*A SYNTHESIS OF URBAN TRAVEL
PATTERNS IN METROPOLITAN
LAFAYETTE, INDIANA*

*OCTOBER 1965
NO. 28*

*Joint
Highway
Research
Project*

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

by
S.W. RICKS

**A SYNTHESIS OF URBAN TRAVEL PATTERNS
IN METROPOLITAN LAFAYETTE, INDIANA**

**To: G. A. Leonards, Director
Joint Highway Research Project**

October 29, 1965

**From: H. L. Michael, Associate Director
Joint Highway Research Project**

**File: 3-3-36
Project: C-36-54JJ**

Attached is a Final Report "A Synthesis of Urban Travel Patterns in Metropolitan Lafayette, Indiana" by Mr. Stephen W. Ricks, Graduate Assistant on our staff. The research reported was approved by the Board on October 28, 1964, and has been directed by Professor W. L. Grecco. Mr. Ricks also used the report as his thesis in his MSCE graduate program.

The research applied previously developed regression models for vehicle trip prediction to Lafayette, Indiana; and evaluated their usefulness in that small city. Techniques were also developed to provide estimates of the variables required as inputs to the models. Several recommendations are made relative to possible improvements in the models to make them more applicable to the small city.

The report is presented to the Board for the record and for acceptance as fulfillment of the research plan.

Respectfully submitted,

Harold L. Michael, Secretary

ELM:bc

Attachment

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Final Report

**A SYNTHESIS OF URBAN TRAVEL PATTERNS
IN METROPOLITAN LAFAYETTE, INDIANA**

by

**Stephen W. Ricks
Graduate Assistant**

Joint Highway Research Project

File: 3-3-36

Project: C-36-54JJ

**Purdue University
Lafayette, Indiana
October 29, 1965**

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Acknowledgments is given to the Indiana State Highway Commission and the Tippecanoe County Area Plan Commission for their cooperation in the research project.

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ABSTRACT

Ricks, Stephen Wayne. MSCE, Purdue University, January 1966. A Synthesis of Urban Travel Patterns in Metropolitan Lafayette, Indiana.

Major Professor: William L. Grecco.

This study was concerned with the application of eight previously evolved regression models for vehicle trip prediction. The models were derived from data obtained from the census and from recent transportation studies for 14 cities, each of which were part of a standard metropolitan statistical area. The application was made on the metropolitan area of Lafayette-West Lafayette, Indiana which was not a part of a standard metropolitan statistical area.

The models provided estimates of the total vehicle trips in a study area, the ratio of external vehicle trips to total vehicle trips, the ratio of local vehicle trips to internal vehicle trips, the vehicle trips to and from the central business district, intrazonal central business district vehicle trips, vehicle trips generated and attracted by a zone, vehicle trips between a zone and the central business district, and inter-zonal vehicle trips.

An important contribution from the research deals with the methodology and techniques utilized to provide estimates of the variables required as inputs to the models.

The travel patterns predicted by the models for 1964 were checked for internal consistency and against a screen line volume count.

The application of these models proved inadequate to predict travel patterns in an area where a large number of input variables are outside the range of values used in the model development.

INTRODUCTION

In 1960, approximately sixty-five percent of the 180 million persons living in the United States were residing in areas having an urban environment (1)*. Many of the 1980 projections indicate a population of 245 million persons with seventy-five percent of them living in urban areas (2).

Table 1 shows a breakdown of the 1960 population by size of urban place. From this illustration it is interesting to note that a sizable percentage of the population resides in urban places of moderate size (25,000 - 100,00 population).

Today, virtually all of our cities are facing a traffic and transportation problem. The cause of the problem is the ever-increasing population coupled with the popularity and commonplace ownership of the private automobile. Many disciplines are involved in attempting the solution to the problem and their approaches are quite varied.

Since the early 1940's transportation planning studies have been conducted in urban areas throughout the country in an increasingly comprehensive manner. The knowledge of travel patterns in urban areas is of prime importance in the planning, design and operation of transportation routes and terminals. A multi-disciplinary approach has become quite common in conduct of these studies.

Over the recent years, the comprehensive transportation planning studies have provided considerable data related to travel patterns. The

* Numbers in parentheses refer to entries in the List of References.

TABLE 1
1960 U. S. POPULATION DISTRIBUTION BY SIZE
OF URBAN PLACE REFERENCE (1)

Size of Urban Place*	Number of Places	Population (1,000's)	Percent of Population
One Million or More	5	17,484	9.8
500,000 - 1,000,000	16	11,111	6.2
250,000 - 500,000	30	10,766	6.0
100,000 - 250,000	81	11,652	6.5
50,000 - 100,000	201	13,836	7.7
25,000 - 50,000	432	14,951	8.3
10,000 - 25,000	1134	17,568	9.8
5,000 - 10,000	1394	9,780	5.5
2,500 - 5,000	2152	7,580	4.2
Under 2,500	596	690	0.4

*Urban Place - current census definition

analyses of these data are establishing interrelationships between various parameters and travel. Several theories on urban travel are emerging. The theories are mathematical formulations of economic and sociological data together with land use information, travel times and other characteristics of existing transportation facilities. Examples of such theories are: Gravity Model, Fratar Model, and Opportunity Model. Each of these models require an origin and destination (O-D) study in order to establish the factors which affect trip making. The mathematical models are developed from the existing travel patterns established by the origin and destination study and the significant factors are projected to some future year in order to estimate future travel patterns.

In general, the models have been developed and applied in large cities where the required sample percentage could be small, thus providing a lower per capita cost for data collection. With each new application of most models, the unique characteristics of the particular study city requires a modification of the model, which would be based on some data collection. The dependence of these models upon a comprehensive O-D study makes their use expensive and time-consuming.

Past studies indicate a similarity of travel patterns in cities of similar size and it is now generally acknowledged that travel of urban residents has many similar characteristics, (3, 4). Because of these facts, it seems logical to synthesize travel patterns directly from the characteristics of a given city and of its inhabitants. This concept is still in its infancy but has great potential particularly in light of the increasing availability of computers necessary to handle the large amount

of data which would be involved. To date, there has been little work on a universal model capable of application to all or a group of cities. Most models have been developed for a single city and when applied to other cities, have required considerable modification.

The need for synthetic models which will develop travel patterns without a previous base study is critical for cities of moderate size. The urgency is further emphasized by reference to Table 1, which indicates the large number of these cities. There are relatively few places of over 500,000 population (21). These are the cities in which most of the comprehensive transportation planning studies have been initiated. At the same time, there are many (714) cities from 25,000 to 250,000 population. These are the cities where a transportation planning process must be established if we are to provide for the anticipated increases in traffic movements and population. If a quick, inexpensive, reliable method of determining travel patterns for smaller cities were available it would be a valuable planning tool.

A first step toward the development of a universal model was taken by J. J. Schuster in a report entitled "Development of Travel Patterns in Major Urban Areas" (5). Schuster availed himself of data from recent O-D studies conducted in 14 cities ranging in population city size from 72,355 to 627,525. All cities were in standard metropolitan statistical areas. Utilizing data from the 1960 census of population for each of the study cities, Schuster developed eight prediction equations which were said to "permit the development of the travel patterns of urban areas." The equations or models were derived using regression techniques. The amount

of variability (R^2) explained by the models ranged from a low of seventy percent to a high of ninety-eight and one-half percent. In all, there were thirteen distinct study area characteristics used in the models. These characteristics included: population, vehicle ownership, median income, and various area measurements.

An application of the models in a city other than those used in the derivation was not undertaken by Schuster but was stated as a recommendation for further study.

The primary advantage of the wholly synthetic technique would be the economic development of urban travel patterns for cities. Indiana, in particular, currently has nine metropolitan areas which are required by the 1962 Federal Aid Highway Act to establish a continuing Transportation Planning Program. It is possible that a synthetic method could fully satisfy the requirements of such a program.

Purpose and Scope

The purpose of this research was to evaluate the results obtained from an application of Schuster's research. The actual application was in an area somewhat smaller than the range suggested by Schuster for the application of the models. The area selected was not a standard metropolitan statistical area. Therefore, an important part of this work was the evaluation of the availability of accurate data for the significant variables. An attempt was made to establish techniques for quantifying the significant variables so that the developed models could be used in cities which are not in Standard Metropolitan Statistical Areas.

The study consisted of a single application of the models in the Lafayette-West Lafayette Metropolitan Area. Current data sources were investigated and data were collected and input to the models to develop the 1964 area travel patterns. A screen-line volume check at all bridge crossings was made to provide a check on the accuracy of the resultant travel patterns.

REVIEW OF LITERATURE

The subject of trip interchange, although relatively new, has produced a substantial body of literature. There have been many different methods proposed. The underlying principle in each of the proposed formulae and methods, is that travel between any two points in space increases with the relative attraction for such travel, and decreases as the resistance to travel increases.

The methods differ in their manner of recognizing this underlying principle. The principle is either taken into account directly within some mathematical relationship or is implicit within the method of forecasting. Martin, Memmott, and Bone in their publication, Principles and Techniques of Predicting Future Demand for Urban Area Transportation, provide an excellent review of the various methods. They classify the methods into two main groups, according to the logical basis underlying each.

The first group includes the growth factor methods, namely: uniform factor, average factor, Detroit and Fratar. Each of these methods are basically the same. They hypothesize that given the present travel patterns obtained by traffic counts and O-D data, it is possible by means of multiplication by a suitable measure of growth, to calculate a future travel pattern when such growth has taken place.

For these methods, a growth factor for each zone is calculated. This is obtained from projections of land use and trip generation. This factor is the multiple of base year trip ends which provides an estimate of future trip ends. The methods differ in the way that they combine the zonal growth factors to give trip interchange expansion factors.

Martin, et al., summarize the advantages and disadvantages of the growth factor methods as follows: (6)

Advantages

1. Growth factor methods are basically simple, well tested, and require no distance parameters (travel time, distance, etc.).
2. They can be applied to directional peak hour flows as well as for average daily traffic in the urban area. They can be used for different trip purposes or for trips between specific land uses.
3. Growth factor methods are especially useful in updating recent origin and destination data.

Disadvantages

1. Growth factor methods require a comprehensive origin and destination survey to provide the necessary input data.
2. Possible major changes in the urban area are not recognized, in that growth factor methods
 - a. require rigid zonal and regional boundaries
 - b. assume that travel resistance will remain constant with time or that the urban transportation facilities will be improved sufficiently (quantitatively and distributionally) to maintain present travel resistance factors.
 - c. cannot be used effectively if there are substantial changes anticipated in land use patterns.
3. Weakness in handling small interchange volumes.
 - a. If the present zonal interchange volume is zero, the predicted future interchange volume must necessarily remain zero.
 - b. Instability of small number events is preserved in future interzonal estimates.

4. The results are not independent of arbitrary distribution procedures, and are subject to iteration inaccuracies.
5. Growth factor methods depend upon the accurate determination of zonal growth factors, which cannot usually be done in terms of a single numerical value.

The second group of trip distribution methods includes the inter-area travel formulas. Included in this group are the gravity model, interactance model, and opportunity model. With these methods, it is necessary to analyze existing travel data in order to establish the relationships between trips and the variables which are a measure of attraction and resistance.

The gravity model was the first attempt to forecast trips in terms of the complex underlying causes of such trips. The hypothesis of this model states that all trips emanating from a given zone will distribute themselves according to the number of effective trip terminal opportunities offered to the trip makers by each destination zone. Trips are attracted or pulled, to various land uses. The strength of this pull is related directly to the size of land use development (attractor) and indirectly related to distance or travel time between the origin and attracting land use (7). A small sample home interview, as part of an O-D survey, is often conducted to provide the necessary correlation data.

The primary advantage of the gravity model is that it accounts for the competition for trips between different land uses. The gravity model, as used today, recognizes the effect of trip purpose on travel resistances. The main weakness of the gravity model is that it attempts to apply a simple physical law (i.e., Newton's Law of Gravitation) to social behavior. While apparent similarities do exist, a more fundamental procedure related to human behavior is needed.

The interactance model is a variation of the gravity model method. The basis of the method is a complete O-D survey. Curves representing the interactance formulae are drawn for trips vs. driving time between zones. The trips are a measure of the attractive force of or the trip opportunities in each zone and the time distance is a measure of the resistance to travel. Different sets of graphs are drawn for each different trip purpose (work, commercial, social or miscellaneous) and for two modes of travel (auto and transit). For each separate purpose, there is a set of curves, each referring to zones with varying proportions of the total area employment within different time radii. In this way, account is taken of variation in attraction rates caused by locational factors. The method represents a marked advance over the early gravity model method which assumes that an average travel pattern can be applied to all zones (8).

The opportunity model is a probability function based on the premise that in urban area travel, total travel time from a point is minimized, subject to the condition that every destination point considered has a stated probability of being acceptable. More precisely, the opportunity model states that the probability that a trip will terminate within some volume of destination points is equal to the probability that this volume contains an acceptable destination, times the probability that an acceptable destination closer to the origin of the trip has not been found.

Proponents of this method claim accuracy and reliability of predicted trip values as high as or higher than the gravity model methods. Disadvantages of the model include a loss of simplicity and cost inherent with obtaining necessary input data.

There has been some development of regression models for prediction of trip generation and distribution. With this procedure, techniques can be "designed" to evaluate the impact that changes in land-use would have on traffic patterns. The models do not have to be dependent on a base study for the area.

Regression equations are not uncommon in the literature of traffic estimation. They are being used to provide an estimate of the expected growth of traffic in an area. Also, they have been used to estimate trips of a specific nature or purpose or to a specified area.

R. G. Spiegelman and K. E. Duke developed regression models for San Mateo County based on a 1960 study (9). Regression models were developed for the 1990 prediction of work trips, employment and population per household. These were inputs into a gravity model for determining work trip interchanges.

Trips on residential land was the subject of a study by Sharpe, Hansen and Hamner (10). Regression equations were developed from the 1948 study and these were tested against a study performed in 1955. The variables tested for their effect on residential trip production were population, car ownership, income, distance to CBD and population density. Car ownership proved to be the best predictor of trips on residential land.

Shuldiner also developed prediction equations for trip generation from the home (11). Significant variables used in his equations were vehicles per dwelling unit and persons per dwelling unit.

Through the years, the Central Business District (CBD) of a study area has received a considerable amount of study reflecting its importance in the determination of travel patterns. B. C. S. Harper and H. M. Edwards investigated the prediction of person trips in areas within the CBD (12). They related trips to such variables as: retail floor space, service-office floor space, and manufacturing warehouse floor space.

All of these equations were developed for the express purpose of estimating growth for use in distributing trips, usually by a gravity model or similar procedure. Further, they generally were developed for use in only one city and even if the general equation form were to be successful when applied to other cities, it was necessary to evaluate new constants to reflect the unique characteristics of the new area.

A step, toward the development of the regression equation for the purpose of distributing trips between zones, was taken in California where the same general form of multiple regression equation was used to predict interzonal trips for each of the cities of Modesto, San Diego and Vallejo (13). The models as used are reproduced below:

$$\text{Modesto: } Y = B_0 + B_1 \frac{P}{(1 + D)^2} + B_2 \frac{E^2}{(1 + D)^2} + B_3 \frac{V}{(1 + D)^2} + B_4 \frac{L}{(1 + D)^2}$$

$$\text{San Diego: } Y = B_0 + B_1 \frac{P^2}{D^{1.5}} + B_2 \frac{E^2}{D^{1.5}} + B_3 \frac{V}{D^{1.5}} + B_4 \frac{L}{D^{1.5}}$$

$$\text{Vallejo: } Y = B_0 + B_1 \frac{(PV)^{1/2}}{(1 + D)^2} + B_2 \frac{E^2}{(1 + D)^2} + B_3 \frac{C}{(1 + D)^2} + B_4 \frac{I}{(1 + D)^2}$$

where: B_i = constant; $i = 0, 1, 2, 3, 4$

Y = trips between zones

D = straight line distance between zones

P = population in each zone

E = employed persons in each zone

V = vehicles owned in each zone

I = industrial acreage in each zone

L = land use index of each zone

C = commercial acreage in each zone

To use the above models, it was necessary to evaluate a set of coefficients for each city based on a sample O-D survey. The predicted trips were then compared to actual survey trips and adjustments were made in the equation form and coefficients as required. After the coefficients were evaluated and adjustments made, it was possible to substitute the estimated value of the independent variables for the design year into the equation and to calculate the theoretical trips between zones for the design year.

The work of Schuster went one step further and proposed eight models that were to completely describe the travel pattern for an urban area of the size range for which the models were developed. These are the models that were studied in this report. The models were to predict trip movements as listed below:

1. Total number of vehicle trips per day in a study area.
2. Ratio of external trips per day to total vehicle trips per day.
3. Ratio of local vehicle trips per day to internal vehicle trips per day.
4. Vehicle trips to and from the CBD per day.
5. Intrazonal CBD trips per day.

6. Total number of vehicle trips per day attracted and generated by a zone.
7. Number of vehicle trips per day in both directions between a zone and the CBD.
8. Number of vehicle trips per day in both directions for zonal interchanges between Non-CBD zones.

Tables 2 and 3 were taken from Schuster's report and show ranges for basic areas and ranges of data for trip prediction respectively. To utilize the models developed by Schuster, the actual areas and data should be within the ranges shown. Also shown in the tables are the actual areas and ranges of data as used in this application of the models.

TABLE 2

RANGES FOR BASIC AREAS (SCHUSTER'S MODEL VS. LAFAYETTE)

Area	Range (mi ²)	Lafayette
Transportation Study Area	58.5 - 610.3	48.6
Central Business District	0.120 - 0.725	.098
Internal Zones	0.19 - 8.22	0.12 - 6.78

TABLE 3

RANGES OF DATA FOR TRIP PREDICTION (SCHUSTER'S MODEL VS. LAFAYETTE)

Data	Range (mi ²)	Lafayette
Transportation Study Population	73,260 - 855,551	78,000
Transportation Study Population Density (Persons per square mile)	397 - 3,442	1,605
Percent of Employed Persons Using Public Transportation to Work	2.6 - 30.1	5.3
Percent of Employed White Collar Workers	38.3 - 52.5	52.6
Median Income of Families	4,766 - 6,687	6,540
Number of Cars Owned in Each Internal Zone	0 - 11,678	3 - 2,829
Straight Line Distance in Miles from the Centroid of Each Internal Zone to the CBD	0.57 - 9.27	0.29 - 4.27
Population of Each Internal Zone	0 - 69,666	0 - 7,842
Percent of Population in Each Internal Zone that are Workers	0 - 55.19	0 - 54.62
Angle in Degrees Between the Centroids of Zone i and Zone j with the Vertex at the CBD Centroid	5 - 180	0 - 180
Straight Line Distance in Miles Between Centroid of Zone i to Centroid of Zone j	0.78 - 12.75	0.38 - 7.38
Median Income of Families for Each Zone	0 - 19,615	0 - 9,310
Percent of Population Under 34 Years Old that are Enrolled in School for Each Zone	0 - 54.17	0 - 75.30

PROCEDURE

Statement of the Models and Data Required

The actual models as postulated by Schuster are shown below in mathematical notation utilizing the list of independent variables shown in Table 4.

Model #1

Y = Total number of vehicle trips per day in the study area

$$Y = + 142,010 + 1.53441 X_1 - 8731.8 X_3$$

Model #2

Y = Ratio of external vehicle trips per day to total vehicle trips per day

$$Y = + 0.4126 + 10^{-10} \left[0.0242 X_1 X_2^2 - 4644.2 X_1 - 11,351 X_2^2 + 452.1 \frac{X_1^2}{X_2} - 1,576,380 \frac{X_1}{X_2} \right]$$

Model #3

Y = Ratio of local vehicle trips per day to internal vehicle trips per day

$$Y = 0.545 + 10^{-7} \left[- 0.0267 X_1 X_2 - 17.4 X_2^2 + 7.00 (10^{-5}) X_1 X_2^2 + 0.656 \frac{X_1^2}{X_2} - 2774 \frac{X_1}{X_2} \right]$$

Model #4

Y = Vehicle trips to and from the central business district per day

$$Y = 39,570 + 0.04948 X_1 + 41,335 X_6 - 1443.9 X_3 + 1492.0 X_4 + 28.755 X_6 \frac{X_1}{X_2}$$

Model #5

Y = Intrazonal central business district trips per day

$$Y = 5,790 + 6406.7 X_6 + 0.8432 \frac{X_1}{X_2} - 1.18459 X_5 - 0.00017 X_1 X_3 \\ + 0.01909 X_1 X_6$$

Model #6

$Y_{(i)}$ = Total number of vehicle trips per day attracted and generated by a zone i

$$Y_{(i)} = -7655 - 1326.4 X_{12(CBD-i)} + 5.0602 X_{7(i)} - 0.01714 X_1 \\ + 43.416 X_2 + 7.2513 \frac{X_1}{X_2} + 2.07 (10^{-6}) X_{9(i)} X_{8(i)} X_{7(i)}$$

Model #7

$Y_{(i-CBD)}$ = Number of vehicle trips per day in both directions between a zone i and the central business district

$$Y_{(i-CBD)} = +498 + 0.46257 X_{8(i)} - 96.700 X_{12(CBD-i)} + 0.68270 X_{7(i)} \\ + 0.01331 X_{9(i)} X_{8(i)} - 0.01967 X_4 X_{8(i)} - 0.00300 X_{12(CBD-i)} \\ X_{9(i)} X_{8(i)} + 0.001767 X_{12(CBD-i)} X_4 X_{8(i)}$$

Model #8

$Y_{(i-j)}$ = Number of vehicle trips per day in both directions for zonal interchanges between non-CBD zones

$$Y_{(i-j)} = +796.2 - 0.1084 X_{7(i)} - 0.04275 X_{7(j)} - 133.7 X_{12(i-j)} \\ - 6.223 X_{13(i-j)} + 15.29 (10^{-4}) X_{8(i)} X_{11(i)} \\ + 20.84 (10^{-4}) X_{8(i)} X_{9(i)} - 0.7401 (10^{-2}) X_{8(i)} X_{12(i-j)} \\ + 0.1018 (10^{-4}) X_{8(j)} X_{11(j)} - 0.5256 (10^{-5}) X_{8(j)} X_{9(j)} \\ + 0.7234 (10^{-3}) X_{8(j)} X_{12(i-j)} + 52.37 (10^{-6}) X_{7(i)} X_{7(j)}$$

$$\begin{aligned}
& + 1.262 X_{12(i-j)} X_{13(i-j)} \\
& - 11.10 (10^{-10}) X_{8(i)} X_{11(i)} X_{8(j)} X_{11(j)} \\
& - 3.564 (10^{-14}) X_{8(i)} X_{10(i)} X_{8(j)} X_{10(j)} \\
& - 8.876 (10^{-10}) X_{8(i)} X_{9(i)} X_{8(j)} X_{9(j)} \\
& - 0.3867 (10^{-11}) X_{8(i)} X_{8(j)} X_1 \\
& + 0.1507 (10^{-6}) X_{8(i)} X_{8(j)} X_3 \\
& - 0.1886 (10^{-6}) X_{8(i)} X_{8(j)} X_{12(i-j)} \\
& + 1.443 X_{12(i-CBD)} X_{12(j-CBD)} X_{12(i-j)} \\
& - 0.1514 X_{12(i-CBD)} X_{12(j-CBD)} X_{13(i-j)} \\
& - 232.1 \frac{X_{8(i)} X_{9(i)}}{X_{8(j)} X_{9(j)}}
\end{aligned}$$

Note: When using this model to determine intrazonal trips between zone i and zone j, zone i is taken as being the smaller populated zone.

Description of the Study Area

The metropolitan Lafayette, Indiana area was chosen for this study because it was close to the researcher and it is of a size that could be conveniently handled by available personnel. It also is an area that is in need of a comprehensive travel pattern study and the cooperation of the Division of Planning of the State Highway Commission and the local Area Planning Office was assured should such a study be initiated.

Figure 1 shows the geographic location of the study area in Indiana. The figure also shows the primary highway and railway connections with other cities in the midwest.

TABLE 4

INDEPENDENT VARIABLES REQUIRED FOR SCHUSTER'S MODEL

X_1	= transportation study area population
X_2	= size of transportation study area in square miles
X_3	= percent of employed persons using public transportation to work
X_4	= percent of employed persons who had white collar occupations for the standard metropolitan statistical area
X_5	= median family income for the standard metropolitan statistical area (dollars)
X_6	= area of the CBD in square miles
$X_{7(i)}$	= number of passenger cars owned in zone i
$X_{8(i)}$	= population of zone i
$X_{9(i)}$	= percent of population in zone i that are workers
$X_{10(i)}$	= median income of families in zone i
$X_{11(i)}$	= percent of population of zone i under 34 years old enrolled in school
$X_{12(i-j)}$	= straight line distance in miles between the centroids of zones i and j
$X_{12(i-CBD)}$	= straight line distance in miles between the centroid of zone i and the centroid of the CBD
$X_{13(i-j)}$	= angle in degrees between the centroid of zone i and the centroid of zone j with the vertex at the centroid of the CBD (Angle $\leq 180^\circ$).

Note: i = numbers designating a traffic zone; i = 1,2,3,4.....N
 j = numbers designating a traffic zone; j = 1,2,3,4.....N
 N = total number of traffic study zones

FIG. 1. LAFAYETTE-WEST LAFAYETTE INDIANA
LOCATION AND TRANSPORTATION CONNECTIONS

The metropolitan area includes the two incorporated places of Lafayette and West Lafayette which are separated by the Wabash River.

Lafayette is an industrial and commercial center for a large portion of northwestern Indiana. It provides the main business district for all of Tippecanoe County and portions of surrounding counties.

West Lafayette is the home of Purdue University with over 18,000 students in 1964. The population of the metropolitan area increased from 58,117 to approximately 78,000 from 1950 to 1964.

Previous Traffic Survey

An O-D traffic survey of the metropolitan area of Lafayette, West Lafayette, Indiana was authorized by the State Highway Commission of Indiana in 1950. Actual collection of the data was begun in September 1952. The Metropolitan Area Traffic Survey Unit had the responsibility for the collecting, processing, and analyzing of survey data and the preparation of the charts and graphs included in the final report. State highway personnel received assistance from the Bureau of Public Roads, the Joint Highway Research Project and civic and governmental leaders of Lafayette and West Lafayette.

Figure 2 shows the 1952 traffic study zones as they were delimited by the study group.

Delimiting the Study Area

The Lafayette-West Lafayette metropolitan area has experienced a growth of some 20,000 persons during the period from 1950 to 1964. The

FIG. 2. LAFAYETTE, INDIANA 1952
TRAFFIC STUDY ZONES

growth was primarily to the south in Lafayette and to the north and west in West Lafayette. During this period six new shopping centers were built in the area. These ranged in size from neighborhood centers to a large community center. Two of the six were in West Lafayette with the remaining four in Lafayette.

Because of this growth, it was necessary to expand the original study area and to include several new zones in order to obtain complete travel patterns.

New zones were formed by dividing existing zones and by incorporating new development into new zones. Existing zones were divided where differential land use development occurred over the years. The main criteria used for the delimitation of the new zones was uniformity of land use type. Topography and man-made features such as highways and railways were also taken into consideration. Aerial photographs and field investigations of the area were used.

There were a number of rural subdivisions surrounding the two cities. Interaction between these areas and the cities was assumed large enough to warrant the inclusion of these areas in the study area. This necessitated the forming of several large zones on the perimeter of the study area.

Originally there were 75 study zones. After new zones had been formed and old ones had been divided, there were a total of 113 zones. To provide flexibility in analysis, the 113 zones are referred to as sub-zones and are grouped as shown in Table 5 to form 51 traffic zones. Figure 3 shows the final study area and the 113 sub-zones as they were used in this study. Figure 4 shows the 51 traffic zones.

TABLE 5
SUB-ZONE GROUPING FOR 51 TRAFFIC ZONES

Traffic Zone	Sub-Zones	Traffic Zone	Sub-Zones
1	113	31	59, 60
2	112	32	63, 64
3	111, 22	33	92, 93
4	23, 24	34	56, 57, 94
5	17	35	39, 40
6	16, 18, 19	36	38, 43
7	11, 12	37	58, 96, 97
8	10, 21	38	55, 95
9	26, 9	39	44, 45
10	7, 8	40	51, 53, 54
11	6, 14, 15	41	48, 49, 50
12	1, 2, 98	42	108
13	5, 105	43	46, 47
14	27, 104	44	41, 42
15	3, 103	45	61, 62
16	99, 102	46	65, 66
17	100, 101	47	109
18	28, 29, 107	48	4, 106
19	110	49	13, 20
20	81, 82, 83, 25	50	30, 73
21	84, 85, 86, 87	51	52
22	78, 79, 80, 88, 89, 90, 91		
23	76, 77		
24	74, 75		
25	31, 32		
26	71, 72		
27	69, 70		
28	67, 68		
29	33, 34		
30	35, 36, 37

FIG. 3 LAFAYETTE, INDIANA 1964
TRAFFIC STUDY SUB-ZONES

FIG. 4 LAFAYETTE, INDIANA 1964
TRAFFIC STUDY ZONES
(51 ZONES)

Data Collection

It is important to note here that the models as derived by Schuster were intended for use in Standard Metropolitan Statistical Areas (SMSA). The required data would then be readily obtainable from published census reports. SMSA are subdivided into smaller areas known as census tracts, whereas metropolitan areas outside of SMSA are not tracted. Data from SMSA are published by tracts thereby facilitating the gathering of information for traffic zones, especially if the traffic zone coincides with the census tract boundaries. Data for smaller metropolitan areas are published only as gross figures representing the characteristics of the entire metropolitan area, thereby making the collection of zonal data for these areas more difficult.

The use of regression equations requires that the independent variables be fixed and be measured without error. An effort was made to obtain the most accuracy in the required data as was practical. Data was collected on a sub-zonal basis and aggregated to provide data for the 51 traffic zones.

Data Sources

Listed below are agencies and departments that were used for the acquisition of data for this study.

A. Federal Agencies

1. U. S. Dept. of Commerce, Bureau of the Census

B. State Agencies

1. Indiana State Highway Commission

2. Indiana Employment Security Division (Lafayette Office)

C. Local Agencies

1. Tippecanoe County Area Plan Commission
2. Credit Bureau of Lafayette, Inc.
3. Lafayette City Engineer's Office
4. Lafayette Post Office
5. Purdue University
6. Lafayette, West Lafayette City Directory

U. S. Department of Commerce, Bureau of the Census. The Indiana volume of 1960 census of population reports can provide much valuable information. Available here are data on a county and city basis. Values of median family income for the study area, percent of employed persons using public transportation to work, and percent of employed persons who had white collar occupations for the study area were obtained from this source.

In order to facilitate the interviewing of persons within smaller metropolitan areas, the census bureau subdivides these areas into enumeration districts. Data from enumeration districts can be extremely valuable when there is some correlation between the enumeration districts and the traffic zones, because this makes it possible to obtain estimates for zonal data from the enumeration district data. For this study, the PH-1 tables for Tippecanoe County on an enumeration district basis were obtained. The PH-1, Population and Housing Characteristics, tables provided a basic population count and age distribution breakdown which were of value to the study. Investigation of the possibility of obtaining

other census data by enumeration districts revealed that 1.) virtually all other data is expanded from a twenty-five percent sample and 2.) there is a considerable amount of time and money involved in obtaining this data.

Indiana State Highway Commission. The 1952 Lafayette O-D study data and charts were available from the Planning Section of the State Highway Commission. The original traffic zone map was utilized as a base for the 1964 study. The final trip tables furnished a rough check on the predicted trip movements.

As with most O-D surveys, a street code had been prepared for the 1952 study. This code was updated to 1964 and proved to be indispensable in the collection of sub-zonal data.

Indiana Employment Security Division. This agency was a source of considerable information concerning employment. Data on the number and type of jobs in the Lafayette area was available, not only for the current year but for the several years previous. Data, such as type of business, place of business, number of employees and payroll were made available. Reports of occupational wage surveys were used.

Tippecanoe County Area Plan Commission. A local planning department of this type can provide much information of value to a transportation planning study. Land use information, population forecasts, and plans for future development should be considered. A neighborhood analysis survey was found to be of use for this study. Large scale detailed maps are frequently available from the planning office.

Credit Bureau of Lafayette, Inc. A complete listing of motor vehicles registered in Tippecanoe County was found to be available from this source.

In the absence of such an agency, it may be necessary to utilize the State Motor Vehicle Bureau, Licensing Branch for this information. Vehicle registration lists for other than the current year were not available from the Credit Bureau. The State Motor Vehicle Bureau does have past records available.

Lafayette City Engineer's Office. The city engineer's office can provide much information necessary for updating or creating a street code. Plat maps were available here showing residence addresses and street names. This office is also a good source for up to data development maps.

Lafayette Post Office. While updating the street code there were a few streets that could not be located except through this office. Street name changes, new street names, and streets outside of the corporate limits posed problems for which the local post office was of considerable assistance.

Purdue University. As with any large industry, Purdue University is a large generator of traffic. The campus police department made available their vehicle registration lists. Various student housing officials supplied information on the numbers of students and student addresses.

Lafayette-West Lafayette City Directory. Published by R. L. Polk and Company, the 1964 city directory was found to be an excellent source of information. The directory provides a listing of all residents over 21 years of age together with their occupation, place of employment, address, etc. Information taken from the directory for this study included a tabulation of students, heads of household, occupation, place of work, and address. The directory would also serve as a good source for establishing the number of dwelling units.

Evaluation of Independent Variables

Transportation Study Area Population (Variable X_1). The total population was obtained from the PH-1 tables for Tippecanoe County. The transportation study area boundary was superimposed on a map showing enumeration district boundaries. From this overlay, it was possible to determine the 1960 population recorded by the census and included in the study area. When the total population was projected to 1964 and combined with an adjusted average enrollment for Purdue University, a good estimate of the transportation study area population was obtained.

Transportation Study Area (Variable X_2). The area was determined by planimetry on a large scale map showing the study boundaries.

Percent of Employed Persons Using Public Transportation to Work (Variable X_3). This percentage was taken from the Indiana volume of 1960 census of population reports. A city bus company is the only form of public transportation in the Lafayette area. Therefore, the number of persons utilizing bus transportation for work, in the two cities, divided by the total number of persons employed in the two cities, gave the desired percentage.

Percent of Employed Persons having White Collar Occupations (Variable X_4). The 1960 census reports were used to establish this percentage. In this case, the number of persons having white collar occupations for the two cities was divided by the total persons employed in the two cities to give the required percentage.

Median Family Income (Variable X_5). General figures are published in the census reports for each of the two cities and for the county as a whole. To achieve an approximation of median family income for the study

area, it was necessary to take the weighted (by number of families) average of the median family incomes for Lafayette and West Lafayette.

Central Business District Area (Variable X_6). The central business district area can be defined as being that area which is fundamentally of a commercial nature or in general, as those city blocks where parking demand exceeds the supply. Sub-zones 35, 36 and 27 were taken to be the central business district for this study. The actual area was determined from calculations using block lengths shown on plat maps.

Passenger Cars Per Zone (Variable $X_{7(i)}$). To determine the number of automobiles owned in each sub-zone, it was necessary to use the street code. This code correlates every residence address with a sub-zone number. In its final form, the code listed the segments of all streets by sub-zone in both the incorporated and unincorporated parts of the study area. A sample page taken from the street code is shown by Figure 5.

Utilizing the vehicle registration listing from the credit bureau, it was a simple although tedious matter to assign each passenger car to its sub-zone of registration. Using a similar procedure, the campus police vehicle registration list was used to account for the large numbers of out-of-county cars owned by Purdue students and faculty.

Zonal Population (Variable $X_{8(i)}$). Sub-zonal populations were determined by utilizing the PH-1 tables and enumeration district map. Enumeration districts are formed strictly for the convenience of census enumeration and consequently their boundaries do not coincide in any regular fashion to the boundaries of the study sub-zones. Figure 6 shows the 1960 enumeration district boundaries. The non-alignment of these

N 27th St	Laf	/001- <u>63</u> -99/351- <u>57</u> -650/ /1600- <u>55</u> -2099/
S 27th St	Laf	/001- <u>63</u> -310/311- <u>66</u> -705/706- <u>68</u> -899/
N 28th St	Laf	/001- <u>63</u> -99/200- <u>57</u> -699/
S 28th St	Laf	/001- <u>63</u> -310/311- <u>66</u> -709- <u>68</u> -1399/
N 29th St	Laf	/001- <u>63</u> -99/200- <u>57</u> -899/1500- <u>55</u> -1699/
S 29th St	Laf	/001- <u>63</u> -310/311- <u>66</u> -709/710- <u>68</u> -1099/
N 30th St	Laf	/001- <u>63</u> -149/150- <u>57</u> -899/
S 30th St	Laf	/001- <u>63</u> -310/311- <u>66</u> -709/710- <u>68</u> -1211/
N 31st St	Laf	/001- <u>63</u> -150/500- <u>57</u> -799/
S 31st St	Laf	/001- <u>63</u> -310/311- <u>66</u> -709/710- <u>68</u> -1099/
Adams St	Laf	/900- <u>72</u> -910/911- <u>70</u> -1616/1617- <u>69</u> -1999/
Agricultural Mall	WL	/All in <u>20</u> /
Airport Rd	WL	/0-EVEN <u>21</u> -500/
Alabama St	Laf	/001-32-199/200-EVEN-37-ODD <u>32</u> -214/ /215- <u>33</u> -410/411- <u>34</u> -699/ /1000-EVEN <u>61</u> -ODD <u>34</u> -1099/1100- <u>61</u> -1699/
Albany St	Laf	/2000-EVEN <u>51</u> -ODD <u>52</u> -2014/2015- <u>53</u> -2599/
Alder Dr	Laf	/1000- <u>84</u> -1205/
Algonquin	Laf	/2900- <u>86</u> -2950/
Allen St	WL	/600- <u>14</u> -816/816- <u>6</u> -999/
America St	Laf	/100- <u>30</u> -299/
Andrew Pl.	WL	.101- <u>18</u> -114/115- <u>16</u> -199/
Apache Dr.	Laf	/2300- <u>86</u> -2431/
Arapahoe Dr.	Laf	/2000- <u>86</u> -2217/
Archway	Laf	/1000- <u>84</u> -1240/

FIG. 5. STREET CODE ILLUSTRATION

FIG. 6 LAFAYETTE, INDIANA 1960
CENSUS OF POPULATION
ENUMERATION DISTRICTS

boundaries made the use of a proportioning technique necessary. By superimposing maps of the enumeration districts and sub-zones, it was possible to formulate a relationship between enumeration district populations and sub-zonal populations. After a population figure had been determined for every sub-zone, each sub-zonal figure was updated on the basis of the total population increase from 1960 to 1964. Population additions were made to those sub-zones containing Purdue University dormitory units.

Percentage of Workers for Each Zone (Variable $X_{9(i)}$). The city directory was used to determine the percentage of population in each sub-zone that are workers. Through the use of the directory and the street code, workers were recorded by sub-zone of residence. The total number of workers per sub-zone was divided by the sub-zonal population establishing the percent of population in each sub-zone that are workers.

Median Family Income for Each Zone (Variable $X_{10(i)}$). The determination of this variable was extremely difficult. No reliable method of estimation is generally available. The variable is used only in Model 8 and doesn't contribute significantly to the trip interchanges. For this reason it was decided to make an estimate by assigning an income to each worker from analyzing occupation and place of work data. Guidelines for basic occupation incomes were provided from three different sources.

Purdue University officials were able to supply figures representing average 1964 yearly incomes for their employees according to fairly narrow job categories.

A manufacturing wage survey report for 1964 was obtained from the Indiana Employment Security Division Office in Lafayette. This report provided information on average wages for typical jobs in manufacturing industries.

The third source of information was the Tippecanoe County Area Plan Commission. On record here were the results of a partially completed neighborhood analysis in which personal interviews had been performed and income and occupation data were gathered.

After assigning an income for each person, a total sub-zonal income figure was tallied for each sub-zone. When this gross figure was divided by the total of heads of household for each sub-zone, the resultant figure was used as representative of the median family income by sub-zones.

Percentage of Population Under 34 Years of Age Enrolled in School for Each Zone (Variable $X_{11(1)}$). The number of students in each sub-zone was recorded from the directory. This figure represented persons over 21 years of age who were students. An accurate count of students in dormitories and other housing units was available from the University. The PH-1 tables gave an age breakdown of population, from which the elementary and high school age students could be determined. These three sources of student enrollment were combined to provide a good estimate of students per sub-zone. All students were assumed to be under 34 years of age. This total of students was divided by the total sub-zonal population to give the percent of population under 34 years of age enrolled in school for each traffic study sub-zone.

Straight Line Distance in Miles Between Each Zonal Centroid Including the CBD Zones (Variable $X_{12(i-j)}$) and Angle in Degrees Between the Zonal Centroids with the Vertex at the CBD Centroid (Variable $X_{13(i-j)}$). These variables are finite physical dimensions reflecting the physical relationship of one traffic zone to another. After determining the centroid of each traffic zone, the coordinates of each centroid were determined by plotting them on a large graph with the zero-zero coordinates set at the CBD. A computer program was written which would yield the straight line distances between every pair of zonal centroids (X_{12}) and also the angle less than 180 degrees for each pair of zonal centroids using the CBD as vertex (X_{13}). These data were punched on IBM cards for use as inputs for evaluating the models. It should be observed that there are a large number of unique values for each of these variables. It is strongly recommended that a computerized solution for obtaining these data be used.

Screen-Line Counting Procedure

A direct check on the accuracy of model results was a screen-line volume check of daily traffic crossing the Wabash River.

There are four traffic bridges crossing the Wabash River in the Lafayette area. Of these, three connect the two cities near the downtown area. The fourth is part of the U. S. 52 By-Pass that lies north of the two cities. There were several studies being conducted of the 52 By-Pass which were concurrent with this study. Therefore, it was not necessary to initiate a counting program at this bridge location as the desired information was already available.

The remaining three bridges were subjected to a continuous count program begun on March 8, 1965 and ended on March 26, 1965. Actual recording of traffic was accomplished through the use of Streeter-Amet pneumatic traffic counters.

One fifteen-minute recording counter was placed on each side of the three bridges. Total volume by fifteen minute intervals were recorded of traffic crossing each bridge counted as two axle vehicles.

One-half hour classification counts were made at each bridge for each direction of traffic flow. There were three sets of these manual counts made. One count was made during a peak hour period, the second and third were made at a daylight off-peak hour and an evening off-peak hour respectively. By application of these classification factors to the counts recorded, it was possible to determine the total volume of trips made across the river per day. It was decided that an average of the total crossings for the days of Tuesday, Wednesday and Thursday would best reflect the normal condition.

An adjustment for seasonal variation was not deemed necessary after observing the plotted results of a study of Indiana permanent traffic recording stations. From these results shown in Figure 7, it can be seen that the expansion factor for the month of March is close to one.

When the final counts for each of the three bridges were added to the existing count across the bypass bridge, the total daily traffic crossing the river in both directions was established.

This volume was 54,817 vehicles and represents trips by vehicles of all types.

FIG. 7 VOLUME EXPANSION FACTORS FOR URBAN AREAS IN INDIANA

Model Computation

The first five models make use of only areawide data. Because of their simplicity, it was expedient to merely substitute in the required variables and solve the equations by hand computation, for the various dependent variables. The results are recorded later in this report.

Models 6 and 7 were considered to be of sufficient complexity to justify a computerized solution. Both models make use of essentially the same data so that it was possible to solve both models with only one program and one set of data cards. The work was performed on an IBM 7094 computer, but the storage requirements were such that computers of smaller size could have been used. The results, as provided by the computer, are shown later in this report.

There are 1,224 unique solutions to Model 8 for the Lafayette study area, and this ruled out the feasibility of a hand-calculated solution. Therefore, Model 8 required the writing of a separate computer program. A large amount of data was contributed by the Variable X_{12} (straight line distance between zonal centroids) and X_{13} (angle between zone centroids, vertexed at the CBD). These data had been punched on IBM cards at the time of their evaluation. The results as provided by the computer are shown later in this report.

RESULTS

The model titles together with their final calculated solutions are shown below:

Model 1 predicts the total number of vehicle trips per day in the study area which includes external-external, external-internal, internal-internal, and intrazonal trips.

$$Y = 215,363 \text{ trips}$$

Model 2 predicts the ratio of external vehicle trips per day to total vehicle trips per day where external trips includes external-external, external-internal trips.

$$Y = 0.2738$$

Model 3 predicts the ratio of local vehicle trips per day to internal vehicle trips per day where the local trips are the external-internal trips and the internal trips are the internal-internal and intrazonal trips.

$$Y = 0.2560$$

Model 4 predicts vehicle trips to and from the CBD per day which includes both internal-CBD and external-CBD trips.

$$Y = 43,627 \text{ trips}$$

Model 5 predicts intrazonal CBD trips per day.

$$Y = 99 \text{ trips}$$

Model 6 predicts the total number of vehicle trips per day attracted and generated by each zone. Total trips include internal-internal,

external-internal, and intrazonal trips. This model is not valid for the CBD (Zone 30). Models 4, 5 and 7 are used for the CBD zones. The results are shown in Table 6.

Model 7 predicts the number of vehicle trips per day in both directions between a zone and the central business district. This model is not valid for predicting intrazonal CBD trips. The results are shown in Table 7.

Model 8 predicts the number of vehicle trips per day in both directions for zonal interchanges between non-CBD zones. The results of this model in combination with the results of Model 7 form a complete trip table of interzonal trips. For this study there were approximately 1,200 trip interchanges predicted by Model 8. Trip interchanges involving the CBD zone are not predicted by this model. These trip interchanges are predicted by Model 7. In order to conserve space in this report, it was felt sufficient to report only a small percentage of the trip interchanges predicted by Model 8. A random selection of fifty trip interchanges are shown in Table 8.

TABLE 6

MODEL 6 RESULTS - PREDICTED TOTAL TRIPS FOR EACH ZONE

Zone	Trips	Zone	Trips
1	1,532	28	6,402
2	149	29	8,284
3	1,839	30	-- (CBD)
4	3,264	31	8,491
5	4,918	32	5,261
6	18,689	33	1,688
7	16,417	34	5,205
8	14,157	35	8,455
9	2,756	36	4,860
10	6,451	37	5,788
11	13,303	38	7,497
12	1,809	39	6,757
13	6,307	40	7,457
14	4,462	41	2,511
15	2,457	42	852
16	1,750	43	5,195
17	922	44	8,271
18	1,172	45	7,210
19	2,567	46	5,442
20	4,290	47	1,028
21	16,686	48	3,455
22	1,879	49	3,740
23	6,754	50	5,864
24	5,704	51	5,116
25	5,021		
26	7,190	Total	286,001
27	8,745		

TABLE 7

MODEL 7 RESULTS - PREDICTED TRIPS BETWEEN EACH ZONE AND CBD

Zone	Trips	Zone	Trips
1	229	28	525
2	146	29	760
3	274	30	-- (CBD)
4	390	31	342
5	563	32	485
6	1,426	33	271
7	311	34	252
8	264	35	581
9	375	36	470
10	535	37	171
11	1,036	38	645
12	289	39	612
13	515	40	460
14	393	41	330
15	353	42	199
16	205	43	320
17	218	44	312
18	84	45	548
19	307	46	557
20	220	47	216
21	679	48	385
22	230	49	461
23	324	50	440
24	650	51	558
25	399		
26	460	Total	21,823
27	1,048		

TABLE 8

SELECTED MODEL 8 RESULTS - PREDICTED TRIPS BETWEEN ZONAL PAIRS

Zonal Pair	Trips	Zonal Pair	Trips
50 - 10	97	19 - 39	- 77
21 - 15	- 52	31 - 16	72
1 - 2	322	26 - 6	- 67
18 - 14	509	38 - 14	133
29 - 36	-219	12 - 6	398
19 - 20	341	40 - 1	29
11 - 22	- 92	27 - 6	-132
39 - 46	127	1 - 11	331
34 - 25	-101	4 - 42	49
25 - 27	157	8 - 27	-203
42 - 34	276	15 - 18	37
21 - 19	311	36 - 15	342
25 - 39	-233	37 - 21	55
11 - 24	-113	26 - 44	24
3 - 22	- 17	36 - 42	162
27 - 15	- 67	39 - 31	327
14 - 24	-234	8 - 18	42
25 - 32	- 31	15 - 44	162
12 - 19	21	37 - 48	201
8 - 42	- 40	37 - 21	55
29 - 6	- 65	34 - 10	- 12
15 - 7	244	24 - 12	7
5 - 16	170	40 - 5	91
31 - 39	327	49 - 7	628
35 - 16	221	24 - 37	- 68

ANALYSIS OF RESULTS

There are two factors which have a strong influence on model results. These are - the transportation study area size and the number of traffic zones. To illustrate the effect of transportation study area size, two study areas were considered. Area A (48.6 square miles) is comprised of the 113 sub-zones as discussed previously. Area B (20.3 square miles) includes only the first 106 sub-zones. Varying numbers of traffic zones were considered. This was possible thru the grouping of sub-zones to form traffic zones of varying size. Where applicable, the results of the models are compared also with the 1953 data.

Model 1

The predicted values of total vehicle trips per day for study areas A and B are shown below and compared to the actual number of total trips (except intrazonal) as reported by the 1953 study.

	Area A	Area B	1953 Lafayette Study
Total Trips	215,363	209,225	134,313

The compounded annual growth rate representing the difference between 1953 and 1964 Lafayette trips is 4.38 percent for area A and 4.11 percent for area B. These percentages are reasonable. The difference in trips for area A and area B is logical. The larger area A should include more trips than area B.

The number of traffic zones considered has no bearing on the value predicted by this model since the only variables in the model are transportation study area population and percent of employed persons using public transportation to work.

Model 2

Model 2 predicts the ratio of external vehicle trips per day to total vehicle trips per day. This ratio is logically influenced by the relationship of the cordon line to the developed area. If the cordon line (study limits) is placed far outside the developed area, it would be expected that the ratio be low, indicating a greater percentage of trips being made within the study area. The wide disparity between the 1964 and 1953 study areas necessitated the evaluation of the model using 1953 data in order to make a valid comparison.

The values of the required variables for 1953 were determined and are shown below.

Transportation Study Population = 60,000

Transportation Study Area = 15.17 square miles

The comparison between the ratio predicted for 1953 and the actual ratio as determined from the 1953 Lafayette O-D Study is shown below.

	1953 Predicted	1953 Actual
Ratio of External Vehicle Trips Per Day to Total Vehicle Trips Per Day	.4684	.2658

Reference to Tables 2 and 3 will show that the data for 1953 as shown above is outside the range of values from which the model had been derived.

This could be the reason for the model's failure to predict the actual 1953 ratio.

Initially the 1964 study area was selected to include only the first 106 sub-zones (Area B). The remaining area was classified as suburban or rural and was not expected to contribute greatly to the overall travel patterns. The necessary data for Area B was collected and the model was again evaluated. The predicted ratios for 1964 for study areas A and B can be compared as shown below.

	Area A	Area B
Ratio of External Vehicle Trips Per Day to Total Vehicle Trips Per Day	.2738	.4060

As the study area is decreased, it is logical for the ratio to increase. However, the amount of increase shown above from area A to area B is greater than what would be anticipated since the additional area is not densely developed. Data for area B is outside the ranges shown in Tables 2 and 3. Data for area A is closer to the lower limit of the ranges. A comparison of the 1953 actual ratio and the 1964 predicted ratio is shown below.

	1964		1953 Actual
	Area A	Area B	
Ratio of External Vehicle Trips Per Day to Total Vehicle Trips Per Day	.2738	.4060	.2998

It seems reasonable that with the proper selection of a new cordon line, the ratio will remain somewhat constant for the update year. The study area A ratio agrees favorably with the 1953 value. Therefore on the basis

of this model alone, study area A would seem to be most appropriate. The most critical variable in the evaluation of this model is the transportation study area density. The model is not affected by the number of traffic zones considered.

The study area densities of the original fourteen cities used in the model derivations by Schuster were evaluated for comparison. Results of this investigation are shown in Table 9, together with data from the various study areas selected for the Lafayette area.

When the density value used in the models is close to the median of the values used in the derivation, the results are reasonable. However, when higher values are used and these are outside the range (area B and the 1953 study area) the model yields questionable results. The density value for a given study is directly dependent on the size of study area. It is unfortunate that there is not a uniform procedure available for delimiting a study area. To illustrate the effect of area on density, we can look at area A and area B for this Lafayette study. Intuitively both study areas are large enough to adequately enclose the traffic patterns. Area A (48.6 square miles) has a population of 78,000 persons. Area B (20.3 square miles) has a population of 74,000 persons. The resultant transportation study area densities are 1,605 and 3,660 for areas A and B respectively. This variable was found also to have a pronounced effect on the results of models 3, 4, 5 and 6. Schuster models, being derived from cities having study area densities with median value 1,710, would be expected to yield more realistic results for area A than for area B. In criticism of this model and regression models in general, the variables

TABLE 9
POPULATION DENSITIES

City	Study Area Population	Study Area (Sq. Miles)	Study Area Density		
1 Charlotte	202,262	120	1,690		
2 Chattanooga	241,709	205	1,180		
3 Dayton	425,000	129	3,290		
4 Denver	816,700	420	1,950		
5 El Paso	268,968	102	1,660		
6 Huntsville	73,260	65	1,130	Mean	1,925
7 Nashville	357,585	235	1,520	Median	1,710
8 New Orleans	855,551	250	3,420	Standard Deviation	1,311
9 Omaha	296,449	116	2,560		
10 San Antonio	586,586	192	3,010		
11 Springfield	99,020	58	1,710		
12 Toledo	405,000	120	3,380		
13 Tucson	242,550	610	398		
14 Tulsa	240,419	92	2,620		
Lafayette, Area A	78,000	48.6	1,605		
Lafayette, Area B	74,000	20.2	3,660		
Lafayette, 1953	60,000	15.2	3,956		

selected should be only those capable of explicit definition and unfortunately study area is not.

Model 3

This model predicts the ratio of local (external-internal) vehicle trips per day to internal (internal-internal and intrazonal) vehicle trips per day. The various predicted and actual ratios are shown below.

Ratio of Local Vehicle Trips Per Day to Internal Vehicle Trips Per day	1964		1953	
	Area A	Area B	Predicted	Actual
	.2559	.4034	.4715	.2998

In all cases, the data used in this model is the same as that for Model 2. As noted above, the model is unable to accurately predict the 1953 study ratio. Similarly to Model 2, the ratio will logically increase with a decrease in the size of the study area. However, the difference between 1964 predicted ratios from study areas A and B again appears to be excessive. There is a close agreement between the 1964 area A predicted ratio and the 1953 actual ratio. The ratio would not logically be expected to change over a period of years. These facts suggest that the 1964 area A predicted ratio is closer to the correct ratio for these trips. Higher transportation study area densities have the effect of increasing predicted values greatly. The size and number of traffic zones considered has no bearing on the model results.

Model 4

This model predicts total vehicle trips to and from the CBD per day.

Comparison of the results are shown below.

	1964		1953
	Area A	Area B	Actual
CBD Trips	43,627	49,228	31,537

The compounded annual growth rates representing the difference between 1953 actual trips and 1964 predicted trips are approximately 2.75 percent and 3.75 percent for areas A and B respectively. For a given urbanized area a shift in the cordon line should not cause any increase or decrease in the number of trips to and from the CBD. In Model 4 a decrease in study area from A to B shows an increase in trips to and from the CBD. As noted previously, this model also is sensitive to the proper selection of the study area. The 2.75 percent annual increase in trips to the CBD seems reasonable since Model 1 showed a general annual increase in trip making of 4.38 percent. The smaller annual increase in trips to and from the CBD can be explained in part due to the development of new suburban shopping centers in the area during this time period. The density for study area A, which approximates the median density of the model development, provides the most reasonable estimate of trips to the CBD. The grouping of sub-zones into traffic zones has no effect on the results of this model.

Model 5

Intrazonal CBD trips per day are predicted by Model 5. The CBD is considered to be the area encompassed by the previously existing sub-zones

35, 36 and 37. Considering intra-CBD trips to be interzonal trips between these three sub-zones enables a comparison to be made between the predicted trips and the actual 1953 trips. The comparison is shown below.

	1964		1953
	Area A	Area B	Actual
Intrazonal CBD Trips	99	2456	1103

The wide disparity in predicted trips is the result of the transportation study area density variable. Although the density variable for Area B is beyond the suggested range, it is seen that the predicted value of intra-CBD trips is more reasonable than that predicted for Area A. Similar to Model 4, the position of the cordon line should not affect intrazonal-CBD trips. Further, it is highly improbable that actual CBD trips have decreased since 1953. The model is also sensitive to changes in the area of the CBD. The predicted value is dependent on the size of the CBD. The CBD area for 1964 is identical to the CBD area for 1953. Further, this CBD area is smaller than any and considerably smaller than most of the CBD areas considered by Schuster in the derivation of the model. These facts may explain the model's failure to accurately predict 1964 intrazonal CBD trips. The number and size of traffic zones considered has no effect on the model's results.

Model 6

The total number of vehicle trips per day attracted and generated by a traffic zone as predicted by this model, varies greatly with the size of transportation study area and the number of traffic zones considered. The

model is not to be used for CBD zones. To illustrate the effect of transportation study area, the model was evaluated for Area A and Area B. To allow for comparison with 1953 values, each of the sub-zones were treated as traffic zones. The predicted values for a given zone should be identical. Comparisons of model results for eight of the traffic zones (sub-zones) with the actual number of trips attracted and generated by each unchanged zone for 1953 are shown below.

Sub-Zone	1964 Trips		1953 Trips
	Area A	Area B	
1	1418	15,138	286
2	1880	15,600	97
3	1348	15,068	744
5	6063	19,783	4009
6	5279	18,999	3574
7	2577	16,297	848
8	6299	20,020	1850
9	2172	15,892	74

The results for Area A are of a magnitude which may reflect the increased volumes for the eleven year span. The results for Area B are grossly in error. The transportation study area density variable is responsible for the variance between the two estimates. In light of the above, further analyses were made considering only Area A.

The number of traffic zones considered was not a factor influencing the results of Models 1, 2, 3, 4 or 5, but it does have an effect on Model

6. The model was therefore evaluated for Area A divided into 113, 52, 51, 49, 42 and 19 traffic zones. Figures 8 through 11 show the study area with traffic zone boundaries for 52, 49, 42 and 19 traffic zones respectively. Model 6 predicts internal-internal, external-internal, and intrazonal trips for each traffic zone. Therefore, the summation of zonal trips for Model 6 represents; twice the study area total of internal-internal trips, the total of external-internal trips and the total of intrazonal trips. The number of external-internal trips for a given study area remains constant regardless of the number of traffic zones considered. As the number of traffic zones decreases, a number of the internal-internal trips will become intrazonal, because of the increasing size of zones, and because intrazonal trips are counted only once, the summation of Model 6 will decrease. This fact is reflected by a comparison of the area totals shown below.

Number of Zones	113	52	51	49	42	19
Model 6 Total	428,855	287,778	286,001	279,123	260,333	209,676

A comparable total for the 1953 O-D study area is 201,131. This adjusted total represents twice the total of internal-internal trips and the sum of all external-internal trips. It does not include intrazonal trips. The totals for the six evaluations of Model 6 are shown in graphical form in Figure 12. From this graph using a midpoint value of 51 zones, the predicted total is 286,001. This figure includes intrazonal trips. Estimating 3 percent of the total 1953 study area trips to be intrazonal trips, a total which is comparable to Model 6 results in a value of 205,160. The compounded annual growth rate representing the difference in 1953 actual and 1964 predicted totals is about 3 percent which is a reasonable value to represent the increase in vehicle trips for the time span.

FIG. 8 LAFAYETTE, INDIANA 1964
TRAFFIC STUDY ZONES
(52 ZONES)

FIG. 9 LAFAYETTE, INDIANA 1964
TRAFFIC STUDY ZONES
(49 ZONES)

FIG. 10 LAFAYETTE, INDIANA 1964
TRAFFIC STUDY ZONES
(42 ZONES)

FIG. II LAFAYETTE, INDIANA 1964
TRAFFIC STUDY ZONES
(19 ZONES)

FIG. 12 MODEL 6 TOTALS VERSUS TRAFFIC ZONES

Model 7

Model 7 predicts the number of daily vehicle trips between each zone and the CBD. The transportation study area density is not included in the variables used in this model. The number of traffic zones selected influences the distribution of CBD trips, but for a given study area, the summation of these values for all zones in a study area should be constant regardless of the number of traffic zones considered.

The model was evaluated for Area A considering the same numbers of traffic zones as presented with Model 6. The summations of trips to the CBD for each of these evaluations are shown below.

Number of Zones	113	52	51	49	42	19
Trips to and from the CBD	41,088	22,103	21,823	21,019	18,426	11,049

The total from the 1953 study comparable to Model 7 totals is 24,565 trips. The 21,823 internal-CBD trips predicted for the 51 zone analysis is less than the 24,565 internal-CBD trips recorded in 1953. Model 4 predicts an increase in total CBD trips. This situation can be explained in part by the large development of shopping centers in the area from 1953 to 1964. The shopping centers may be attracting a larger percentage of internal-internal shopping trips, resulting in a larger percentage of total CBD trips being external-internal trips. This would seem logical, realizing that shopping trips coming from outside the study area are likely to be for comparison shopping purposes which are best served by the CBD.

Model 8

Model 8 distributes trips between non-CBD zones. The number of these interchanges is quite large. The usual method for evaluating such a trip distribution is by a screen line count. The model distributes only internal-internal trips. Therefore, the screen-line volume count as presented previously had to be reduced to represent such trips. This was done by estimating the number of thru-trips across each of the four bridges. The U. S. 52 By-Pass study indicated that only 36 percent of the crossings here were due to local traffic. An allowance of 5 percent for thru-traffic on each of the other bridges was applied. The resultant volume, representing only internal-internal trips was 43,428 vehicles per day.

Trip distribution tables were computed using Model 8 for Area A only and considering 113, 52, 51, 49, 42, 19 and 3 traffic zones. The screen-line crossings represented by each of these distributions were computed by totaling trip interchanges between zones on opposite sides of the river. Since this model does not predict trips to and from the CBD, it was necessary to add the number of CBD trips crossing the screen-line from Model 7 to the screen-line crossing figure. The total screen-line crossings are shown in the comparison below.

Number of Traffic Zones	113	52	51	49	42	19	3
Screen-Line Crossings	210,592	48,570	44,093	39,369	30,336	10,981	10,771

This information is shown in graphical form in Figure 13. By this method it was possible to predict the screen-line crossings resulting from a given number of traffic zones. Or, conversely, it was possible to select the

FIG. 13 SCREEN LINE CROSSINGS VERSUS TRAFFIC ZONES

optimum number of traffic zones given the actual screen-line count. It is seen that the 51 zone study area most nearly predicts the actual screen-line crossings. It seems illogical that the volume of screen-line crossings would vary according to the grouping of subzones in different numbers of traffic zones. This deficiency in the model is due to variable X_{13} , the angle between two zonal centroids with the vertex at the CBD, and not to the specific numbers of traffic zones selected. A further analysis of this variable is shown below.

In the evaluation of Model 8, it was observed that the angle between two zonal centroids with vertex at the CBD (Variable X_{13}) has an unexpectedly large effect on the predicted trip interchanges. An example is shown to illustrate this effect. Traffic zones 12 and 27 are used in the example because the initial angle between their centroids with the CBD as vertex is nearly 180 degrees.

The model was checked for the change in predicted interchanges for each thirty degree change in the CBD angle, while holding all other zonal data constant. Zone 27 was arbitrarily rotated about the zone 12 centroid, holding the distance between centroids of zones 12 and 27 constant as shown in Figure 14. The distance between zone 12 and the CBD will remain the same. The distance between zone 27 and the CBD became greater as the central angle decreased from 180° to 0° . The resultant predicted interzonal trips for each new position of zone 27 are indicated below.

Angle	180°	150°	120°	90°	60°	30°	0°
Trips	-102	- 39	+ 17	+ 72	+141	+241	+360

FIG. 14 CENTRAL ANGLE EFFECT
DIAGRAM

There seems to be no logic for the change in predicted trip movements as reflected by the angular change. The centroidal angle (variable χ_{13}) was felt to contribute heavily to the prediction of trip interchanges. The prediction of negative trips has no real meaning and for all purposes these are considered to be zero.

Model Consistency Test

The following evaluation was made to check the internal consistency of model results. Results considered are those from the 51 zone analysis. A check will be made for internal-internal trips as computed from the results of the first six models compared to the same type trips established from Models 7 and 8.

The first step in the evaluation was the breakdown of total trips for the study area into the various types of trips. Model 1 predicts 215,363 total vehicle trips per day. Included in this total are external-external, external-internal, internal-internal and intrazonal trips. Utilizing the Model 2 ratio of external vehicle trips per day to total vehicle trips per day, 58,966 external vehicle trips are predicted. These include external-external and external-internal trips. The total trips minus external trips results in the value of 156,397 internal trips. The Model 3 ratio applied to internal trips yields a predicted value of 40,022 local (external-internal) vehicle trips per day. Total external trips minus local trips gives the predicted number of thru trips as 18,944. These are external-external trips.

Total internal trips includes both interzonal and intrazonal. To determine the number of each type of trip, it is necessary to use results

from Models 4, 5 and 6. Model 6 predicts the total number of trips attracted and generated by each non-CBD traffic zone. When these zonal totals from Model 6 are combined with the comparable total for the CBD zone from Models 4 and 5, the summation represents twice the total of internal-internal trips, the total of external-internal trips and the total of intrazonal trips. Subtracting from this summation the total local trips (external-internal) and the total internal trips (internal-internal trips plus intrazonal trips), the remainder represents the interzonal trips (internal-internal). Intrazonal trips are then simply the total internal trips minus the interzonal trips. When this was done, the predicted number of interzonal trips was determined to be 133,308 and intrazonal trips totaled 23,089.

A summary of these results, from Models 1 through 6, are shown below.

Thru Trips (external-external)	18,944
Local Trips (external-internal)	<u>40,022</u>
Total External Trips	58,966
Interzonal Trips (internal-internal) . . .	133,308
Intrazonal Trips	<u>23,089</u>
Total Internal Trips	<u>156,397</u>
Total Trips	215,363

Unlike other methods of trip distribution, Models 7 and 8 predict interzonal trips on the basis of zonal data alone and are not required to distribute any given total of zonal trip generations. Therefore, a comparison between the number of interzonal trips distributed by Models 7 and 8,

and the predicted total of interzonal trips from Models 1 through 6 as shown above, will indicate the degree of internal consistency for all eight models.

Model 7 distributes trips to and from the CBD. Model 8 distributes trips between every pair of non-CBD zones. A summation of the results of Models 7 and 8 provide an estimate of trip ends for all non-CBD zones. If the CBD trip ends from Model 7 are added to the above total and the final total is reduced by a factor of two, the resultant value is the total number of interzonal trips in the study area. This value was determined to be 216,145 trips. A comparable value from Models 1 through 6 was only 133,308 interzonal trips. Although the trip distribution from Models 7 and 8 gave an accurate estimate of screen-line crossings, it is seen that they apparently overestimated on the interzonal trip total.

CONCLUSIONS

This report has been concerned only with the application of Schuster's regression models, developed from an analysis of 14 urban areas, to the metropolitan area of Lafayette-West Lafayette. The following conclusions are felt to be valid for applications of the models to other communities of similar size.

1. Careful attention must be given to selection of the study area. Models 1 through 6 are particularly sensitive to the transportation study area density. This value must be within the given range of values (Table 3) and preferably near the median value, for the models to give reasonable results.
2. A screen-line count is necessary to determine the optimum number of traffic zones to give the best trip distribution result. Unfortunately, when this is done the screen-line count can no longer be utilized as a field check. Removal of Variable X_{13} from Model 8 would eliminate this problem.
3. Indeterminate area measurements are poor variables for use in regression models.
4. The model development ignored the generally accepted principle of delimiting traffic zones on the basis of homogeneous land uses. In fact, the distribution Models 7 and 8 would provide unrealistic results if traffic zones were segregated on the basis of predominant land use.

5. Available census data are limited for metropolitan areas that are not defined as SMSAs.
6. An important contribution of this work has been the methodology and techniques evolved for establishing the variables required for use in the models. These may serve as a valuable tool for communities that are not classed as SMSAs in developing data banks for future planning.

RECOMMENDATIONS

During this study, several problems were encountered which could be reconciled only by further research. The following items are recommended for continued study.

1. The redevelopment of Schuster's models, sacrificing some predictability if necessary, by eliminating variables that were either costly to measure, difficult to reproduce with any consistency or showed negative model results. These variables were the transportation study area, the CBD area and the centroidal angle vertexed at the CBD.
2. The development of similar models for cities not in standard metropolitan statistical areas.
3. The development of new models which would include terms reflecting predominate zonal land use. The inclusion of redundancy in the predicted dependent variables would provide more internal checks on model results.

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