REGIONAL TRAVEL PATTERNS OF A SMALL METROPOLITAN AREA

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by

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AND
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Joint Highway Research Project

PURDUE UNIVERSITY
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Technical Paper

REGIONAL TRAVEL PATTERNS OF A SMALL METROPOLITAN AREA

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

December 30, 1966

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

Project: C-36-54EE

The attached technical paper entitled "Regional Travel Patterns of a Small Metropolitan Area" has been prepared by Mr. L. H. Tittemore and Prof. J. C. Oppenlander of our staff. The paper has been prepared from material previously reported to the Board by Mr. Tittemore in a Final Report entitled "Analysis of Regional Travel Patterns for a Medium-Sized Community."

The technical paper includes the development of 24 statistical models which describe the various arrangements of trip purpose, travel types, and area designation for traffic interchange between the central city of Fort Wayne, Indiana, and those communities within its surrounding zone of influence. This information provides basic data for the planning of transportation routes between communities.

The paper is presented for approval of publication in the <u>Journal of the Urban Planning and Development Division</u> of the American Society of Civil Engineers.

Respectfully submitted,

Harold L. Michael/jcd

Harold L. Michael, Secretary

HLM:jgs

Attachment

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Technical Paper

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by

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Lafayette,   Indiana

December 1966
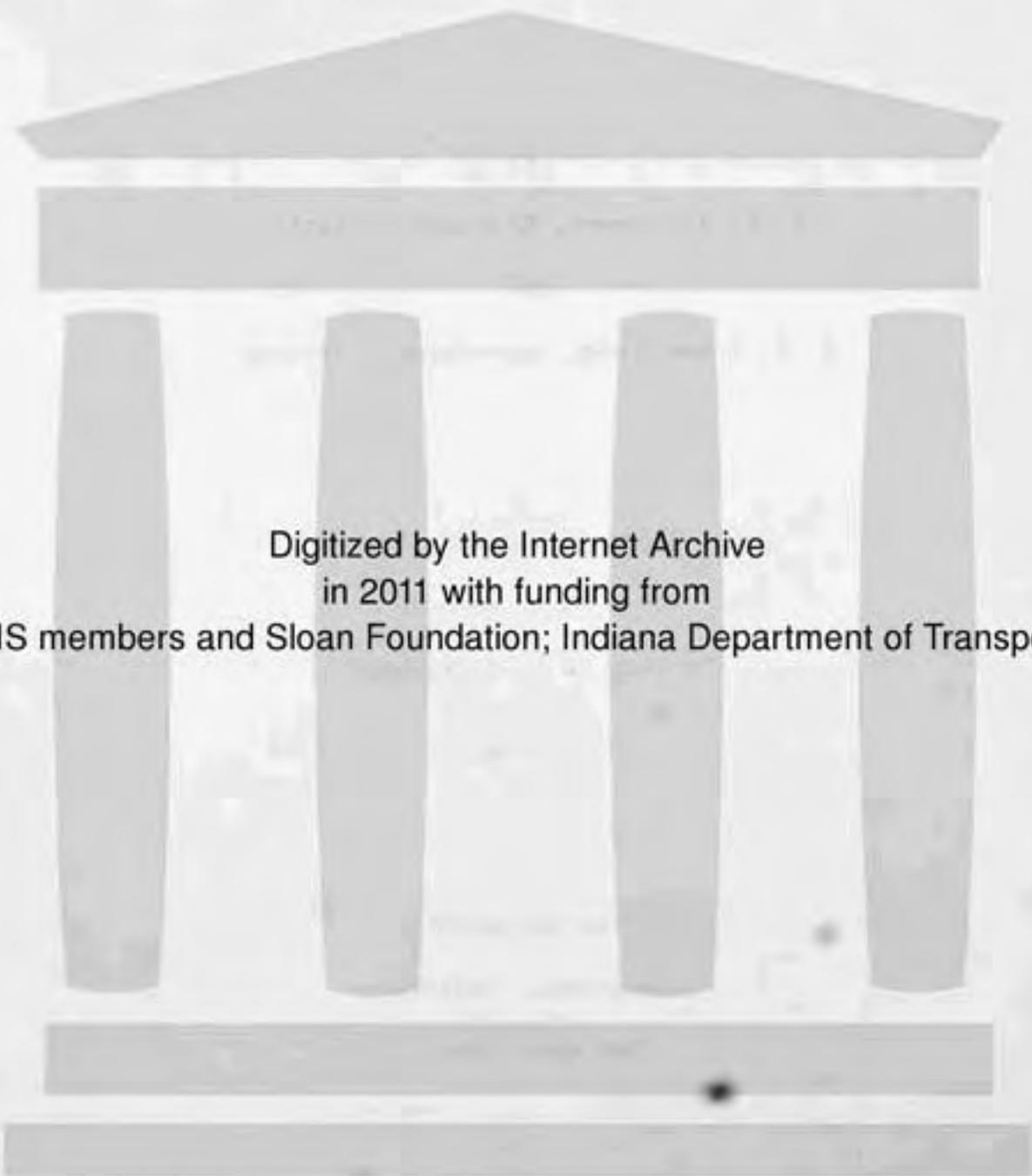
REGIONAL TRAVEL PATTERNS OF A SMALL METROPOLITAN AREA

by

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and

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SYNOPSIS

The purpose of this study was to determine the factors that generate highway travel between the central city of a region and the communities in its surrounding zone of influence. The central city, Fort Wayne, Indiana, depends on the people in the smaller communities to sustain its regional facilities. In the same manner, these smaller cities depend upon the central city for various needs. This inter-dependence that produces and attracts these traffic movements was analyzed in this investigation.

This development of regional travel patterns included the modeling of trips attracted to and trips produced by the central city. The basic form of the regression equations used to describe this flow of traffic was the gravity model; that is, trip production or attraction is directly

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proportional to the product of a given mass function of the two cities and inversely proportional to some power of the distance between these communities. Internal and external competition factors were introduced into the models to describe more completely the variations in regional trip generation and distribution.

The separation of trips into specific trip purpose categories (work, shopping, social-recreational, and all-purpose) and travel types (produced and attracted) provided better estimation models. In addition, the division of the total study region into core and fringe areas demonstrated that the internal competition within a city had a negative effect on trip generation throughout the study region. However, the external competition of other cities was only significant in reducing trip generation for communities in the fringe area. A total of 24 statistical models was developed to describe the various arrangements of trip purpose, travel type, and area designation.

INTRODUCTION

In recent years many types of transportation studies have analyzed origin-destination data related to individual urban areas. These studies accomplish their purpose by reporting present urban transportation deficiencies. However, with the increased distance in travel that has accompanied improvements in both the means of travel and the highway system, the sphere of influence of the city is no longer confined to its planning boundaries. Unfortunately, traffic studies have not kept pace with the broader aspects of regional travel. Perhaps this fact is due to a lack of knowledge concerning the significant factors influencing regional travel patterns. When those factors underlying present travel motivation are better understood, more reliable estimates of future travel will be possible.

The traffic within an urban area flows from zones of production to zones of attraction. For example, each morning people travel from residential zones to zones of commercial and industrial activities. Each evening the flow is reversed with people returning to their homes. The community statistics which have been used to quantify this flow of traffic include population, employment, work-force size, wholesale and retail sales, car registration, and recreational facilities. This investigation utilizes this concept of flow between zones with the exception that the zone is not part of the city but is the city itself.

Population and car registration are two statistics that have been generally selected to explain the magnitudes of regional traffic movements.

There has been little attempt, however, to evaluate regional trip generation with analytical methods to discover the real factors that underlie the production and attraction of vehicular trips. The relative importance of an urban center as a traffic generator is shown by its potential to attract trips from and to produce trips to other primary, secondary, and tertiary communities. The interchange of trips within a region is illustrated in Figure 1.

The purpose of this research investigation was to study the intercommunity traffic linkages between Fort Wayne, Indiana, and surrounding communities in northeastern Indiana, northwestern Ohio, and southern Michigan. Estimation models were developed to predict both trip total and trip purpose interchanges between the various classes of urban centers. (10)[*]

Fort Wayne is linked to the surrounding communities by the highway network. Over this network of roads, various communities of the region supply Fort Wayne with the people and goods which are necessary to maintain its position as a city of regional importance. These communities, in turn, depend on Fort Wayne for employment, educational, and religious opportunities and for various recreational, shopping, and medical facilities. This interdependence generates the traffic movements that were analyzed in this research study. The daily movements between Fort Wayne and the surrounding communities were obtained as part of a comprehensive urban origin-destination study. These trip totals were evaluated to

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[*] Numbers in parentheses refer to items listed in the Bibliography.

FIGURE I TRIP INTERCHANGES WITHIN A REGION

---- TRIPS PRODUCED BY THE CENTRAL CITY

—— TRIPS ATTRACTED BY THE CENTRAL CITY
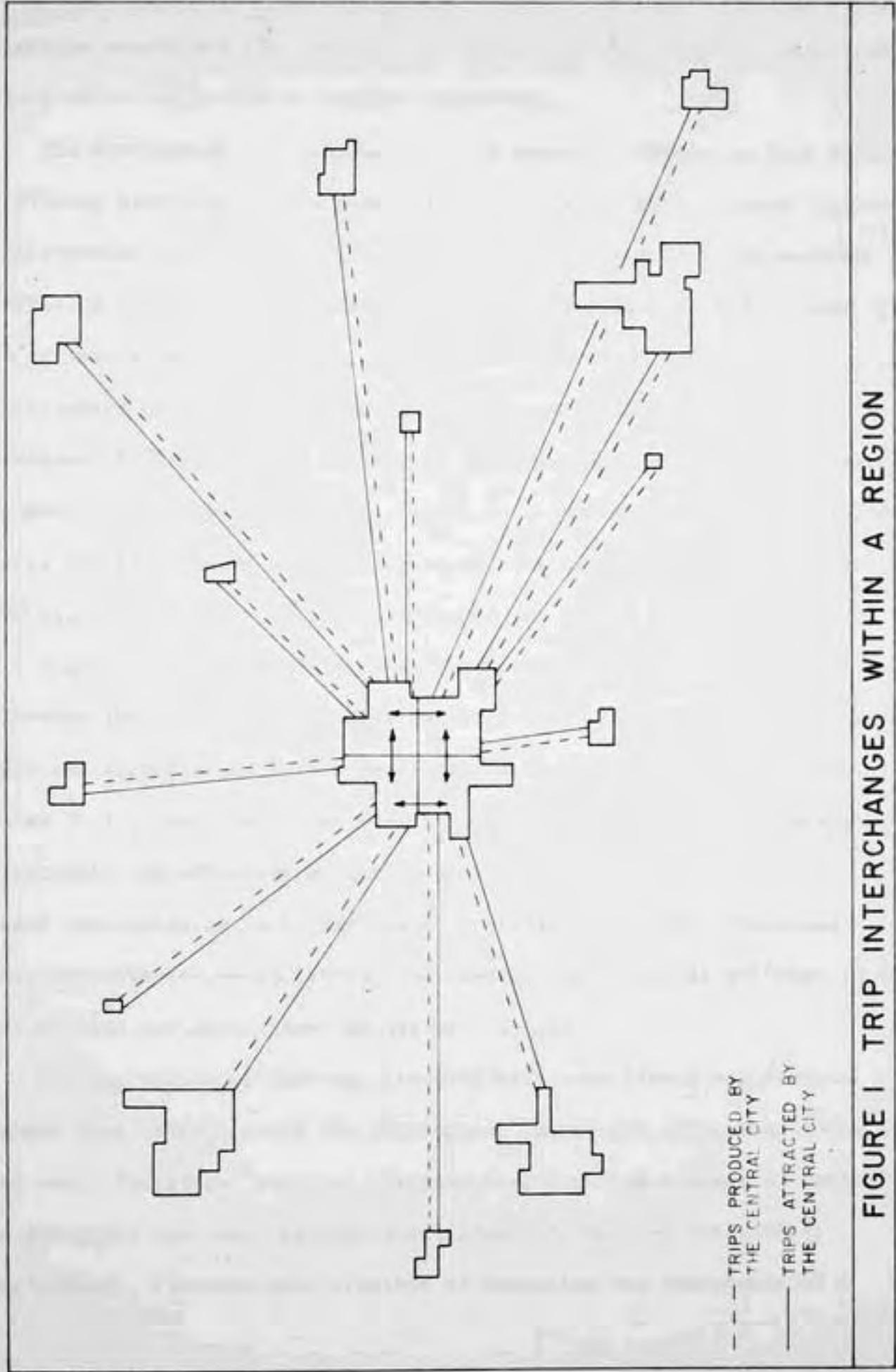
determine quantitatively those factors which significantly influence the magnitude and direction or regional movements.

The development and evaluation of mathematical models is most useful in highway planning. These models afford an opportunity to gain further understanding of the regional significance of highway linkages between central cities and outlying communities. After models have been developed for various regions within the United States, regional travel patterns can be estimated on a nationwide basis. These estimates can then be used to determine the locations of additional highways where they will best serve the desires for regional travel. Also, on a smaller scale, these traffic models provide a means of choosing among alternate locations for inter-city highway routes to satisfy the demand for travel between cities.

Highway linkage findings offer quantitative information by which to determine the needs for improving existing rural highways. These improvements are accomplished by the redesign and reconstruction of existing routes or the location of new facilities. Mathematical models represent an economic and efficient manner of obtaining planning information needed for assigning functional uses to traffic facilities, defining administrative responsibilities, and determining financial policies in the construction and maintenance of highway systems.

The discipline of land-use planning will also have a new tool. Highway facilities promote the development and growth of various forms of land use. Therefore, regional planning benefits from a means of estimating the potential use that regional facilities will receive after their development. Planners gain a method of measuring the dependence of a

community on outside sources for the satisfaction of the needs of its residents. Both public and private interests will be able to appraise their competitive status for existing or proposed services.

Studies designed to determine the impact of actual or proposed changes in local or regional facilities, interstate or primary highways, industrial development, shopping centers, centralized schools, etc., can make use of traffic models. Traffic patterns are flexible and bend with environmental and land-use changes. Therefore, these models serve to indicate the changes in travel desires produced by alterations in regional land-use activities.

REVIEW OF LITERATURE

During the past decade, several methods of forecasting travel patterns have met with varying degrees of acceptance. Although there is no clear agreement as to which method is best, the gravity concept appears to have sufficient potential to attract periodic attention.

The first known explicit statement of the gravity concept as applied to social behavior was proposed by H. C. Carey in the early 1800's. In this work, the fundamental law of gravitation was applied in explaining the social interaction between people. (1) The principal difficulty with this analogy is that men and molecules are basically different in nature. Man can make decisions on which to base his actions, while the individual molecule is presumably not capable of rational thinking.

The gravity concept lay dormant until the late 1920's when W. J. Reilly postulated his "Law of Retail Gravitation." This law states that a city attracts retail trade from individuals in the hinterlands in direct proportion to the population of the city and in inverse proportion to the square of the distance between the individual and the city. Between any two cities, which are competing for retail trade, there exists a point of equilibrium where their competitive influences are equal. (7) This point can be located by using the following relationship:

$$\frac{P_i}{(D_{ix})^2} = \frac{P_j}{(D_{jx})^2} \tag{1}$$

where P_i = the population of city i,

P_j = the population of city j,

x = the point of equilibrium on the line joining i and j,

D_{ix} = the distance from city i to point x, and

D_{jx} = the distance from city j to point x.

During the early 1940's, both J. Q. Stewart and G. K. Zipf developed similar hypotheses which state that the interaction between two population centers varies directly with the product of the masses of the two centers and inversely as the square of the distance between them. (8, 9, 19, 20) A mathematical representation of this relationship is:

$$Y_{ij} = k \frac{P_i P_j}{(D_{ij})^2} \tag{2}$$

where P_i = the population of city i,

P_j = the population of city j,

D_{ij} = the distance between city i and j,

k = a proportionality constant needed to correct for the difference in dimensions, and

Y_{ij} = the number of interchanges between city i and city j.

The nature of the gravity concept lends itself to graphical representation. The total potential of a community can be calculated at a series of points and plotted on a map of the study area. On these maps, areas of differing potential are apparent, and interrelationships between areas are visibly evident.

There is general agreement among investigators that the attractive power of a community is proportional to some measure of its size. (2, 3, 4, 7, 18) However, complete agreement does not exist as to how the influence of distance should be represented.

J. D. Carroll has reported a technique for describing the magnitude of the influence of a city on surrounding communities. In testing this theory, Carroll used both long-distance telephone calls and intercity auto travel between 21 major cities located in southern Michigan. The power to which distance was raised ranged from 3.36 for calls from a neighborhood center to 2.84 for calls from a major regional center. The corresponding exponent for intercity travel was 2.98. Based upon these results, Carroll concluded that the influence of a city is inversely proportional to the cube of the distance from that city. (2)

While attempting to explain the relationship between traffic volume, population, and distance, F. C. Ikle separated composite traffic into specific trip purposes to make the influence of population stand out more clearly. Ikle anticipated that population would affect one type of trip more strongly than another. Empirical testing of automobile trips between Fort Wayne, Indiana, and counties in northern Indiana produced an exponent of 2.57 for the distance factor. Similar intercity travel characteristics were evidenced in the State of Washington, where an exponent of 2.6 was determined. (5)

Until the past few years, most researchers agreed that the function representing the attraction between communities was the product of their masses, although the community characteristic used to represent this mass differed from one investigation to another. However, recent studies have

introduced transformations of the mass term to obtain better explanations of the interaction between people.

W. Mylroie applied the gravity concept to explain the relative desires for travel between cities in the State of Washington. A square-root transformation of population was used to represent the mass function, and the distance function was raised to the second power. (6)

As part of a project conducted at the University of Illinois, G. W. Greenwood developed multiple linear regression and factor analysis equations for travel in the region surrounding Champaign-Urbana, Illinois. The traffic totals used in this study were classified by trip purpose to develop the basic factors underlying traffic generation. Prediction models were formulated for trips attracted to and trips produced by the urban center of Champaign-Urbana. The region of analysis was divided into a core and a fringe area to obtain homogeneity in type of trips and in community statistics. The method used for defining the region was similar to that developed by Carroll. The division of trips into specific trip categories and the region into core and fringe areas made it possible to explain the effect of the mass function on travel more completely. (4)

While investigators are in general agreement that the attractive power of any city is proportional to its size, recent studies have questioned the form of this function. It is also evident that the influence of distance is not uniform. Rather, the exponent is a variable which depends upon unique characteristics of the situation under study.

DESIGN OF STUDY

This section translates the overall theoretical concepts into useful traffic prediction models. The theory underlying the development of mathematical models is explained as applied to regional travel. The equations developed can possibly be extended to estimate nationwide travel patterns and provide quantitative planning information for evaluating the needs of the rural highway system.

Intercity Competition Concept

The gravitational concept hypothesizes that the attractive force of interaction between two cities is produced by the masses of the two cities and that the distance between the two cities acts as a deterrent to this interaction. This relationship can be stated as:

$$Y_{1-2} = \frac{M_1 \cdot M_2}{(D_{1-2})^{\alpha}} \tag{3}$$

where Y_{1-2} = the total vehicle trips between area 1 and area 2,

M_1 = some measure of the traffic generating potential of area 1,

M_2 = some measure of the traffic generating potential of area 2,

D_{1-2} = the distance between area 1 and area 2, and

α = an exponent.

While equation 3 is applicable to the prediction of trip interchange between pairs of cities, areas, etc., it has serious limitations as a regional model for travel estimation. This model yields only total inter-change and conceals any difference between the two areas as to their ability to produce or attract trips. Because communities do vary con-siderably in this ability, provision must be made to allow for these inherent differences. This basic form also implies that the two commun-ities are in a state of isolation; that is, they are removed from the influence of other communities. These stipulations are not practical as the basis for a regional approach to the prediction of motor-vehicle interchanges because many communities of varying size and activity are located within a region.

Conversion of the Basic Model for Regional Analysis

The basic model is converted to a regional model by changing the subscripts to denote whether Fort Wayne acts as the producer or the attractor of vehicular trips and by eliminating the mass term for Fort Wayne from the basic equation, because this term appears in all models. In this investigation, all trips are defined as one-way with either the origin or the destination within the City of Fort Wayne.

Trips Produced by Fort Wayne

Subscript 'a' refers to any trip attracting community in the region, and the subscript 'fw' indicates Fort Wayne as the producing community. The basic model now becomes:

$$Y_{fw-a} = \frac{M_{fw} \cdot M_a}{(D_{fw-a})^\alpha} \tag{4}$$

Because Fort Wayne is the producer of trips to the cities throughout the study region, the index of productiveness of Fort Wayne (M_{fw}) is a constant term and can be dropped from the model. The inclusion of this term is simply equivalent to multiplying each community index (M_a's) by the same value. All indices are affected in the same proportion, and consequently the mass of Fort Wayne has no bearing upon the development of the regional model. The produced-trips model can now be written as:

$$Y_{fw-a} = \frac{M_a}{(D_{fw-a})^\alpha} \tag{5}$$

Trips Attracted by Fort Wayne

The analogy for the situation in which Fort Wayne is the destination for trips which originate in the other population centers of the region is similar to that for the produced trips. Subscript 'p' refers to any trip producing community in the region, and the subscript 'fw' indicates Fort Wayne as the attracting community. The model is written as:

$$Y_{p-fw} = \frac{M_p \cdot M_{fw}}{(D_{p-fw})^\alpha} \tag{6}$$

Because the productiveness index of Fort Wayne is a constant term, it can be deleted from the equation. The regional model for attracted trips reduces to the following form:

$$Y_{p-fw} = \frac{M_p}{(D_{p-fw})^\alpha} \qquad (7)$$

Models (5) and (7) were developed by tailoring the basic concept of human interaction to fit a regional approach. These models in their present forms do not account for competitive forces.

Theory of Competition

Competition between communities is viewed as a type of pull or force similar to that implied in the basic gravity concept. This concept requires the inclusion of both positive attraction and negative competition before the basic model can be applied on a regional basis.

The inhabitants of a region have three alternatives for satisfying their needs and desires:

1. They can patronize the facilities within their own community;

2. They can make regional trips to major communities other than the central city; or

3. They can make regional trips to the central city.

The hypothesis is made that factors contributing to the selection of one of the above alternatives are the result of competitive forces. The relative strength of competitive forces exhibited by the various communities must be evaluated and included within the prediction models as modifying factors affecting intercommunity travel.

The ability of one community to attract trips is dependent upon two different types of competition. The first, internal competition, is defined as a measure of the ability of the trip producing community to satisfy the desires of its inhabitants within its own boundaries. The

second is external competition, which is defined as a measure of the ability of other communities to vie with the attracting city for the chance to satisfy the needs of the people in the trip producing community.

Internal Competition

Internal competition is inherent to the trip producing central city; therefore, the internal competition factor is a constant and is not required because all models are affected in the same manner. This reasoning is not valid when considering trips attracted by the central city. The internal competition factor is required because this variable differs with each trip producing community. (4)

The extent of internal competition can only be considered in relation to individual trip purposes. For example, as the number and the type of shopping facilities within a community increase, the ability of the community to meet the needs of its inhabitants is enhanced. Adequate internal shopping facilities reduce the number of shopping trips made to outlying communities.

With the addition of internal competition, equation (5) remains unchanged for produced trips, and equation (7) for attracted trips becomes:

$$Y_{p-fw} = \frac{M_p}{(D_{p-fw})^\alpha} + C_p \tag{8}$$

where C_p = a measure of the ability of the producing community

to satisfy its residents' needs.

External Competition

External competition is defined as a measure of the ability of major communities within the region to vie with each other and with the central city for the opportunity to serve the people in the trip producing community. As in the case of internal competition, the external competition factor was omitted as an explicit factor when dealing with trips produced by the central city. The effects of this element of competition are already included within the basic variables (M_a's) of the model. As long as consideration is focused on trips produced by the central city, all outlying cities are competing with one another to attract these trips. Therefore, the effectiveness of this competition depends on the value of the relevant attraction variables within these communities and the distance of these communities from the central city. Because external competition is implicitly incorporated within the basic variables of the produced trip models, it is redundant to include it again as an explicit component.

The logic underlying the inclusion of external competition in the models for trips attracted to the central city is more obvious because this situation involves multiple trip production sources and a single attractor. Every community of the region is a possible producer of trips, while the influence exerted by each competitor varies from one community to another. Therefore, external competition was explicitly incorporated as a variable within the attracted trip models.

The inclusion of internal competition in the attracted trip models and external competition in the produced trip and the attracted trip models

necessitated the quantification of these variables. Internal competition is represented by those community statistics which describe activities directly related to trip purpose.

On the other hand, external competition presented a different problem. There are many competing cities that exert influences on the trip generation pattern of a trip producing community. Based on the results of a previous study, the decision was made to use only the competing community, c, with the highest probable value of competition. (4)

Once the limits for competing cities had been defined, an external competition factor was evaluated in three steps:

1. The major competitors within the study region were identified;

2. The communities under the influence of a common competitor were grouped together forming the competition zone of that competitor; and

3. The external competition factor was quantified.

The following criteria were used in the identification of major competitors:

A. The competitor was located in the sphere of influence of the central city;

B. The competitor had a population of 25,000 or more (The selection of population size was justified because population can be considered as a composite measure of all other indices.);

C. The competitor had a minimum of ten trip interchanges per day between it and the central city; and

D. The competitor with the highest probable value of competition was selected from among the major competitors. For a given producer, p, the competition of each competing community was evaluated by the following expression:

$$\frac{M_{c_i}}{(D_{c-p})_i} \tag{9}$$

where M_c = some measure of the attractiveness of the major

competitor,

D_{c-p} = the distance between the outlying community and the

major competitor, and

i = 1, 2, ..., n - the major competitors.

The second step involved the establishment of competition zones. Population was selected as the most appropriate community index to define competition zones. Population is a general statistic and allows one configuration of zones to be used irrespective of which particular trip purpose was analyzed. In the actual calculations, the ratio of population to distance was used to define the competition zones.

The area dominated by the central city was first delimited. The procedure developed by J. D. Carrol was used to define the zones of competition. This technique involved the determination of where the retail trade influences between the central city and the competing cities were equal. The boundary of this zone was a set of points representing the location of a state of equilibrium between the influence of the central city and that of each competing city.

The distance from Fort Wayne to various points on the boundary of dominant influence was obtained by solving the following relationship:

$$\frac{P_{fw}}{D_i} = \frac{P_c}{D_{i-c}} \tag{10}$$

where D_i = the distance from Fort Wayne to the balance point on
the boundary of the influence zone,

D_{i-c} = the distance between the same point on the boundary
and the competing city,

P_{fw} = the population of Fort Wayne, and

P_c = the population of the competing city.

However, $D_{i-c} = D - D_i$, where D is the distance from Fort Wayne to the
competing city. The previous relationship can now be rewritten as:

$$\frac{P_{fw}}{D_i} = \frac{P_c}{D - D_i} \tag{11}$$

and solving for D_i,

$$D_i = \frac{D\,(P_{fw})}{P_c + P_{fw}} \tag{12}$$

By evaluating this relationship between Fort Wayne and each competing
city, the zone of primary influence was located for Fort Wayne. This
procedure was repeated to establish the influence zones for all the
centrally-located major competitors in the study area.

Zonal boundaries were also established by application of the popula-
tion to distance relationship for adjacent pairs of non-centrally-located
competing cities. Zonal boundary lines were extended toward Fort Wayne
by computing the highest probable values of competition relative to the
non-centrally-located competing cities for several outlying communities.
The boundaries were then located so that each community was within the
zone of influence of the most probable competitor.

Two distinct levels of competitive influence were defined for Fort
Wayne - the core area in which Fort Wayne exerted the principal influence

and the fringe area where the influence of the competing cities predomin-
ated. This subdivision of the total area produced two areas that were
each more homogeneous than the total area.

The final step involved the quantification of the external competi-
tion factor. For any given competitive zone, the effect of the major
competitor was incorporated into the trip attracted model by an expression
which contains a measure of the attractiveness of the competing city and
the distance between the trip producing city and the competing city.

After the study region was separated into core and fringe areas, it
was necessary to evaluate the influence of external competition. Within
the core area, the effect would either be measured as described above or
neglected entirely. This latter alternative was predicated on the minor
external competition exerted by the communities within the zone of
primary influence for the central city. The absence of external competi-
tion necessitated the application of a second condition to the concept of
highest probable value of competition. In order for a community, p, to
be considered under the influence of a competitor, c, the value of $(\frac{P_c}{D_{p-c}})$
would have to be greater than $(\frac{P_{fw}}{D_{p-fw}})$. That is, models for trips
attracted to Fort Wayne contain an external competition factor only when
the trip producing community fell outside the primary influence area of
Fort Wayne. The external competition factor was included in the analysis
for the core area.

The addition of external competition to models (5) and (8) yielded:

For trips produced by Fort Wayne (no change)

$$Y_{fw-a} = \frac{M_a}{(D_{fw-a})^\alpha} \tag{5}$$

For trips attracted by Fort Wayne

$$Y_{p-fw} = \frac{M_p}{(D_{p-fw})^\alpha} + C_p + C_c \qquad (13)$$

where C_c = a measure of the external competition produced by the

major competitor of Fort Wayne.

A summary of competition forces with the reasons for inclusion or exclusion of competition factors is given in Table 1.

Measures of Separation

Three measures that are used to quantify the separation between communities are highway distance in miles, travel time in minutes, and travel cost in dollars. The total cost of travel would be an excellent way of weighting the distance factor, because travel cost reflects many considerations important to the traveler. However, travel cost is extremely difficult to evaluate properly because of intangibles such as comfort and convenience incorporated within it. Travel time also measures the friction against travel and is particularly appropriate within congested areas.

While distance alone does not include all the factors that affect travel, this measure was selected for use in this study. The rural highways within the study region have approximately the same travel characteristics so that the selection of a route based solely on miles of travel was considered an adequate criterion. The shortest possible highway distance was used in the analysis of all travel linkages.

TABLE 1

SUMMARY OF COMPETITION FORCES

I. Internal Competition.

    A. Produced Trips - internal competition is a constant

                          term and therefore omitted.

    B. Attracted Trips- an explicit factor must be included

                          to measure internal competition.

II. External Competition.

    A. Produced Trips - external competition is included

                          within the mass variables.

    B. Attracted Trips- an explicit factor must be included

                          to measure external competition.

Selection of Community Statistics

This section is devoted to the selection of community statistics used to measure the ability of a community to produce or attract trips. Population and employment totals are reported in persons, and sales totals are in thousands of dollars. The independent variables used in the development of the various traffic generation and distribution models are presented in the following listing:

1. Population,

2. Total employment in a community,

3. Employment in the construction industry,

4. Employment in the manufacture of durable goods,

5. Employment in the manufacture of non-durable goods,

6. Employment in transportation, communication, and other utilities,

7. Employment in wholesale and retail trade,

8. Employment in finance, insurance, and real estate,

9. Employment in business and repair services,

10. Employment in personal services,

11. Employment in entertainment and recreational services,

12. Employment in professional and related services,

13. Employment in public administration,

14. Employment in agriculture and related services,

15. Total sales in a community,

16. Wholesale sales in a community,

17. Sales by merchant wholesalers,

18. Retail sales in a community,

19. Sales in lumber, building materials, hardware, and farm equipment,

20. Sales in the general merchandise group,

21. Sales in the food group,

22. Sales by automotive dealers,

23. Sales by gas stations,

24. Sales by apparel and accessory stores,

25. Sales by furniture, home furnishings, and equipment stores,

26. Sales by eating and drinking places,

27. Sales by drug and proprietory stores,

28. School enrollment (kindergarten, elementary, secondary, and college),

29. Number of hospital beds in a community, and

30. Acres of recreational open space.

The types of trip-purpose categories were work, shopping, social-recreational, and all-purpose trips. The wide range of activities that generate the social-recreational trips made it necessary to select variables which explain both classes of recreation travel - social and commercial. In this study, overall social activity was described by population size. The measurement of commercial recreation is complicated because the establishments which produce this form of recreation are heterogeneous in terms of activities, patronage, and physical size. The measure of dollar sales was considered, but a serious limitation was inherent to this statistic because a large portion of the facilities did not have reportable sales. As a result, employment was the only index available.

The characteristics of the work, shopping, and social-recreational trips are sufficiently described by their names alone. However, the all-purpose trip was a special category comprised of all trips between

Fort Wayne and the other communities in the study region.

Certain variables employed as measures of trip generation can also be used to describe competition. External competition was evaluated by the population of the competing city. However, for internal competition the index differs with each trip category. The explicit variables used with attracted trip models were total employment for work trips, retail sales for shopping trips, acres of recreational open-space for social-recreational trips, and population for all-purpose trips. For produced trip models, internal competition is implicit in the measurement variables themselves as these variables also describe the attractiveness of a community to its own residents.

There is a distinction to be made concerning the dual function of community variables. The magnitude of the variables can both increase and/or decrease the generation of regional travel. For example, a large employment center attracts workers from the hinterland, and regional travel is produced. On the other hand, people within the community where the industry is located can also find employment. This condition reduces trip making potential of the community.

Mathematical Models

The development of functional relationships between the dependent variables and the independent variables involved the formulation of mathematical models. The type of linear regression equations developed was:

$$Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \tag{14}$$

where   Y = predicted mean dependent variable,

   a = intercept,

   b = regression coefficient,

   X = independent variable, and

   n = number of independent variables.

The multiple linear regression equation for each trip category was developed under the assumption that the sample data were randomly selected from normal populations. It was also assumed that homogeneity of variance existed for the study variables.

Criteria for Selecting a Model

The choosing of the regression equation with the highest correlation coefficient is not, in itself, sufficient criterion for assuming the adequacy of a model. Logical interpretations exist in addition to the statistical considerations. The logical requirements selected in this investigation demand that the model pass a critical appraisal to assure that the relationship represented is reasonable in terms of competition theory. Strict adherence to statistical evaluations may bias the results toward those variables or transformations that provide the "best" fit and away from those basic variables which truly influence traffic patterns. The selection of the appropriate model was based both on a priori considerations of competition and on examination of inter-correlations between proposed independent variables. In addition, the Student 't' test was used to evaluate the hypothesis that the true value of the regression coefficient was equal to zero.

PROCEDURE

This investigation of regional travel patterns was conducted with the community of Fort Wayne, Indiana, as the central city. The regional influence of Fort Wayne as an attractor and a producer of highway travel included portions of Indiana, Michigan, and Ohio.

Data Collection

Origin-destination data were collected by the Indiana State Highway Commission as part of a traffic survey for Fort Wayne in June 1961. From the original field sheets, trips were broken down into two categories - those originating in Fort Wayne and those having Fort Wayne as a destination. In addition, the other trip terminal was recorded for this analysis of regional travel.

Almost 90 percent of the trips were found to lie within an area comprising northeastern Indiana, northwestern Ohio, and southern Michigan. This area, as shown in Figure 2, was designated as the sphere of influence for Fort Wayne. Only those trips having both origins and destinations within this region were evaluated in this traffic linkage study. To provide reasonable values for the statistical analysis, a community had to have a total of ten or more interchanges with Fort Wayne. With these limitations imposed on the study area, a total of 156 communities, 97 in the core area and 59 in the fringe area, represented about 85 percent of the trips in the origin-destination data. The total travel data used in the regression analysis were 20,020 one-way trips of which 45 percent

FIGURE 2. THE REGION UNDER THE SPHERE OF INFLUENCE OF FORT WAYNE, INDIANA

were work, 16 percent were shopping, and 11 percent were social-
recreational. The remaining 28 percent were only included in the all-
purpose category. The four trip type totals made up the dependent vari-
ables used in the regression analysis.

Community statistics, which were necessary for the development of
the regression equations, were collected from the U.S. Census of Popula-
tion; 1960, Vol. I, Characteristics of the Population (12, 13, 14),
U.S. Census of Business; 1958, Vol. II, Retail Trade-Area Statistics,
parts 1 and 2 (15), U.S. Census of Business; 1958, Vol. IV, Wholesale
Trade-Area Statistics (16), U.S. Census of Business; 1958, Vol. VI,
Selected Service-Area Statistics (17), and various state publications. (11)
The population census figures were taken as reported for 1960, and the
information from the business census was projected from 1958 to 1961.
After the necessary community statistics had been entered on summary
sheets, the information was punched on IBM data cards suitable for use
with the IBM 7094 Computer.

Data Analysis

Before the model building was performed, the study region was
divided into core and fringe areas according to J. D. Carroll's "tent"
method of describing urban trade areas. (2) The cities which compete
with Fort Wayne and meet the competition criteria are summarized in
Table 2. Once the competing cities were selected, the relationship,

TABLE 2

MAJOR COMPETING CITIES

State	City	Population	Distance from Fort Wayne	Trips
Indiana	Anderson	165,806	79	24
	Elkhart	37,854	66	75
	Indianapolis	476,258	118	220
	Kokomo	47,197	82	28
	Marion	40,274	50	177
	Muncie	68,603	67	124
	Richmond	44,149	92	30
	South Bend - Mishawaka	165,806	90	170
Michigan	Ann Arbor	75,000	142	10
	Battle Creek	44,169	94	12
	Jackson	50,720	110	10
	Kalamazoo	82,089	113	14
Ohio	Dayton - Kettering	316,794	115	36
	Findley	30,344	90	17
	Lima	51,037	64	74
	Toledo - Maumee	330,066	108	82

$$D_i = \frac{D(P_{fw})}{P_c + P_{fw}} \qquad (12)$$

where D_i = the distance from Fort Wayne to any point on the

boundary of the influence zone,

D = the distance from Fort Wayne to the competing city,

P_{fw} = the population of Fort Wayne, and

P_c = the population of the competing city,

was solved to obtain the zone of primary influence for Fort Wayne. This relationship was also used to delimit the zones of influence for the competing cities. The competition zones within the study region are shown in Figure 3. A more complete description of this procedure was developed in the Design of Study.

## Basic Procedure of Model Evolution

In the model evolution phase, traffic interchange models were developed by specific trip purposes. The first decision in this development involved the use of either the composite or the individual variable approach. For illustrative purposes, a general expression for trips produced by Fort Wayne is discussed. The composite variable form is:

$$Y_p = F(X) \qquad (15)$$

where $X = \dfrac{M_a}{D_{fw-a}}$

The independent variables, which measure the attractive power of the community and the distance from Fort Wayne to the attractor, were combined into a single term. This form required a single regression coefficient for each combination and was used in the development of the regression

FIGURE 3. COMPETITION ZONES WITHIN THE STUDY
REGION
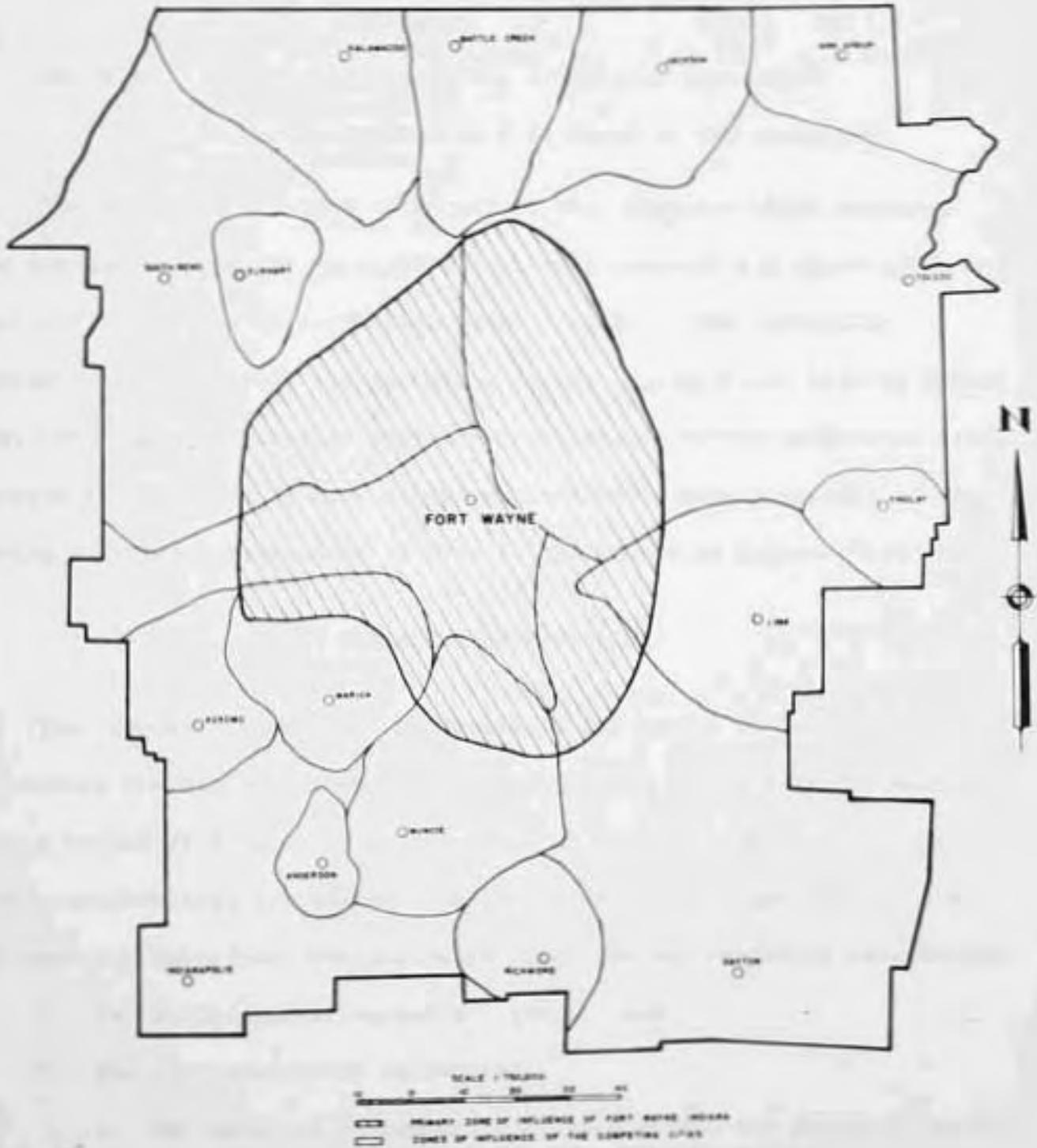
equations.

The individual variable approach differs because each variable retains its own identity. The resulting relationship takes the form:

$$Y_p = F(M_a; D_{fw-a})$$
(16)

where M_a = the measures of the attractive force and

D_{fw-a} = the distance from Fort Wayne to the attractor.

The desirable solution is to select that approach which measures the maximum information obtainable from each variable and which performs most efficiently as an estimation model. Although the individual approach is intuitively the technique to employ, empirical testing showed that the composite variable approach provided the better estimation model. Because an objective of this study was to develop models capable of producing efficient estimations of travel, the composite approach was chosen.

Selection of Variables

The community variables, as listed in the Design of Study, were used to measure the attractiveness and productiveness of hinterland communities. From a review of literature in the field of traffic linkage, the most common mathematical transformations of the data were logarithms, roots, and powers. Therefore, the following forms for the variables were chosen:

1. For the dependent variable - linear, and

2. For the independent variables:

    a. For measures of community attractiveness and productiveness -
        linear and square root.

    b. For the distance variable - square root and

first, second, third, and fourth powers.
Different combinations of these variables were tested by correlation
with the trip data.

Application of Intercommunity Competition Theory

Because the produced trip models required no explicit competition
factors, only regression coefficients for the variables were required
to validate the equation. On the other hand, the models depicting
attracted trips required the evaluation of the external and internal
competition factors in addition to the basic variables. Population of
the competing city divided by the distance separating the competing city
from the producing city was chosen as the external competition factor.
The internal competition factor, however, varied with the trip category
under consideration. With all-purpose trips, this factor was the
population of the producing city divided by the distance from the center
of the city to its periphery. For the work trip, shopping trip, and
social-recreational trip categories, population was replaced by total
employment, retail sales, and recreational open-space, respectively.

Multiple Linear Regression and Correlation Analysis

A build-up regression procedure was used to evaluate the composite
variables selected for this investigation. In the computational procedure
an "F-to-remove-value" for each independent variable in the regression
equation and an "F-to-enter-value" for each independent variable not in
the equation were computed at each step. Independent variables were added
or deleted in accordance with the following criteria:

1. If one or more independent variables in the regression equation
    had an F value less than the critical "F-to-remove-value"
    specified, then the variable with the smallest F value was
    removed;

2. If no variable was removed and one or more independent variables
    which were not in the regression equation passed the tolerance
    test, the variable with the highest F value was added; and

3. The process was terminated when no variable was added or deleted.

The values of 0.01 and 0.005 were set as F levels for inclusion and
deletion of independent variables, respectively. In regard to criterion
No. 2, an independent variable which was not in the regression equation
passed the tolerance test if its tolerance value was equal to or greater
than the minimum specified value of 0.001.

Model Selection

Model selection was based largely on the form that produced the
highest correlation with the trip data. However, the choosing of the
equation with the highest correlation coefficient was not the only
criterion for assuming the adequacy of the model.

The following requirements were used in the determination of
variables for inclusion in the multiple linear regression equations:

1. The equation contained those variables which were logical in
    terms of competition theory;

2. A coefficient of determination of 0.50 or greater was desired;

3. The final form of the model contained as few variables as possible while still performing its function; and

4. The multiple coefficient of determination did not increase significantly with the inclusion of additional variables.

These requirements were applied to the regression equations developed in the model building phase of the analysis. After the regression analysis had been performed on the many combinations of mass-variable transformations and distance exponents by trip purpose, trip type, and area designation, the "best" model was chosen for each of the 24 combinations.

RESULTS

In this investigation mathematical models were developed to describe the generation and distribution of regional travel patterns. A key to the variables included in these models is given in Table 3, and the models are presented in Tables 4 to 7. The subscripts of the composite variables, X, in the regional trip models relate to the subscripts of the mass functions, M, listed in Table 3. Produced and attracted work trip models are listed in Table 4 for total, core, and fringe areas. The same format is followed in Tables 5, 6, and 7, respectively, for shopping trip, social-recreational trip, and all-purpose trip models. The basic form of the composite variables for the description of traffic interchange was the gravity model; that is, trip interchange is directly in proportion to the product of a given mass function of two communities and inversely proportional to some power of the distance separating these two communities. The pertinent statistical features of each model are presented in Table 8. These equations provide a method of measuring the travel linkages provided by the interdependence between Fort Wayne, Indiana, and the communities within its zone of regional influence.

Due to the number and the complexity of equations that are presented, the following hierarchy is used in reporting the results. The various travel models are discussed in relation to:

TABLE 3

KEY TO VARIABLES IN THE REGIONAL TRIP MODELS

M_1 = Population.

$M_2 - M_{14}$ = Employment totals.

M_2 = Total employment.

M_3 = Construction.

M_4 = Durable goods manufacturing.

M_5 = Non-durable goods manufacturing.

M_6 = Transportation, communication, and other public utilities.

M_7 = Wholesale and retail trade.

M_8 = Finance, insurance, and real estate.

M_9 = Business and repair services.

M_{10} = Personal services.

M_{11} = Entertainment and recreational services.

M_{12} = Professional and related services.

M_{13} = Public administration.

M_{14} = Agriculture.

$M_{15} - M_{27}$ = Sales totals (thousands of dollars).

M_{15} = Retail sales.

M_{16} = Wholesale sales.

M_{17} = Total sales.

M_{18} = Lumber, building materials, hardware, and farm equipment.

M_{19} = General merchandise.

M_{20} = Food group.

TABLE 3 (continued)

M_{21} = Automotive dealers.

M_{22} = Gas service stations.

M_{23} = Apparel and accessory stores.

M_{24} = Furniture, home furnishings, and equipment stores.

M_{25} = Eating and drinking places.

M_{26} = Drug and proprietory stores.

M_{27} = Merchant wholesalers.

M_{28} = School enrollment (kindergarten, elementary, secondary, and college).

M_{29} = Number of hospital beds.

M_{30} = Recreational open-space.

M_{31} = Internal competition factor.[*]

M_{32} = External competition factor.[+]

D_1 = Distance from Fort Wayne to the attracting community.

D_2 = Distance from the producing community to Fort Wayne.

D_3 = Distance from the producing community to the competing city.

D_4 = Distance from the center of the producing community to its periphery.

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[*] All-purpose = population; Work = total employment; Shopping = retail sales; Social-recreational = open-space.

[+] Population of the competing city for all models.

TABLE 4

WORK TRIP MODELS, PRODUCED AND ATTRACTED

Model No.	Trip Type	Independent Variable Form	Regional Trip Models
17	Produced Work Trip Total Area	$\frac{R_{EW}}{D_J}$	$Y_{PW4} = 5.65 - 10748R_J^* - 1883R_8^* - 64490R_5^*$ $+ 30734C_5^* + 24052R_{10}^* + 01948R_{12}^*$ $+ 20369C_{13}^*$
18	Attracted Work Trip Total Area	$\frac{R_{EW}}{D_J}$	$Y_{J-PW} = 5.01 + 4936R_4^* + R_8^* + 175_{11}^*$ $- 8022R_{13}^* + 2507R_{14}^* + 0.00006R_{93}^*$
19	Produced Work Trip Core Area	$\frac{R_{EW}}{D_J}$	$Y_{PW4} = 4.14 - 6366R_2^* + 3045R_5^* + 6106R_7^*$ $- 2570R_9^* + 16644R_5^* + 21194R_{11}^* + 26616R_{12}^*$ $+ 36362_{13}^*$
20	Attracted Work Trip Core Area	$\frac{R_{EW}}{D_J}$	$Y_{J-PW} = 7.37 + 2118R_2^* + 5061R_5^* + 5640R_7^* - 658_8^*$ $+ 602R_8^* - 0.13R_{10} + 13_{11}^* + 2706_{12}^*$ $- 1555X_{13}^* + 3046R_{14} + 0.0017R_{91}^*$
21	Produced Work Trip Fringe Area	$\frac{R_{EW}}{D_J}$	$Y_{PW4} = 1.49 - 8077R_5^* - 7386R_6^* + 8899R_9^*$ $+ 25433C_8^* + 7290R_{10}^* + 37760R_{11}^*$ $- 22009X_{13}^*$
22	Attracted Work Trip Fringe Area	$\frac{R_{EW}}{D_J}$	$Y_{J-PW} = 26.2 - 8290C_5^* + 3260R1 + 94_7^*$ $- 52488R_8^* + 9631R_{10}^* - 0008R_{18}^*$ $- 3774R_{11}^* - 20870R_{13}^* - 0.0009R_{93}^*$

* Significant at the 5 percent level

TABLE 5

SHOPPING TRIP MODELS, PRODUCED AND ATTRACTED

Model No.	Trip Type	Independent Variable Form	Regional Trip Models
33	Produced Shopping Trip Total Area	$\frac{P_i}{D_i}$	$Y_{Prod} = 7.20 + 3459X_3^* + 1523X_{14} + 3073_{17}$ $- 7985X_{19} - 9534X_{20}^* + 10938X_{23}^* + 7849X_{21}^*$ $- 12323X_{24} + 6451X_{26} + 7746X_{28} - 1303X_{33}^*$
34	Attracted Shopping Trip Total Area	$\frac{\sqrt{P_i}}{D_i}$	$Y_{Prod} = 6.92 + 5452X_{17}^* + 3347X_{31}^*$ $- 12991X_{26}^* - 1619000_{44} - 0.000008_{51}$ $- 0.003173_{33}$
35	Produced Shopping Trip Core Area	$\frac{P_i}{D_i}$	$Y_{Pr-c} = 7.25 + 1000X_3^* + 1125X_{12}^* + 1532_{10}$ $- 1000 sX_{20} - 3140X_{23} - 10045_{45}$ $- 17113X_{24}^* + 39178X_{26} + 9012_{27}$
36	Attracted Shopping Trip Core Area	$\frac{P_i}{D_i}$	$Y_{D-c} = 7.45 + 211X_1^* + 200X_9 - 748X_{14}^* + 9435_{20}$ $- 1292X_{22} + 7780X_{23} + 27185_{24} + 10429_{24}$ $- 3472_{27} - 0.00019_{44}$
37	Produced Shopping Trip Prime Area	$\frac{\sqrt{P_i}}{D_i}$	$Y_{Pr-c} = -1.49 + 5180X_{14}^* + 8451X_{19} - 315X_{16} - 4695_{18}$ $- 8793X_{20} - 7975X_{23} + 6076X_{24} + 5360_{26}$ $+ 3992_{27}$
38	Attracted Shopping Trip Prime Area	$\frac{P_i}{D_i}$	$Y_{D-c} = 0.44 + 1022X_{14}^* + 7110X_{16}^* + 69555_{20}$ $+ 3419X_{21} - 38979X_{23} + 3967X_{24}$ $- 7982X_{26} - 0.000089_{38}$

* Significant at the 5% confidence level

TABLE 6

SOCIAL-RECREATIONAL TRIP MODELS, PRODUCED AND ATTRACTED

Model No.	Trip Type	Independent Variable Form	Regional Trip Models
29	Produced Social-Recreational Trip Total Area	$\dfrac{\sqrt{X}}{N_i}$	$Y_{P_{S-R}} = 7.49 + 4279 X_1^* + 27660 X_{11}^* + 13575 X_{20}^*$ $+ 26278 X_{30}^*$
30	Attracted Social-Recreational Trip Total Area	$\dfrac{X}{N_i}$	$Y_{A_{S-R}} = 1.56 + 172 X_1^* + 16370 X_{11} + 865 X_{14}$ $+ 7935 X_{25}^* + 1046 X_{26}^*$ $- 0.000033 X_{35}$
31	Produced Social-Recreational Trip Core Area	$\dfrac{\sqrt{X}}{N_i}$	$Y_{P_{S-R}} = 7.90 + 2340 X_1^* + 6135 X_{11} + 11355 X_{20}^*$ $+ 13773 X_{25}^* + 1968 X_{30}^*$
32	Attracted Social-Recreational Trip Core Area	$\dfrac{X}{N_i}$	$Y_{A_{S-R}} = 3.58 + 4349 X_1 + 19600 X_{11} + 30420 X_{14}$ $+ 95811 X_{25} - 23618 X_{26}$
33	Produced Social-Recreational Trip Fringe Area	$\dfrac{\sqrt{X}}{N_i}$	$Y_{P_{S-R}} = 0.74 + 46110 X_1^* + 14055 X_{11} + 11480 X_{14}$ $+ 11975 X_{25} + 13617 X_{30}^*$
34	Attracted Social-Recreational Trip Fringe Area	$\dfrac{X}{N_i}$	$Y_{A_{S-R}} = 5.49 + 163 X_1^* + 15651 X_{11} + 4844 X_{14}$ $+ 25862 X_{25}^* + 0.000012 X_{35} - 0.000035 X_{35}$

* Significant at the 5-percent level

TABLE 7
ALL-PURPOSE TRIP MODELS, PRODUCED AND ATTRACTED

Model No.	Trip Type	Independent Variable Form	Regional Trip Model
35	Produced All-Purpose Trip — Total Area	$\dfrac{\sqrt{Y}}{N_i}$	
36	Attracted All-Purpose Trip — Total Area	$\dfrac{Y}{N_i}$	
37	Produced All-Purpose Trip — Core Area	$\dfrac{\sqrt{Y}}{N_i}$	
38	Attracted All-Purpose Trip — Core Area	$\dfrac{Y}{N_i}$	
39	Produced All-Purpose Trip — Fringe Area	$\dfrac{\sqrt{Y}}{N_i}$	
40	Attracted All-Purpose Trip — Fringe Area	$\dfrac{Y}{N_i}$	

* Significant at the 5 percent level

Table 9

Summary statistics of the estimation equations

Trip Type	Independent Variable Form	Coefficient of Correlation	Coefficient of Determination	Standard Error of the Estimate
Attracted Work Trips				
18 Total Area	P_i/D_i^3	0.89	0.78	25.4
20 Core Area	P_i/D_i^2	0.93	0.83	26.1
22 Fringe Area	P_i/D_i^4	0.87	0.76	8.0
Produced Work Trips				
17 Total Area	P_i/D_i^4	0.87	0.76	11.9
19 Core Area	P_i/D_i^3	0.90	0.82	13.6
21 Fringe Area	P_i/D_i^4	0.88	0.77	8.0
Attracted Shopping Trips				
24 Total Area	$\sqrt{P_i}/D_i^2$	0.84	0.70	33.7
26 Core Area	P_i/D_i^2	0.86	0.75	35.4
28 Fringe Area	P_i/D_i^4	0.87	0.76	4.0
Produced Shopping Trips				
23 Total Area	P_i/D_i^3	0.79	0.61	8.5
25 Core Area	P_i/D_i^2	0.77	0.60	7.3
27 Fringe Area	$\sqrt{P_i}/D_i^2$	0.81	0.65	7.5
Attracted Social-Recreational Trips				
30 Total Area	P_i/D_i^3	0.82	0.67	8.0
32 Core Area	P_i/D_i^2	0.86	0.74	8.5
34 Fringe Area	P_i/D_i^2	0.81	0.65	7.1
Produced Social-Recreational Trips				
29 Total Area	$\sqrt{P_i}/D_i^3$	0.86	0.63	11.9
31 Core Area	$\sqrt{P_i}/D_i^2$	0.72	0.52	10.6
33 Fringe Area	$\sqrt{P_i}/D_i^3$	0.95	0.94	8.0
Attracted All-Purpose Trips				
36 Total Area	P_i/D_i^3	0.90	0.81	88.5
38 Core Area	P_i/D_i^4	0.92	0.85	91.2
40 Fringe Area	P_i/D_i^4	0.97	0.94	33.0
Produced All-Purpose Trips				
35 Total Area	$\sqrt{P_i}/D_i^2$	0.87	0.76	65.4
37 Core Area	$\sqrt{P_i}/D_i^3$	0.89	0.79	56.5
39 Fringe Area	$\sqrt{P_i}/D_i^3$	0.96	0.91	33.6

1. Trip purpose.

    a. Work trip models.

    b. Shopping trip models.

    c. Social-recreational trip models.

    d. All-purpose trip models.

2. Travel type.

    a. Produced-trip models.

    b. Attracted-trip models.

3. Area designation.

    a. Total-area models.

    b. Core-area models.

    c. Fringe-area models.

The stratification process was accomplished in three steps. The first step was the separation of work, shopping, and social-recreational trips from the overall trip totals. A fourth set of models, the all-purpose trips, had previously been evolved using the overall totals. The next division involved separating each trip-purpose category into trips produced by Fort Wayne and trips attracted to Fort Wayne. The final activity involved the subdivision of the total study region into the core area, which is that portion of the study region primarily under the influence of Fort Wayne, and the fringe area, which includes the area of the study region under the influence of the competing cities.

Trip Purpose

Separate trip purpose models were developed for work, shopping, social-recreational, and all-purpose trips because the mass variables of a community vary with the type of trip interchange. For example, the work and shopping trip models are composed primarily of employment totals and sales totals, respectively. In the social-recreational trip models, population and recreational open-space are used to describe those forces which produce social recreation. Commercial recreation forces, on the other hand, are represented by retail sales totals and employment in eating and drinking places. The all-purpose trip models differ from the specific purpose models because they predict trips in general. As a result, variables were included to describe the combined generation of work, shopping, and social-recreational travel. Employment in public administration, sales by automotive dealers, and acres of recreational open-space are some of the influencing measures that describe work, shopping, and social-recreational trip linkages respectively, in the all-purpose model.

In general, the work and all-purpose trip models had higher correlations with the produced and attracted trip data than did the shopping and social-recreational trip models. The lower correlations are partially explained by the difficulty of choosing variables to represent those forces that generate shopping trips and especially social-recreational trips.

Six models were evolved for each trip category to ascertain the best method of stratifying the trip data. No two models within a specific

trip category contained exactly the same composite variables. The work trip models, numbers 17 to 22, show only one constant mass variable, employment in public administration, and the form of the composite variable was dissimilar from one model to another. This pattern was also evident for the other trip-purpose categories.

While population has been used to describe the attractive and productive forces of a community in many previous studies, an inspection of the 24 estimation models reveals that the composite variables which contain population, X_1, are present in only 13 situations. When variables which are more closely associated with the forces producing and attracting trips, such as employment and sales totals, are used, population no longer remains highly significant as a measure of travel potential. Eight of these 13 instances include the six social-recreational models, numbers 29 to 34, and the two all-purpose models for the fringe area, numbers 39 and 40. Population serves as a measure of social recreation, the visiting of friends and relatives, in the social-recreational models 29 to 34 and in the all-purpose models 39 and 40 for the fringe area.

Travel Type

The forces responsible for produced and attracted trips are fundamentally different. This finding is evidenced in the different forms of the composite variables in the produced and attracted shopping, social-recreational, and all-purpose trip models, equations 23 through 40. For example, the core-area social-recreational produced trip model has the variable form $\sqrt{M/D^2}$, while the corresponding model for attracted trips has the form M/D^4. This pattern of differences is evident in the travel

type pairs for other trip purposes.

The change in the composite variable form in the produced or attracted models was not the only difference observed. In one equation a specific variable serves as a generator of trips, and in another equation this same variable acts as a competition factor. This dual role was observed in variable X_{18}, which is negative (competition factor) in equation 27 and positive (trip generator) in equation 28, and in variable X_{27}, which is positive (trip generator) in equation 27 and negative (competition factor) in equation 28.

The theory of competition was included in the models of this investigation. Internal competition is defined as the ability of a community to satisfy the wants and needs of the residents within its own boundaries. On the other hand, external competition is defined as the ability of major cities within the region to vie with each other and with the central city for the opportunity to serve the people in the trip producing community. Internal and external competition factors, represented by variables X_{31} and X_{32}, respectively, were included in the attracted trip models. The reasons for not including these explicit factors in the produced trip models are that internal competition is a constant term and external competition is incorporated within the variables of the basic model. The inclusion of these explicit factors made it possible to study the precise role of intercommunity competition in regional traffic interchange.

Internal competition was significant at the 5-percent level in eight of the 12 attracted trip models. The four equations in which this factor was not significant were total-area work trips, total-and fringe-area shopping trips, and core-area all-purpose trips, models 18, 24, 28, and 38,

respectively.

External competition was not expected to be significant in the four core area models. Only the four total region and and the four fringe area models remained for consideration. Five of these eight models did contain the explicit external competition factor. All-purpose models, numbers 36 and 40, lacked the explicit external competition factor. This evaluation suggests that population alone is not capable of describing external competition in the all-purpose category.

Area Designation

The final step of subdividing the total study region into core and fringe areas was necessary because trips originating in either the core or the fringe area are basically different. The core and fringe trip models provided better estimations of travel interchange than did the models developed for the total area alone. This separation of the study region improved predictions for both trips produced by Fort Wayne and trips attracted to Fort Wayne. For example, the produced all-purpose trip models have correlation coefficients of 0.87, 0.89, and 0.96 for the total, core, and fringe areas, respectively. The coefficients of correlation increased because the core and fringe division created two sub-groups of trips, each of which was more homogeneous than the original larger group.

The creation of these two areas revealed that a variable may affect travel differently as the distance between origin and destination changes. The composite variable X_{13} is positive (trip generator) in equation 38 for

attracted core-area all-purpose trips and negative (competition factor) in equation 40 for attracted fringe area all-purpose trips. In the same equations, composite variable X_{25} is negative (competition factor) for the core area and positive (trip generator) in the fringe area. This comparison again demonstrates that the same variables may act as a trip generator in one model and as an internal competition factor in another.

Internal competition was evident in both the core and fringe areas. Explicit internal competition factors were included in core area models 20, 26, and 32 and fringe area models 22, 34, and 40. A city located in either the core or fringe area of the central city is capable of satisfying some needs of its residents.

External competition, on the other hand, was not expected to be significant within the core area. An inspection of these models reveals the absence of this factor from all the core models, equations 20, 26, 32, and 38. Communities located in the core area are primarily under the influence of Fort Wayne, and no other city exerts as much influence within this area.

The explicit factor for external competition appears in two of the four fringe area attracted trip models. The all-purpose model for the fringe area, model 40, and the work model for the fringe area, model 22, did not contain this external competition factor. Again, population can not always be effectively used as a substitute for a specific purpose variable in a specific purpose model.

Although the effect of distance on travel generation differed between trip purpose and travel type, a pattern was not obvious until models were developed for the core and fringe areas. In general, the work and shopping

trip models had higher exponents for distance in the fringe area than in the core area. The exponent of distance remained constant in both core and fringe areas for the social-recreational and all-purpose models. Evidently, the increase in distance that a person must travel to make a work or shopping trip from or to the fringe area has a greater influence on travel. Normally, work and shopping needs can be satisfied relatively near a person's home, and the influence of distance is quite pronounced. However, for social recreational and all-purpose trips, distance exerts similar influence on both the core and fringe area trips. This result seems reasonable because these two trip categories, especially social-recreational, contain very specific destinations regardless of the distance that must be traveled.

Comparative Results

The results of this study partially verify an investigation by G. W. Greenwood at the University of Illinois.(4) This previous study developed models for eight trip categories but reported only all-purpose models for the total, core, and fringe areas. The produced trip models contain the composite variable form of $\sqrt{M/D^2}$. The corresponding models in the present study display the same form for the total and core areas, but the fringe area model has $\sqrt{M/D^3}$ as its composite variable form. In comparing the attracted trip models, the mass variables are the same for the total and core areas in both studies, but the exponent of distance differed in all three equations.

Greenwood also included explicit internal and external competition factors in his attracted trip models. This study confirms his conclusions that external competition was not significant in the core area and that internal competition was significant in the total, core and fringe areas. While Greenwood used population as the basic variable to predict travel interchange, the results of the present study suggest that population is less important as the measure of the generating force than other variables more closely associated to trip purpose.

CONCLUSIONS

The results of this investigation are given as mathematical models which represent the relationships between community statistics and regional trip interchange. The following list summarizes results that are strictly valid for the region surrounding Fort Wayne, Indiana. However, these models serve as the basis for developing similar generation and distribution models in other parts of the country.

1. Multiple linear regression equations, composed of composite variables of a gravitational form, provided satisfactory results in this investigation. The magnitude of the coefficients of determination ranged from 0.43 to 0.94. Thus, the type and form of the independent variables accounted for a large percentage of the variation in the regional travel patterns.

2. Produced and attracted trips are fundamentally different in nature and require separate equations for their explanation.

3. Internal competition is significant for the total, core, and fringe area.

4. External competition is significant for the total and fringe areas.

5. The influence of mass and distance on the interchange of regional travel varies with trip purpose (work, shopping, social-recreational, and all-purpose), with travel types (produced and attracted), and with area designation (core, fringe, and total).

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