model performance was "remarkably good" when compared with models of similarly complex processes in their early stages of development.

The recalibration documentation of the statewide model indicates that several methods of determining the model's ability to simulate 1975 travel patterns were employed. A comparison of a TLD curve developed from the model results to the "actual" TLD curve

obtained from survey data showed travel patterns to be very similar and the mean trip lengths, model versus actual, to be 30.860 to 35.399, respectively. It was concluded that the model was doing an "excellent" job of matching the actual travel based upon the number of trips generated and distributed by trip length class given the assumption that the O-D data upon which the "actual" TLD curve was based were biased toward long distance travel (3).

The 1975 ADT's from a traffic flow map were compared to the model forecasts on a link basis. This comparison revealed that with a few exceptions, all links were within a range of ± 10 percent. A comparison of base year (1975) model forecast traffic volumes with 1975 actual ADT's by roadway type for every link in the network was also performed. The results of this test found that forecasted 1975 volumes of 90 percent of all rural roads on the model were within a range of ± 10 percent of the actual 1975 ADT. It was concluded from these comparisons that the model was accurately simulating travel volumes and travel patterns in the state (1). The Michigan DOT provided ratio comparisons of the 1975 assigned to counted volumes for 29 stations (summarized in Table A-1).

The majority of the cases in which links remained uncalibrated occurred where a link was affected by a "special generator" or geographic barrier which was not fully accounted for in the initial trip generation-distribution equations. The correction of these trip generation-distribution patterns took the form of factors called MODS and BETAS. These MODS and BETAS were applied internally in the model to increase or decrease trip interchanges to more closely reflect the real world where the population variable was inadequate (3).

Application Requirements

The use of the Michigan Highway Network Model requires two major steps: input preparation and computer runs. These steps are briefly outlined below.

Step 1: Input Preparation

The basic inputs required for the model operation include:

Population Forecasts. Forecasts of population for a target year must be made for each zone in the network. In Michigan, the state had prepared forecasts on a township basis

for two target dates, 1980 and 2000, as well as for 1965, 1970, and 1975 as well as a program to convert these data to forecasts by in-state zone. Manual preparation of population forecasts for out-of-state zones was required.

Vehicle Miles Per Capita Growth Rate. The Highway Department of the state of Michigan had already prepared estimates of future total vehicle miles for the state for years in the future up to 1990. In conjunction with statewide population figures, these can be applied to provide the growth factor estimate, relative to the base year of 1960, as required for the model.

Vacation Trip Destinations Allocation. Because vacation travel does not follow the same pattern as other traffic movements, it is necessary to allocate expected vacation destinations among the various zones in the state. For the Michigan model, data from a sampling of Michigan and out-of-state vacationers were used. Also, data from the Mackinac Bridge were used to convert the sample data into estimates of total vacation travel.

Vacation Growth Rate. In Michigan, it was felt that vacation travel would probably grow at a faster rate than overall travel. Separate estimates of the growth rate of vacation travel could be incorporated to take this factor into account.

Link Data. Links are specified in terms of the distance and travel time or speed between the two nodes they connect. The links must also be characterized in terms of their capacity, since this factor is used in traffic assignment.

Step 2: Computer Runs

When the above data are available, the following computer runs are performed in three steps.

Skim Tree Run. The network model is employed to develop data on the external population around individual zones and on the interzonal travel times so that traffic generation characteristics for each zone can be computed.

Trip Distribution. Actually, this step entails both generation and distribution of trips. The information from the network model is used to develop the trip generation characteristics of each zone. A gravity model is then employed to determine travel (for each trip purpose) from each zone to each of the other zones and to construct a consolidated

interzonal trip table. The first trip table may be adjusted by an iterative process to obtain an improved fit to the input data.

Traffic Assignment. The network model is run a second time using the trip table produced by the trip distribution model. In this step, the network model determines specific routes which will be followed in making zone to zone trips, computes traffic densities on all links, and performs reallocations of the traffic in cases where one or more set of links are overloaded with respect to capacity.

APPENDIX B

KENTUCKY STATEWIDE TRAFFIC ASSIGNMENT MODELS

KENTUCKY STATEWIDE TRAFFIC ASSIGNMENT MODELS

The statewide modeling system currently being used by Kentucky was initially developed in the 1970's. Kentucky is currently planning to hire a consultant to assess the state of the models, to do initial portions of the model rehabilitation, and to generate a study plan for an entirely new model. Nevertheless, the Kentucky statewide models remain one of the most cited examples of statewide traffic assignment. The descriptions of the Kentucky Statewide Traffic Assignment Models are based on a review of the Kentucky model documentation reports (2,5,6,7,8,9,10,11).

The development of the Kentucky statewide modeling system was divided into seven phases. These phases were: (a) zone and network, (b) travel surveys, (c) trip generation, (d) trip distribution, (e) traffic assignment, (f) analysis, and (g) applications. The following provides an overview of the models developed and the base year assignment results.

Zones and Network

The principles and methodologies employed in the statewide models are patterned after the traditional urban travel forecasting models. The model system uses an "open boundary system for distribution of trips" (10). In today's terminology, this approach could be referred to as a subarea focusing approach where the state is treated as a subarea. Although the "open boundary system" adopted was quite contrary to the "closed system" used in urban travel forecasting models, it was viewed that the "open boundary system" would help in detecting and correcting assignment problems on the cordon line by tracing the actual origin and destination of trips, locating problem trip interchanges, coordinating and monitoring the planning and development efforts by adjacent states, and assessing travel impacts on Kentucky highways due to major development activities in the surrounding areas.

A total of 663 in-state zones were formed corresponding to the census county divisions and aggregation of traffic analysis units in urban and rural areas respectively. Major recreational areas in the state (such as state and national parks, historic sites, and other major traffic generators) were treated as independent zones. Similarly, a total of 118

out-of-state zones were developed by taking a single county or combination of two or more counties in the adjacent states and a single state or combination of states for the rest of the nation. Table B-1 provides a more detailed summary of the in-state and out-of-state zonal structure used for statewide model system for Kentucky.

**TABLE B-1
KENTUCKY STATEWIDE TRAFFIC MODEL ZONAL STRUCTURE**

IN-STATE ZONES				
Zone Type	Number of Zones	Percent of Total	Census Equivalent	Non-Census Equivalent
Zones within Urban Areas	82	12.4	15	67
Urban Area Zones	41	6.2	33	8
Urban-Rural Zones	26	3.9	26	—
Rural Zones	471	71.0	453	18
Recreation Area Zones	41	6.2	41	—
"Dummy" Zones	2	0.3	2	—
Total	663	100.0	570	93
OUT-OF-STATE ZONES				
Zone Type	Number of Zones	Percent of Total		
Collection of States	9	7.6		
Individual States	16	13.6		
Collection of Counties	72	61.0		
Individual Counties	19	16.1		
Foreign Countries	2	1.7		
Total	118	100.0		

The in-state network contained about 11,000 miles of highway system (represented using approximately 6,000 links) which was approximately 17 percent of the total mileage in the state (69,000 miles). Further, it accounted for almost 47 percent of the state-

maintained mileage (25,000 miles). It represented about 70 percent of the actual VMT (considering interzonal trips only) and 85 percent of the actual VMT if both interzonal and intrazonal trips were counted. The breakdown of the network mileage according to functional classification and the State Administrative Systems was as follows:

<u>Functional Classification</u>		<u>State Administrative System</u>	
Interstate	100%	Interstate	100%
Principal Arterial	95%	Toll Roads	100%
Minor Arterial	95%	State Primary	97%
Major Collector	53%	State Secondary	70%
Minor Collector	10%	Rural Secondary	11%
Local	2%	Others	33%

Nine screenlines were formed to check the results of the assignments by using natural or artificial barriers depending on the location. These screenlines are used to summarize the assignment results presented in this appendix.

Travel Surveys

Three types of surveys were conducted to determine the travel characteristics.

- (1) **Household Travel Survey:** The Household Travel Survey was conducted by mailing out questionnaires to the in-state auto-owning households. The nominal sampling rate used in the sample selection was approximately 1.5 percent, and a minimum sample size of 60 households in each county (i.e., a total sample size of 14,979 households) was used. A telephone follow-up was made to reduce the bias from non-responses. The usable response rate was approximately 45 percent (i.e., 6,713 total responses).
- (2) **Roadside O-D Surveys:** Roadside Origin-Destination Surveys were conducted on the cordon line and at certain internal area locations on a sampling basis ranging from 25 to 33 percent. The sampling data collected represented about 95 percent of the total volume of traffic crossing the cordon line.

Roadside O-D data collected by other metropolitan agencies in the state were used to avoid duplication in collecting the data. Data collected, in years other than the base year (1970), were used after "proper factoring".

- (3) Truck Travel Survey: The Truck Travel Survey was conducted along with the FHWA-sponsored National Truck Commodity Flow Survey by sending out questionnaires to truck registrants (2 percent sample); the usable response rate from this survey was 49 percent.

The internal area O-D surveys helped in checking the assignment on "parkways" (tollways) that run parallel to the free facilities.

It should be noted that the household travel survey collected data on **all** auto driver trips made by residents of the household and not just the "intercity" or long trips. The subsequent trip generation models were also for **all** auto driver trips. This is quite different from the Michigan modeling approach which focused on the intercity trips.

Trip Generation -- Production Models

Extensive analysis of the household travel survey data with several stratifications produced the best results on population density strata at the zonal level. The in-state zones were aggregated into five strata according to the population density, and appropriate trip rate was computed per household by level of auto ownership. The statewide average trip rate per household as obtained from raw survey data was 5.65. Trip rate after adjustment for income bias due to a high response rate from higher income households was 5.33. Table B-2 presents these original trip rates. The total trips produced in each zone were computed by taking the auto owning households in accordance with the level of ownership and the appropriate trip rate. The trips were further split into long and short trips based on trip length. Trip greater than 35 minutes were designated as long trips and those less than 35 minutes as short trips. Table B-3 presents the ratio values used to split the trip production estimates into long and short trips.

**TABLE B-2
ORIGINAL TRIP PRODUCTION MODELS
KENTUCKY STATEWIDE TRAFFIC MODEL**

IN-STATE PRODUCTION MODELS			
Population Density Strata	1 Car Households	2 Car Households	3+ Car Households
1	4.90	7.49	9.98
2	4.01	6.81	7.75
3	3.93	5.89	7.97
4	3.87	5.72	6.12
5	4.38	7.02	9.69
OUT-OF-STATE PRODUCTION MODELS			
Population Density Strata	1 Car Households	2 Car Households	3+ Car Households
1	4.54	6.71	8.30
2	3.88	5.88	7.40
3	3.70	5.19	6.56
4	4.04	6.20	7.92
5	4.38	7.02	9.69

POPULATION DENSITY STRATA

- 1: Consists generally of the major urban or urbanized areas except Louisville and the OKI areas, with the density range being 1,690 to 10,613 persons/sq.mi.
- 2: Consists of minor urban areas plus some rural zones and has a density range of 68 to 1,689 persons/sq.mi.
- 3: Consists of rural zones with a density of 37 to 67 persons/sq.mi.
- 4: Consists of rural zones with a density of 10 to 36 persons/sq.mi.
- 5: A special category consisting of Louisville, OKI, and the city of Fulton. These areas had densities of 428 to 13,472 persons/sq.mi. These three areas were isolated regardless of density due to the fact that the external cordon was located to exclude these areas from what is normally called the internal survey area.

**TABLE B-3
RATIO OF LONG TRIPS TO TOTAL TRIPS
KENTUCKY STATEWIDE TRAFFIC MODEL**

IN-STATE					
Population Density Strata					
Cars per Household	1	2	3	4	5
1	.055	.119	.136	.157	.037
2	.069	.119	.163	.203	.038
3+	.093	.114	.163	.200	.015
OUT-OF-STATE (ORIGINAL)					
Population Density Strata					
Cars per Household	1	2	3	4	5
1	.075	.113	.162	.101	.037
2	.067	.130	.130	.098	.038
3+	.068	.144	.144	.104	.015
OUT-OF-STATE (REVISED BASED ON NPTS DATA)					
Population Density Strata					
Cars per Household	1	2	3	4	5
1	.047	.071	.102	.064	.023
2	.042	.082	.121	.062	.024
3	.043	.091	.143	.066	.009

The initial assignment results using these models showed a tendency to significantly over-assign portions of the network. The in-state trip rates were revised based on "a county level comparison of actual versus assigned-volume vehicle miles of travel (VMT)." The developers of the models note that:

... The adjustments came about as the result of the observation that the VMT derived from the assigned base year, model auto-trip volume was significantly greater than the VMT derived from the actual base year volume of autos in the majority of counties. This comparison revealed that the trip rates were too high in spite of previous analyses that indicated the trip rates were reasonably accurate. Since about 80-90 percent of the total trips are short trips, i.e., less than or equal to 35 minutes, the decision was made to adjust only the short trip rate for instate zones. (2)

Since these adjustments were performed geographically, the net effect was a set of trip rates which varied throughout the state. The implementation of these revised trip rates resulted in lowering the average trips per household from 5.33 trips to 5.04 trips.

Trip Generation -- Attraction Models

As will be discussed in more detail in the next section, separate trip distributions were performed for long trips and for short trips. A conventional gravity model was used in the distribution of the short trips (which, of course, requires zonal attraction estimates as input). The trip distribution model used for long trips is of such a design that an independent estimate of long trip attractions at the zonal level was not necessary for its operation. Therefore, only trip attraction models for short trips were developed.

The short trip attractions models were developed using regression analysis. Population and employment were used as the independent variables in the regression process. The value of the dependent variable (i.e., short trip attractions) were obtained from a survey expanded production/attraction (P/A) trip table of the short trips.

The small number of interviews per zone raised questions regarding the reliability of the actual attractions on a zonal level. Subsequent analyses led to the conclusion that a minimum of 10,000 attractions for an area was necessary for adequate reliability. Since there were many zones with less than 10,000 actual attractions, it was necessary to aggregate (combine) zones with similar characteristics. These aggregated areas were designated as "analysis units." In other words, each analysis unit consisted of one or more zones. The subsequent regression analysis used these analysis units as the unit of observation.

As the aggregation of zones to analysis units proceeded, it became evident that exceptions to the minimum 10,000 attractions per analysis unit were necessary. Generally speaking, no exceptions were made for zones having less than 7,500 attractions. During the regression analysis, however, it became apparent that zones containing urban places of 2,500 population or more exhibited characteristics justifying their designation as an independent analysis unit even though the analysis unit did not have 7,500 attractions. These considerations or criteria resulted in the formation of 224 analysis units.

For purposes of analysis and model development, the analysis units were grouped into six categories. The following provides a description of each category:(2)

Urbanized: Analysis units within the urbanized areas of Lexington, Louisville, Northern Kentucky, and Owensboro.

Urban Primary: Analysis units within 75 to 100 percent of the population residing in urban areas or places.

Urban Secondary: Analysis units with 25 to 74.9 percent of the population residing in urban areas or places.

Rural Primary: Analysis units with up to 24.9 percent of the population residing in urban places and having at least 5,000 actual attractions.

Rural Secondary: Analysis units with up to 24.9 percent of the population residing in urban places but having fewer than 5,000 actual attractions, or with total attractions greater than 5,000 but the ratio of attractions to population or employment lower than average.

"Oddball": Analysis units with peculiar attraction characteristics causing them to exhibit extreme variations between actual and simulated attractions. Such things as low income areas, the presence of a university, a major recreation area or major commercial activity sites in urban areas cannot be adequately addressed in regression equations with only population and employment as independent variables. Therefore, these analysis units were generally handled on a case-by-case basis even though a separate regression equation was developed for them.

The step-wise multiple regression analysis program (i.e., the BMD02R program contained in the FHWA package) was used in the development of the short trip attraction models. The models and associated statistics are presented in Table B-4.

Since the short trip attractions models were developed at the analysis unit level rather than at the zonal level, they were subsequently applied at the analysis unit level. For analysis units containing more than one zone, the computed analysis unit trip attractions must be allocated to the zones within the analysis unit. This is accomplished by applying the "appropriate regression equation without the constant" (2) to each zone within the analysis unit and by using these results as the basis for the allocation of the analysis unit attractions to the zonal level.

TABLE B-4
SHORT TRIP ATTRACTION MODELS AND REGRESSION STATISTICS
KENTUCKY STATEWIDE TRAFFIC MODEL

Group	N	Model	R ² (%)	Standard Error/Mean	Percent of Statewide Attractions
Urbanized	28	A = 7312.6 + 0.7865P + 0.9684E	93.4	16.9	34.4
Urban Primary	47	A = -5.1 + 1.0068P + 1.7172E	94.3	13.7	22.7
Urban Secondary	34	A = 3989.0 + 0.3563P + 1.1263E	78.8	12.0	10.3
Rural Primary	85	A = 2893.6 + 0.2287P + 1.0900E	70.6	16.9	19.5
Rural Secondary	25	A = 2107.7 + 0.719P + 0.6799E	82.9	18.5	3.0
Oddballs	5	---	---	---	10.1
Universe	224	---	92.4	19.8	100.0

Trip Distribution -- Long Trips

The developers of the Kentucky models felt that the gravity model was "probably not a suitable model procedure for long trips" and therefore developed a new trip distribution process which they refer to as the Long Trip Distribution Model.

Theory of Model

The description of the theory, upon which the Long Trip Distribution Model is based, uses some special terminology. It is, therefore, useful to briefly define this terminology before presenting the description of the theory (2):

Production/Attraction ratio (P/A ratio): This ratio value is a key element in the new trip distribution model. Given two zones (Zone i and Zone j), the P/A ratio for this Zone Pair ij can be defined as follows:

$$(P/A)_{ij} = T_{ij}/T_{ji}$$

where: $(P/A)_{ij}$ = the P/A ratio for Zone Pair ij

T_{ij} = long trips produced in Zone i and attracted to Zone j

T_{ji} = long trips attracted to Zone i and produced in Zone j

Production area size: Given a Zone Pair ij, the production area size assigned to Zone i is either the population of the urban area containing Zone i or simply the population of Zone i. For application purposes, the Kentucky model uses ten categories of population size ranges for both production area sizes and attraction area sizes:

Population Size Ranges:

1	to	2,500
2,501	to	5,000
5,001	to	10,000
10,001	to	25,000
25,001	to	50,000
50,001	to	100,000
100,001	to	150,000
150,001	to	250,000
250,001	to	500,000
500,001	and above	

Attraction area size: Given a Zone Pair ij, the "attraction area size" assigned to Zone j is either the population of the urban area containing Zone j or simply the population of Zone j.

Time ranges: For application purposes, time intervals (varying in size from 15 minutes to over 200 minutes) are used to describe the trip length frequency estimates for a production zone and to identify potential attraction zones within the specified "time range" or time interval of the production zone. For in-state zones, nine time ranges are used. For out-of-state zones, six time ranges are used. These time ranges are as follows:

Time Ranges Used:

In-state (minutes)	Out-of-state (minutes)
35 - 50	35 - 75
51 - 75	76 - 125
76 - 100	126 - 200
101 - 125	201 - 300
126 - 150	301 - 500
151 - 200	501 - 9999
201 - 300	
301 - 500	
501 - 9999	

The following describes the theory upon which the Long Trip Distribution Model is based:

The model is based on the theory that the trip interchanges between a set of two areas of given population sizes and spatial separation will demonstrate a stable production/attraction ratio that is characteristic of all sets of areas with the same population sizes and spatial separation characteristics. Where the normal stable relationship does not exist, an area has unique and special qualities which require that it be given special study.

The relationships can be expressed discretely by utilizing a three dimensional matrix with production area size, attraction area size, and time range being the axes and the P/A ratios being the cell values.

For a given time range and production area size, the P/A ratio increases as the attraction area size increases. For a given time range and attraction area size, the P/A ratio decreases as the production area size increases, and for a given production area size and attraction area size, the P/A ratio approaches unity as the time range becomes greater.(2)

The actual trip distribution process is complex and difficult to understand. Essentially, the model distributes the long trip productions from a zone based on the estimated trip length frequency for the zone and the estimated P/A ratios for the zonal interchanges. The Long Trip Distribution Model also includes what is referred to as an "oddball interchange module". Rather than to attempt to describe the Long Trip Distribution Model procedures in detail, it is probably sufficient (for purposes of this overview) to simply outline the key input requirements for the model.

Input Requirements

The following briefly outlines the key input requirements for Kentucky's Long Trip Distribution Model (2):

Zonal Long Trip Production Estimates: The estimated number of long trips produced by each zone is a basic input. It should be noted that the model does not require or use trip attraction estimates by zone.

Zonal Long Trip Length Frequency Estimates: An estimated trip length frequency distribution (i.e., the estimated percent trips by time intervals previously described) is required for each zone. In the Kentucky model, 29 different trip length frequency distribution estimates are used. The analyst must specify the appropriate trip length frequency estimate to be used with each production zone. In the trip distribution

process, the trip length frequency results for each zone is constrained to remain within ± 20 percent of the expected trips at each separation interval.

Zonal Population Estimates: The estimated population for each zone (both in-state and out-of-state zones) are required.

P/A Ratio Matrices: As previously noted, the P/A ratio matrix is a three-dimensional matrix indexed by the production area size, the attraction area size, and the time range. In the Kentucky model, the P/A ratios contained in the matrix were developed using a curve fitting process based on results from the external cordon survey. After investigating several functions, an equation of the following form was selected (2):

$$P/A \text{ ratio}_{PS,AS,TR} = \frac{\text{Log}(X * AS)^{Y(TR)}}{\text{Log}(x * PS)}$$

where: PS = the median of the Production Size category (persons)

AS = the median of the Attraction Size category (persons)

TR = the Time Range

PA ratio_{PS,AS,TR} = the estimated P/A ratio for zone pairs in this production size category, this attraction size category, and this time range

X = constant = 1.0

Y(TR) = constant for time range TR
The values of this constant for the 9 time ranges are:

Time Range:	Y(TR) Value:
1	2.42
2	2.01
3	1.32
4	0.83
5	0.53
6 - 9	0.00

It should be noted that there are other input requirements and that the preceding simply highlights the key inputs to the model that are common to all zones. Again, this list is probably sufficient for overview purposes.

Trip Distribution -- Intrastate Short Trips

The gravity model was used to distribute only the internal-internal (i.e., intrastate trips within Kentucky) short trips. The developers of the Kentucky models indicate that it was initially their intention to distribute all the short trips using the gravity model but that they encountered problems. They summarize the problems in the following:

The gravity model was used to distribute just the internal-internal short trips. Initially, the plan was to distribute the two categories of short auto trips by gravity model, i.e., internal-internal, internal-external and vice versa. The external-internal, or vice versa, trips come from the instate and outstate zones that are within 35 minutes of each other. There are 25 outstate zones in the adjacent states area that are within 35 minutes of an instate zone. Similarly, there are 81 instate zones that are within 35 minutes of an outstate zone. . . . An attempt to distribute both categories of trips by gravity model was unsuccessful in the sense that an excessive over-assignment was observed on the cordon links for the model auto short trips. The reason for this over-assignment was that the large number of productions for outstate zones were being forced to the instate zones due to the non-availability of any outstate zone within 35 minutes of the outstate production zone. Further, the gravity model run showed that approximately 10-12 percent of the total trips were being dumped in the last time increment. This caused the model calibration curve to shoot up at the end.

. . . Hence, the decision was made to zero out the productions for the 25 outstate zones and use only the attraction values for them when running the gravity model. A run of the gravity model with zero production and actual attractions for the 25 outstate zones produced a distribution curve that closely resembled the trip distribution curve from the survey data. The problem of trips being lumped into the next to the last trip time increment was completely eliminated. The average trip length was found to be 13.04 minutes which was 2.6 percent lower than the average survey trip length. . . (2)

Since the gravity model was applied only to the short auto trip productions within Kentucky, the expanded base year survey trip table was used to represent the other types of short trips (i.e., external-internal and vice versa). Following the gravity model application, the in-state trip productions which are attracted to the 25 out-of-state zones were set to zero before merging the gravity model trip table with the expanded base year survey trip table.

The problems encountered by Kentucky model developers in applying the gravity model is an interesting problem. While their approach appears to have adequately addressed the problem, there may have been other approaches which could have resolved

these problems. For example, consideration might be given to extending the subset of zones included in the short trip gravity model application substantially beyond the out-of-state zones within 35 minutes of an in-state zone (e.g., all the out-of-state zones within 120 minutes of an in-state zone) which may have moved the problem sufficiently far away from the zones affecting Kentucky to have had little or no impact on the assignment results.

It is also interesting that, in effect, the use of the "open boundary concept" and the splitting of trips into long and short trips for trip distribution purposes did not resolve the distribution and assignment problems in the vicinity of the state's external cordon. The model developers were still forced to rely on an expanded external cordon survey data for the short trip interchanges across the state line. In hindsight, one must even wonder whether there may have been alternatives to splitting of trips into long and short trips for trip distribution purposes.

Trip Distribution -- Interstate Short Trips

As previously noted, the trip table containing expanded external cordon data for short trips (i.e., the interstate short trips) was used in the base year modeling. For forecasting future year traffic, the FRATAR modeling technique is used to growth-factor the interstate short trip table.

Truck Trips

In the initial model applications, the truck trips were handled by factoring the auto trip tables by 13.2 percent. This factor was developed from an analysis of the classification count data on the cordon, screenline, internal area roadside O-D links, and the truck weight stations across the state (which showed the average percentage of trucks to be 13.2 percent).

The later traffic assignments developed during the model development and calibration process were reported to use a "calibrated" truck trip table rather than simply factoring the auto trip tables to account for trucks. The reports available did not describe the process used to develop the "calibrated" truck trip table. It was indicated, however, that the later applications using the "calibrated" truck trip table provided the best assignment results. Without carefully studying the various assignment results presented, it is not clear

how much improvements were realized from the use of the "calibrated" truck trip table.

Traffic Assignment Model

A simple all-or-nothing minimum time path assignment technique using observed speeds was used to assign trips to the network. Other methods such as "weighted" (i.e., both speed and distance as impedance) and STOCH were "tested extensively with little luck in getting improved assignments at the statewide level." Kentucky has a system of parkways (i.e., toll facilities). The monetary value of the toll for autos and trucks was converted into time to account for toll impedance.

Traffic Assignment Results

As previously noted, nine screenlines were formed to check the results of the assignments by using natural or artificial barriers depending on location. These screenlines (shown in Figure B-1) are used to summarize the assignment results for the 86 links crossing these screenlines. In addition, assignment results across segments comprising the state's external cordon (i.e., 66 links) are also presented. Finally, the assignment results for the 66 links crossing the external cordon are summarized by volume groups.

In the model development and calibration process, a number of assignments were performed and analyzed. The early assignment results indicated a significant tendency toward over assignments. As should be recalled, the over-assignment problems led to two major revisions in the model chain:

1. The development of revised trip rates based on county level comparisons of actual versus assigned VMT and
2. The change in the gravity model applications to estimate only the intrastate short trips and to rely on expanded survey data for the estimation of interstate short trips.

In short, there were considerable model refinements necessary before the assignment results were felt to be adequate to declare the model chain calibrated.

Table B-5 summarizes the assigned versus counted volumes for nine screenlines and the external cordon from the final base year assignment. Again, it must be carefully noted

that these are the assignment results after considerable model refinement. In contrast, the Michigan assignment results presented in Appendix A are the initial assignment results without zonal, district, or county level refinements.

**TABLE B-5
SUMMARY OF FINAL BASE YEAR ASSIGNMENT RESULTS
KENTUCKY STATEWIDE TRAFFIC MODEL**

Screenlines	Links	Count	Assigned	Percent Difference	RMS	Percent RMS
Tennessee River	3	14,992	15,795	5.36	863.87	18
Kentucky Dam - Nortonville	6	15,800	25,301	60.13	2504.77	96
Henderson - Hopkinsville	9	15,500	23,711	52.97	2254.19	135
Green River E-W	17	55,598	51,525	-7.33	1337.00	34
Brandenburg - Scottsville	11	30,872	34,791	12.69	1521.00	55
Kentucky River - Rocastle River	14	69,044	64,703	-6.29	2624.00	56
Berea - Frenchburg	5	20,367	22,316	9.57	1228.32	30
Licking River - Jenkins	16	23,484	29,345	24.96	1009.01	64
No. Morgan - Johnson - Martin	5	4,200	4,317	2.79	191.06	20
All Screenlines	86	249,857	271,804	8.78	1745.00	60
All Internal O-D Links	15	78,310	91,298	17	2263.50	45
<u>External Cordon Lines by State</u>						
Tennessee - Kentucky Line	33	69,926	78,267	11	926.57	44
West Virginia - Kentucky Line	13	62,474	61,236	-1	922.77	19
Ohio - Indiana - Kentucky Line	16	198,242	221,898	11	2292.10	19
Illinois - Missouri - Kentucky Line	4	14,286	15,125	5	378.87	8
All External Cordon Links	66	344,928	376,526	9	??	??
<u>External Cordon Links by Volume Group</u>						
0 - 999 vpd	21	10,456	14,302	37	473.39	95
1,000 - 2,999 vpd	19	34,164	36,327	6	988.91	55
3,000 - 7,999 vpd	12	73,394	74,010	1	1315.58	21.51??
8,000 vpd and above	14	226,914	251,887	11	3054.02	14
All External Cordon Links	66	344,928	376,526	9	2263.50	45

ADDENDUM TO KENTUCKY MODEL UPDATE IN PROGRESS

In reviewing the draft of this appendix, the Kentucky Transportation Cabinet (KYTC) indicated that they have hired a consultant, Wilbur Smith Associates (WSA), to update the Kentucky statewide model. As of September 18, 1991, the KYTC reports that WSA has completed the following: the "calibration" of a 1990 base year model; the development of a methodology to update the base year trip table to a future year; and, the conduct of some origin-destination surveys on selected screenline corridors. The technical reports for this work are not available at this time. From the interim information provided by the Kentucky Transportation Cabinet, the following briefly highlights some of the model update efforts:

- The KYTC reports that the main feature of the base year model calibration was the application of a "special" computer program (owned and developed by WSA) that modified the existing trip table to match the 1990 counts.
- Another change was to limit the network extent to Kentucky with external stations at the Kentucky borders.
- A growth factor approach will be used to forecast Future Year trip tables. A computer program (developed by WSA entitled KENGRO) will be used to input county level population and employment data for both the base year (i.e., 1990) and the future year and prepare growth factor estimates for application to the zones within each county. A special feature in the program will allow urban zones and rural zones within the same county to grow at different rates. The resulting growth factors will apply the 1990 base year trip table to the future year (i.e., 2010) trip table. The KENGRO program requires manual input of growth factors for external stations.

The new Kentucky statewide modeling procedures will abandon previous trip distribution models in favor of a simpler growth factor approach. Updating an old trip table to 1990 based on 1990 counts is a particularly interesting means of developing the 1990 base year trip table. It is this new 1990 base year trip table which will be growth factored to forecast the year 2010 travel.

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