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APPLICATION OF GRAVITY AND INTERVENING OPPORTUNITIES MODELS TO RECREATIONAL TRAVEL IN KENTUCKY

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INTRODUCTION

Weekend outdoor recreational travel has a major impact on the highway network in Kentucky. Data from a previous study *(1)* indicate that the number of people visiting 42 typical Kentucky outdoor recreation areas on an average summer Sunday in 1970 was approximately 260,000. Most of these 42 areas, by virtue of their outdoor nature, are located in rural settings. Most have access to major arterial highways only by means of narrow, low standard rural roads. Traffic generated by the recreation areas and their associated developments severely strains these secondary access highways and places a significant additional load on the rural arterial network.

Construction of man-made lakes often inundates a portion of the highway network. It has been the policy of federal and state agencies to reconstruct these displaced highways to the same standards as the original facilities. However, increased traffic due to development of the area for recreational purposes often renders the old standards inadequate. In addition, development of even non-water-based areas sometimes necessitates construction of new access roads. Too often these roads are constructed to handle an insufficient volume of traffic either because of funding limitations or because of an inadequate assessment of travel demands and characteristics.

The purpose of this study was the development of a method for modeling Kentucky's outdoor recreational travel (APPENDIX I contains an outline of the major phases of the study). This information can be used for predicting future travel patterns which allows intelligent planning of highway facilities to accomodate traffic generated by future outdoor recreation developments. As such, this study represents an extension of analyses completed earlier by Pigman *(1)*. It utilizes the same data base but concentrates on the application of gravity and intervening opportunities models to Kentucky's outdoor recreational travel.

LITERATURE REVIEW

Travel Modeling

Travel modeling is a relatively new art. Development of traffic generators and the transportation network which connects these generators has historically occurred in a somewhat haphazard and unstructured manner. This lack of comprehensive planning has often resulted in development of a transportation network which largely fails to meet needs of an increasingly mobile and affluent society. In recent years, those professionally concerned with transportation development, those who must commute to work, and even those who drive their automobiles only for pleasure have realized a need for more effective transportation planning. To evaluate and correct deficiencies of our existing system requires planning; planning which covers not only neighborhoods, cities, counties, or even states, but also the whole nation.

Travel modeling is a necessary component of comprehensive transportation planning. It represents an attempt to simulate and/or predict the number of trips that are made, where they begin and end, and on which routes they are made. Most travel models consist of four distinct phases: generation, distribution, assignment, and modal split. Determination of the number of trips beginning and ending in each zone (the study area is divided into zones) is trip generation. Determination of the number of trips from each origin zone which terminate in each destination zone is trip distribution. Determination of the route of travel is trip assignment. Modal split is the determination of mode of travel, that is, whether the tripmaker travels by automobile, rail, bus, air or other mode.

The first step in developing a travel model is to inventory and simulate existing travel patterns. This requires identification of factors and cause-effect relationships between the factors and resulting travel. If the factors and the cause-effect relationships are found and can satisfactorily simulate existing travel patterns, future travel patterns can be predicted if changes in factors and relationships over time can be estimated.

The first comprehensive travel modeling efforts were made in the 1950's in conjunction with studies of travel within large metropolitan areas. Since then, these early methods have been adapted to other kinds of travel flow. Various agencies have since altered the early methods and in addition have developed totally new methods of travel modeling. Besides the increasing requirement for accurate travel modeling, it is probably the advent of the high speed digital computer that has most encouraged the growth of the art. The volume of data to be processed and analyzed in even a small study makes use of modern computers mandatory. The present widespread availability of the computer now allows the efficient and economical study and development of travel models.

Outdoor Recreational Travel Modeling

Although most of the early development of travel modeling took place in an urban context, the concepts have since been satisfactorily applied to other situations. A large percentage of trips within the urban area are to and from work. Work trips are particularly amenable to simulation since in many instances the number of work trips is almost directly proportional to the number of persons employed. Simulation of other trip types, such as shopping trips or school trips, is somewhat more difficult but is still possible through correlations with available socio-economic data. A major factor influencing urban travel is, therefore, land use. Distances over which trips are made in urban areas are relatively short. The survey area is coterminus with the geographic bounds of the metropolitan area. Availability of data and information is usually considered to be acceptable. Sampling techniques have been developed to allow the planner to gather a large amount of reliable data about the area of interest.

Study of outdoor recreational travel is somewhat different. Reasons for outdoor recreational travel are more obscure. Trips to and from work are an economic necessity; recreational trips are not. Furthermore, individual preferences for different types of recreational activity are difficult to assess. In an urban area, a destination zone will attract work trips in proportion to the number of available jobs. But a recreational area has no such absolute measure of attractiveness. Furthermore, it is almost impossible to quantify the number of persons that a park may accomodate at any one time, that is, its capacity. An outdoor recreation study is often concerned with much larger areas than an urban study. Recreational trip distances may vary from less than one mile to several thousand miles. Unlike an urban study, the outdoor recreation study may require socio-economic data for every state in the nation. An urban study usually divides the survey area into zones of near homogeneous nature. But the outdoor recreation study usually must establish zones along political boundaries because of the way data is compiled (by state, county, etc.) even though the characteristics within the zone can be highly variable. Outdoor recreational travel models in general do not need to consider modal split. Almost all travel to and from these areas is by automobile. The use of automobiles is necessitated not only by the convenience of the automobile (mobility within the park, towing boats and trailers, etc.) but also by the unavailability of other modes of travel to and from recreational areas.

It thus becomes clear that, although the techniques of urban travel modeling are useful for outdoor recreational travel modeling, the problems are by nature different. Study of outdoor recreational travel must determine a cause-effect relationship quantifying: (1) those factors that give residents of an origin zone a propensity for outdoor recreational travel, (2) the cost of such travel (quite often expressed as distance), and (3) those characteristics of an outdoor recreational area which attract visitors. The resulting travel model must be reasonable, must adequately simulate present travel, and must be adaptable to predicting future travel. Simplicity and ease of use are also desirable.

Some modeling efforts stratify trips as to purpose. These models attempt to determine the number of trips for purposes of swimming, boating, camping, etc. for each origin zone. Likewise attempts are made to determine the number of each different type of trip that each recreational area will attract. Trips are distributed according to trip purpose. Although in some instances this method can be useful, the additional work required for such a model was not judged to be warranted in this study of Kentucky's outdoor recreational travel.

Single Equation Models

In many respects, the single equation model is the one that is most easily understood. These models relate the number of trips between each origin zone and each recreation area to various independent variables by means of a single, explicit equation.

Tussey is among those reporting some success with single equation models *(2)*. The model he applied in a simulation of flow to two Kentucky reservoirs was of the following form (see APPENDIX II for a listing of symbols and notation):

$$T_{ij} = a\ POP_i/D_{ij}^{\ b} \qquad (1)$$

where T_{ij} = number of trips from origin i to destination j,
a,b = empirically derived constants,
POP_i = population of origin zone i, and
D_{ij} = distance from i to j.

In a study of travel to multipurpose reservoirs in Indiana, Matthias and Grecco *(3)* found the following model to give satisfactory results:

$$T_{ij} = POP_i \exp\ (-bD_{ij}) \qquad (2)$$

where exp = exponential function. Two calibrations of Equation 2 were performed, one for flows in which there was no intervening reservoir between the zone of origin i and the recreation area j, and the other for flows in which an intervening reservoir was present. Like Tussey, Matthias and Grecco reported rather favorable results with their simulations.

In his study of travel to 42 recreational areas of Kentucky, Pigman *(1)* investigated a number of linear and nonlinear single equation models, including those of Equations 1 and 2. He was unable to achieve with any equation the accuracies previously reported by Tussey and by Matthias and Grecco but did conclude that Tussey's model was the most appropriate among those investigated. Pigman's work was more comprehensive than most prior analyses in that he considered a wide variety of types of recreational areas as well as origin zones throughout the continental United States. In addition, he attempted to add to the single equation models a measure of the attractiveness of the recreational areas.

Cross-Classification Models

Cross-classification is a useful method both for travel modeling and for analyzing trip data in the development of other models. In essence, a cross-classification model provides a discontinuous function for simulating trip interchanges.

Pigman *(1)* constructed a cross-classification model of Kentucky's outdoor recreational travel. Trip interchanges (the number of trips from each origin zone i destined to each recreation area j) in trips per thousand population of the origin zones were stratified by population of the origin zone, distance, and attractiveness of the recreation area. Linear multiple regression analysis was used to develop an equation for estimating the attractiveness of each recreation area (see APPENDIX III for a note on statistics and regression analysis). An average value of trips per thousand population was computed for each cell of the cross-classification matrix. The model was used to simulate the 1970 trip interchanges, which were compared to the actual Origin and Destination (O&D) survey data yielding a squared correlation coefficient of (R^2) of 0.69. The model can be used to predict future trip interchanges by entering the cross-classification table with future distances, attractions, and populations.

A cross-classification model is easy to construct and calibrate from an O&D survey. However, results are not always reasonable. For example, in some cases trips per person decrease, then increase, and again decrease as distance increases. In addition, some cells of the matrix can not be filled from calibration data. If for example, there is no present trip interchange with attractiveness of 100, population of 3,000, and distance of 500 miles, then no value of trips per person for that situation can be computed. In the future, there may be such a trip interchange, but the only means of computing the trip interchange would be by interpolation. Nevertheless, cross-classification is a valuable tool in travel modeling and may be useful in many studies.

Trip Generation

Several distribution models, including factor, gravity, and opportunities models, require as input the number of trips produced at each origin zone (productions) and the number of trips attracted to each destination area (attractions). This phase of travel modeling is termed trip generation. The object of trip generation is to quantify factors which may cause travel in order to allow accurate estimates of attractions and productions.

Pigman *(1)* listed many of those factors which may influence demand for outdoor recreational travel. These factors are classified into five major categories: (1) participant or origin area characteristics, (2) recreation area characteristics, (3) price of recreational experience, (4) time characteristics, and (5) miscellaneous characteristics. From this list, a limited number of variables may be chosen for analysis.

Other studies of outdoor recreational travel have identified several factors particularly useful in estimating productions of an origin zone. Most studies have developed a technique of estimating productions using a multiple regression analysis. Schulman *(4)* noted, as suggested by Wilbur Smith and Associates *(5)*, that on the average there is one socio-recreational trip per dwelling unit per day. However, Schulman did not verify this relationship or develop an equation for productions using this information. Milstein and Reid *(6)* found in a study of outdoor recreational demand in Michigan that population, family income, age, sex, education, race and place of residence were good indicators of recreational demand. From these factors, participation rates were developed to estimate the number of productions from each origin zone. Smith and Landman *(7)* made similar estimates of productions in a study of travel to reservoirs in Kansas using median age, median family income, retail sales, urban population, and a measure of nearness to attractive recreation areas (accessibility). Gyamfi *(8)* found population and accessibility to be adequate indicators of productions to national forests in California. In summary, factors used to estimate productions of an origin zone in studies of outdoor recreational travel can be classed into four categories: (1) measures of population, (2) characteristics of the population, (3) characteristics of the origin zone (land use, etc.), and (4) accessibility of the origin zone to outdoor recreation areas. To determine the relationship between these factors and trip productions, an O&D or participation rate survey is needed. Regression analysis (linear and nonlinear) appears to be the most useful and popular means of analysis.

Factors used in estimating the attractions of an outdoor recreation area are those which describe facilities of the area. In addition, some studies have shown that nearness to population centers is an important factor influencing attractions. As in the estimation of productions, development of a method for estimating attractions usually involves a multiple regression analysis (linear and nonlinear).

Smith and Landman *(7)*, in their study of federal reservoirs in Kansas, were able to estimate attractions from the number of picnic grills, lake area, access road quality, and population within 100 miles. Milstein and Reid *(6)* developed a method of estimating attractions from a very comprehensive analysis of outdoor recreation areas in Michigan. The Michigan study examined an extremely large number of park facilities too numerous to list in this paper and obtained excellent results. Schulman *(4)* found that a linear equation involving the following factors could be used to estimate attractions to Indiana outdoor recreation areas with good accuracy: (1) number of picnic tables, (2) number of campsites, (3) lake area, (4) acres of the park extensively developed, (5) availability of a bath house, (6) capacity of living facilities, (7) availability of fishing, (8) accessibility to a river, (9) availability of electricity, and (10) population within 60 miles. It may be noted that some variables were dichotomous; either they were available or not. Pigman *(1)* found that a linear equation involving the following factors was useful in estimating attractions of Kentucky's outdoor recreation areas: (1) number of golf holes, (2) number of picnic tables, (3) number of overnight accomodations, (4) number of drama seats, (5) miles of hiking trails, (6) miles of horseback trails, (7) lineal feet of beach, (8) square feet of swimming pools, and (9) water acreage. This method appeared to be quite satisfactory.

Multiple regression analysis seems to be the best way of establishing relationships between previously mentioned factors and either attractions or productions. However, in such an analysis one must guard against illogical results. Often a regression analysis involving numerous independent variables yields false or illogical results. For example, in a linear equation for estimating attractions, all terms containing attractive factors must have positive coefficients. In addition, a judgement must be made whether some area facilities (such as picnic tables) are a cause or result of attractiveness. A cause-effect relationship must exist.

Growth Factor Models

Growth factor models are predicated on the premise that present traffic patterns can be projected to future years by the application of multiplicative growth factors *(9)*. There are several growth factor methods which have been used for urban travel modeling.

The simplest of these is the uniform factor method. This model assumes that travel within the study area will increase uniformly. However, there is seldom a realistic basis for this assumption and the model often yields poor results *(9)*. Stated mathematically,

$$T_{ij} = t_{ij}F \qquad (3)$$

where T_{ij} = future trips between zones i and j,

t_{ij} = present trips between zones i and j, and

F = growth factor of the study area.

The average factor method tries to account for differential growth of zones in the study area *(9, 10)*. Stated mathematically,

$$T_{ij} = t_{ij}(F_i + F_j)/2 \qquad (4)$$

where F_i = T_i/t_i and $F_j = T_j/t_j$

T_{ij} = calculated future trips between zones i and j,

t_{ij} = present trips between zones i and j,

T_i = estimated future trips originating in zone i,

T_j = estimated future trips ending in zone j,

t_i = present trips originating in zone i,

t_j = present trips ending in zone j, and

F_i and F_j = zonal growth factors.

In applying this model, an iterative process is necessary because estimated future trips (T_i and T_j) will not agree with the sum of calculated trip ends ($\sum_i T_{ij}$ and $\sum_j T_{ij}$). Therefore the following corrections are necessary:

$$F_{i\ (new)} = T_i/\sum_j T_{ij} \qquad (5)$$

$$F_{j\ (new)} = T_j/\sum_i T_{ij} \qquad (6)$$

$$T_{ij\ (new)} = T_{ij}\ (F_{i\ (new)} + F_{j\ (new)})/2. \qquad (7)$$

Equations 5, 6, and 7, are repeated until the new growth factors approach 1.00.

Other growth factor methods which are more sophisticated than either the average or uniform growth factor methods are available. Two of these are the Fratar method *(11)* and the Detroit method *(12)*. However, all involve extension of present travel patterns by application of growth factors.

Growth factor methods, as most other travel models *(13)*, require a comprehensive O&D study. Growth factor methods are especially useful in updating recent O&D survey data. However, they cannot account for substantial changes in land use patterns or in the transportation network. Growth factor models are particularly weak in projecting small volumes of current traffic. It is likely that growth factor methods would be useful in modeling Kentucky's outdoor recreational travel; but if a new park or reservoir were constructed, the growth factor methods would lose their usefulness.

Gravity Models

Perhaps the most widely used trip distribution model is the gravity model. Newton postulated in the 17th century that the gravitational force acting between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between the centers of mass. This concept has since been borrowed for use in many models which simulate various other types of interaction. In his brief history of the gravity model, Schulman *(4)* indicated that the gravity concept has been used in many disciplines ranging from sociology to marketing. Voorhees *(14)* made the first serious application of the gravity concept to travel modeling in 1955.

A simple gravity model for predicting trip interchanges may be stated as follows:

$$T_{ij} = k\ P_i A_j / D_{ij}^{\ c} \qquad (8)$$

where T_{ij} = trips between zone i and zone j,

k,c = empirically determined constants,

P_i = measure of trips produced by zone i,

A_j = measure of trips attracted by zone j, and

D_{ij} = measure of resistance of travel between zone i and zone j.

In a study of intercity travel, P_i and A_j may simply be populations of cities i and j while D_{ij} may be the distance or travel time between the two cities. In an urban study of work trips, P_i may be the population of zone i and A_j may be the number of jobs available at zone j while D_{ij} may be travel time from zone i to zone j. In another instance, P_i may be trip productions at zone i and A_j may be the trip attractions at zone j. The quantity D_{ij}, being a measure of resistance to travel or travel cost, is most often represented by travel time or travel distance.

It is obvious that, unless there is some storage of trips enroute, the total number of trips in a system ($\sum_i \sum_j T_{ij}$) must equal the number of trips produced by all origin zones ($\sum_i P_i$), which in turn must equal the number of trips attracted to all destination areas ($\sum_j A_j$). The gravity model of Equation 8 does not guarantee that these requirements are satisfied. To help solve this problem and to eliminate the necessity of determining the value of k, the Bureau of Public Roads (now Federal Highway

Administration) *(15)* suggests the following gravity model form:

$$T_{ij} = (P_iA_j/D_{ij}^c)/ (\sum_j A_j/D_{ij}^c) \tag{9}$$

where T_{ij} = trips between zone i and zone j,
D_{ij} = distance between zone i and zone j,
c = empirically determined constant,
P_i = trips produced at zone i, and
A_j = trips attracted to zone j.

It is obvious that $(A_j/D_{ij}^c)/ (\sum_j A_j/D_{ij}^c)$ is merely a fraction which, when summed over all j, is equal to unity for each origin zone i. This form of the gravity model guarantees that the total number of trips in the system is equal to the sum of all trips produced by the origin zones. Attractions must then be adjusted so that $\sum_i T_{ij} = A_j$. The adjustment of attractions will be explained in a subsequent discussion of the calibration of the gravity model.

The above gravity model assumes that resistance to travel can be expressed as a function of some constant power of distance or travel time. However, there is no assurance that this is necessarily true. To avoid reliance on such an arbitrarily chosen function, the Bureau of Public Roads *(15)* further suggests that the resistance to travel be expressed with "F" factors, representing a monotonically decreasing function of distance which are numerically determined as explained in a subsequent discussion of the calibration of the gravity model. The "F" factor form of the gravity model is

$$T_{ij} = P_iA_jF_{ij}/\sum_j A_jF_{ij} \tag{10}$$

where F_{ij} = "F" factor corresponding to the distance from i to j. This model form also requires the adjustment of attractions.

Electrostatic Model

Howe *(16)* created an electostatic model for distributing home-to-work trips. The model is essentially a gravity model and is based on a number of rigid theoretical considerations. The model may be stated as

$$T_{ij} = (W_iR_j/D_{ij})/ (\sum_j R_j/D_{ij}) \tag{11}$$

where T_{ij} = number of workers living in zone i making a work trip to a job in zone j,
W_i = number of workers residing in zone i,
R_j = number of jobs available in zone j, and
D_{ij} = airline distance from zone i to zone j.

The model requires trip-end balancing so that the number of trips sent to each zone is equal to the number of jobs in the zone.

The author considers the electrostatic model to be an inflexible gravity model much like the form of Equation 9 with the constant c equal to unity. Howe required a closed system (no trips originating outside of the study area), which often occurs in the urban situations in which the model has been applied. However, the model has not been adapted to an open system which exists in outdoor recreation. Perhaps the model's single advantage is its simplicity, not requiring an extensive O&D survey.

Opportunities Models

The intervening opportunities model was developed during the Chicago Area Transportation Study *(17)*. This model, like the gravity model, is used to distribute known or estimated attractions and productions.

The intervening opportunities model is based on the concept that a tripmaker prefers to keep a trip as short as possible *(9)*. Trip length is governed by the probability of ending the trip at the nearest destination. But a tripmaker's purpose is not always satisfied at the nearest destination. If the nearest destination does not satisfy the tripmaker's needs, the next nearest destination must be considered, and so on until the tripmaker reaches a satisfactory destination *(17)*. The model distributes trips so that the probability of a trip ending at a destination area is equal to the probability that a trip-satisfying destination is located within the destination area times the probability that an acceptable destination has not been found in all other destination areas closer to the trip origin.

When the problem is stated in limiting small quantities and the differential equation is solved *(17)*, the following results:

$$T_{ij} = P_i[\exp(-LA) - \exp(-L\{A + A_j\})] \qquad (12)$$

where T_{ij} = trips between zone i and zone j,
$\exp$ = exponential function,
P_i = productions of origin zone i,
A_j = attractions of destination zone j,
A = sum of all attractions of zones closer to i than j, and
L = probability that a random destination will satisfy the trip purpose.

It may be seen that the only use of travel cost (time, distance, etc.) is to order destinations in such a way as to enable computation of A.

This model has given good results in the Chicago study. It does have, however, a problem in distributing trips originating from trip generators of greatly different sizes (see "Intervening Opportunities Model, Calibration").

Tomazinis *(18)* developed a competing opportunities model for the Pennsylvania- New Jersey

Transportation Study. This model is based on an application of probability and set theory to transportation modeling. This model has been applied only to urban travel modeling, but may be worth investigation for application to outdoor recreation travel modeling.

The gravity model distributes trips with respect to distance or some other measure of travel impedence. The intervening opportunities model distributes trips according to a measure of bypassed opportunities. Neither model considers both criteria. However, Sullivan *(19)* postulates that in an area containing a dense pattern of destinations the measure of relative location in the gravity and opportunities models is nearly equivalent. On the other hand, Sullivan found that in the distribution of trips within a national forest there is no proportionality between the travel impedence overcome and the number of potential destinations intercepted, because of the clustering of destinations and topographic irregularities. Therefore, an impedence-dependent opportunity model was developed to distribute trips within national forests. This model relates the probability of stopping at a destination not only to the order in which the destination can be reached but also to the extra travel time which would be incurred in reaching the next destination. The mathematics of this model are beyond the scope of this paper, but the impedence-dependent opportunities model presents interesting possibilities for application to outdoor recreational travel modeling and may be well worth future consideration.

Systems Theory Models

Ellis *(20, 21)* developed a systems theory model. The systems theory model is one of the newest approaches to travel modeling and is based on the laws of flow of fluids or electricity in a network -- the transportation system being analogous to a flow network and the trip generating properties of origin and destination zones being analogous to pressures. The model considers all demands at all origins simultaneously and distributes them to all destinations. Much of the development of the model has been in an outdoor recreational context. Therefore, it should be applicable to outdoor recreational travel in Kentucky.

Conclusions

The literature review revealed that the gravity and intervening opportunities models are the most frequently used travel models. They have been thoroughly investigated and have reached a high state of development. Information concerning the application of the models is readily available, and the models have been applied to outdoor recreational travel. Therefore, the gravity and intervening opportunities model were chosen for application to outdoor recreational travel in Kentucky.

Note: Numbers represent origin zone code.

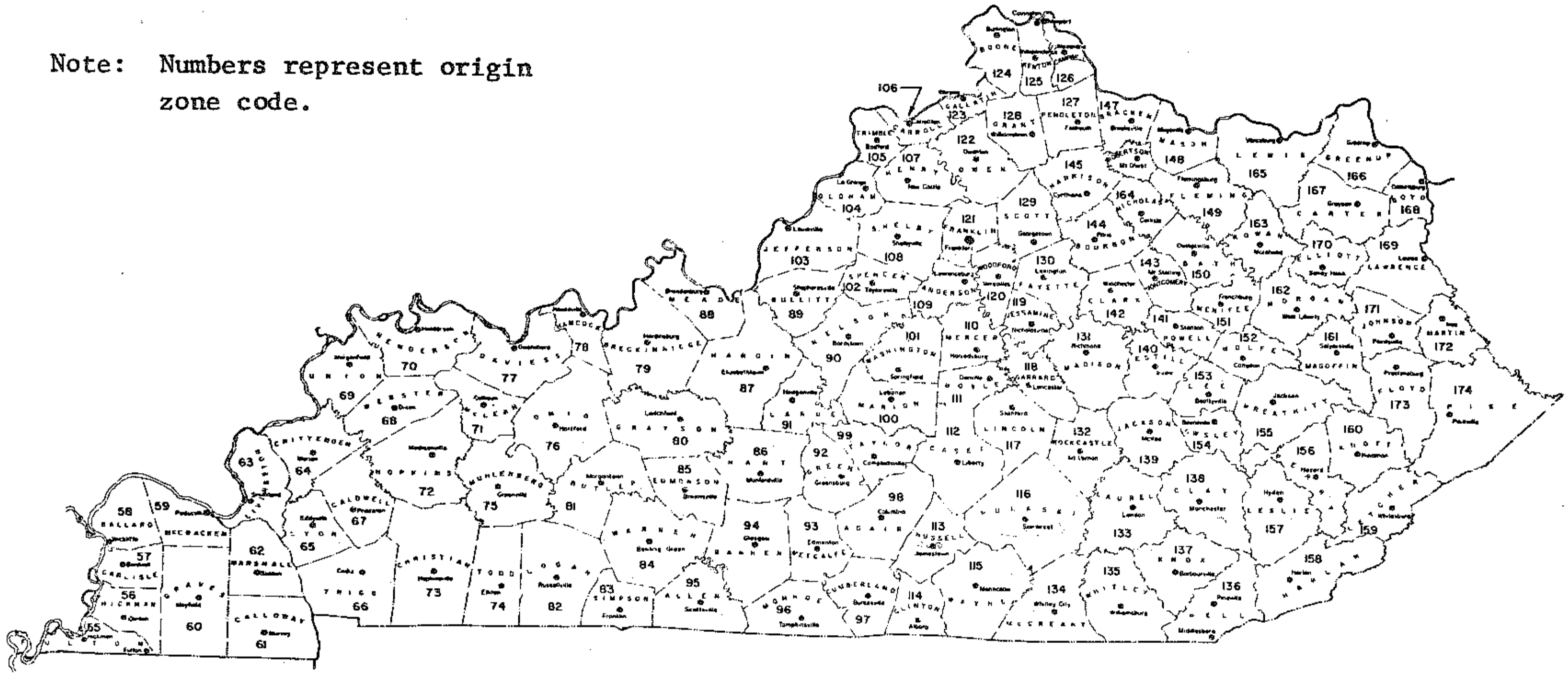

Fig. 1.--Location of Kentucky origin zones

Note: Numbers represent origin zone code.

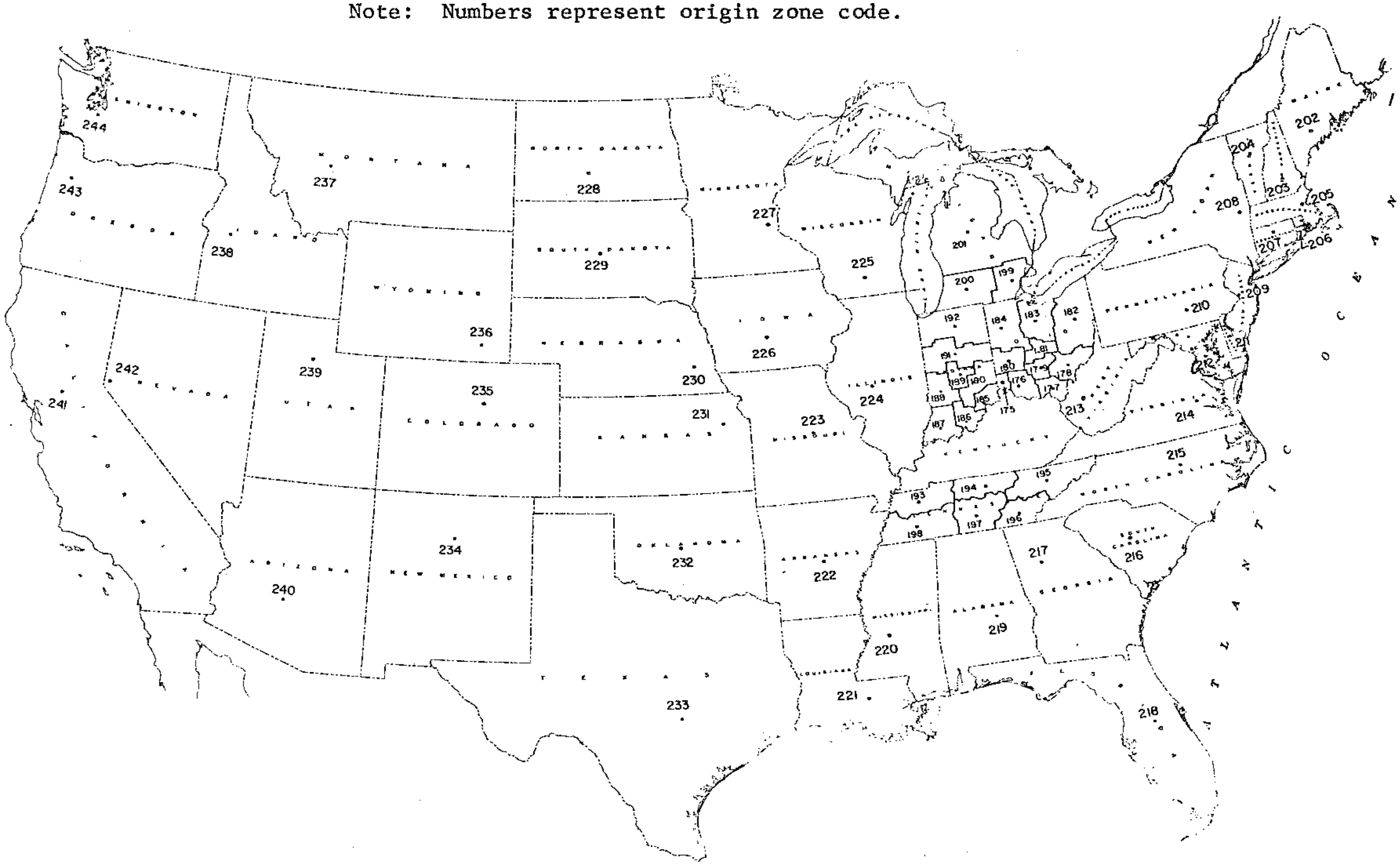

Fig. 2.--Location of out-of-state origin zones

Note: Numbers represent recreation area code.

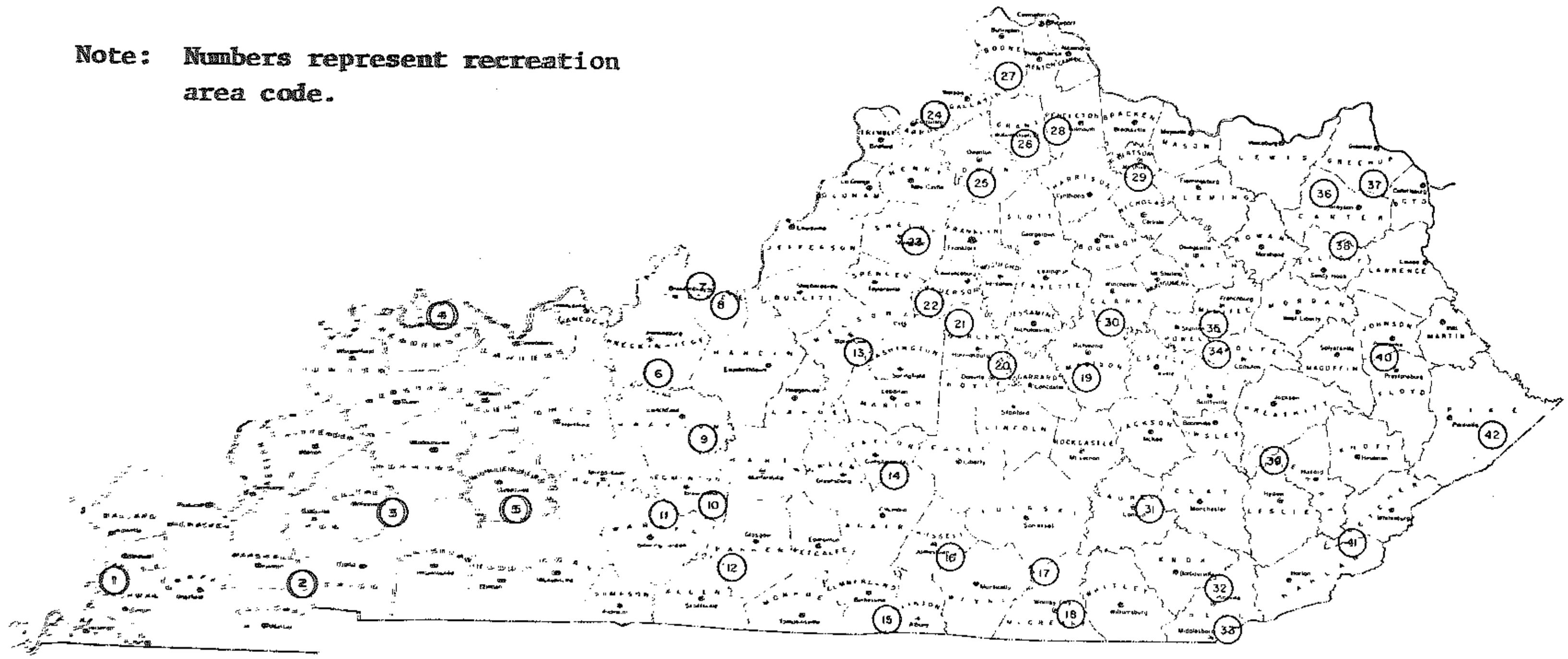

Fig. 3.--Location of outdoor recreation areas

TABLE 1

RECREATION AREA CODES

Code	Area Name	Code	Area Name
1	Columbus Belmont State Park	22	Beaver Lake
2	Kentucky Lake - Barkley Lake	23	Guist Creek Lake
3	Lake Beshear - Pennyrile Forest	24	General Butler State Park
4	Audubon State Park	25	Elmer Davis Lake
5	Lake Malone State Park	26	Lake Boltz
6	Rough River Reservoir	27	Big Bone Lick State Park
7	Doe Valley Lake	28	Williamstown Lake
8	Otter Creek Park	29	Blue Licks Battlefield State Park
9	Nolin Reservoir	30	Fort Boonesboro State Park
10	Mammoth Cave National Park	31	Levi Jackson State Park
11	Shanty Hollow Lake	32	Pine Mountain State Park
12	Barren River Reservoir	33	Cumberland Gap National Park
13	My Old Kentucky Home State Park	34	Natural Bridge State Park
14	Green River Reservoir	35	Sky Bridge and Koomer Ridge
15	Dale Hollow Reservoir	36	Carter Caves State Park
16	Lake Cumberland	37	Greenbo Lake State Park
17	Natural Arch and Rockcastle Areas	38	Grayson Reservoir
18	Cumberland Falls State Park	39	Buckhorn Lake
19	Wilgreen Lake	40	Jenny Wiley State Park
20	Herrington Lake	41	Kingdom Come State Park
21	Old Fort Harrod State Park	42	Fishtrap Reservoir

ESTIMATING PRODUCTIONS

Nature of the Problem

Both the gravity and intervening opportunities models require as input the number of trips produced by each origin zone. Therefore, it is necessary to develop a method for predicting the productions of each origin zone which are destined to Kentucky outdoor recreation areas. Insofar as practical, regularly published data sources (such as the U.S. Census) should be employed to facilitate projections of future travel. This eliminates the need for extensive traffic and socio-economic surveys.

The predictive method must adequately simulate the origin zone productions obtained from the O&D survey, and it must also be able to predict productions at some future time, given the independent variables of the method at the same future time.

Choice of Variables

The literature suggests numerous independent variables which may be useful in predicting origin zone productions. In light of these suggestions and some intuition about this particular situation, the following independent variables which characterize the origin zones were chosen for detailed study: (1) population, (2) motor vehicle registration, (3) number of dwelling units, (4) dwelling units per square mile, (5) effective buying income per household, and (6) accessibility.

Population figures were obtained from the 1970 U.S. Census *(22)*. Future population data may be projected from past trends; such projections are routinely published by various sources allowing their efficient use in travel forecasting. Motor vehicle registration for Kentucky counties was obtained from the Kentucky Department of Highways *(23)*. Motor vehicle registration for the other states was obtained from **Highway Statistics / 1969** *(24)*. The number of dwelling units and the number of dwelling units per square mile were obtained from the **City-County Data Book** *(25)*. These figures may also be projected for future time periods from past trends.

Average effective buying income per household was obtained from a 1970 nationwide survey of buying power *(26)*. Results of similar surveys have been published annually since 1929. Effective buying income is defined as all personal household income minus all taxes, thus reflecting the difference of tax rates in each region. The household unit is defined by the criteria of the U.S. Census.

In addition to these factors, the number of trips produced by an origin zone is dependent on availability of recreation and cost of travel to the recreation areas *(7)*. Accessibility is a term that has been used to reflect the combined effects of recreation availability and travel costs. Gyamfi *(8)* defined accessibility, using distance as a measure of travel cost, as

$$S_i = \sum_j A_j / D_{ij} \qquad (13)$$

where S_i = accessibility of origin zone i to recreation opportunities,

A_j = attractiveness of recreation area j,

D_{ij} = dogleg distance from i to j, and

k = constant.

Other studies use an accessibility term of other forms and consider only the first few destination areas closest to the origin zone *(7)*.

It was intuitively felt that, for the purposes of this study, the accessibility term should include all of the 42 recreation areas rather than just the few closest to the origin zone. Moreover, the gravity model used in this study assumes that the relationship of D_{ij} to travel impedence does not necessarily take the form used by Gyamfi. Rather it expresses the effect of distance by means of "F" factors which correspond to various distance intervals. These "F" factors are derived in the gravity model calibration explained later. Based on the premise that the "F" factors more nearly represent the true effect of distance on travel impedence, the following accessibility term was used in this study:

$$S_i = \sum_j A_j F_{ij} \qquad (14)$$

where S_i = accessibility of origin zone i to recreation opportunities,

A_j = number of trips attracted to recreation area j, and

F_{ij} = "F" factors corresponding to the distance between i and j.

Accessibility for future points in time can be calculated knowing the locations and attractions of all recreation areas at that time.

Calibration

The calibration phase develops a method of simulating known productions obtained from the O&D survey. Three analyses were attempted: (1) regression analysis of productions per capita for each origin zone, (2) cross-classification analysis of productions for each origin zone, and (3) regression analysis of productions of each origin zone. In each case demographic data were used and the attractions of the accessibility term (Equation 14) were the actual attractions obtained from the O&D survey. Preliminary evaluation of these three approaches favored regression analysis of total origin zone productions. Therefore, most of the analysis was concentrated on modeling the number of productions per origin zone.

Two separate estimating equations were developed: one for out-of-state origin zones and one for Kentucky origin zones. Since only Kentucky recreation areas were considered, trip productions to areas outside of Kentucky could not be considered. It is likely that each origin zone will send most of its recreational trips to areas within its own state. Likewise, it is likely that most Kentucky counties send their recreational trips to areas within Kentucky. In addition, the out-of-state production zones are much larger in population and area than the Kentucky counties and consequently are generally of a different nature. Therefore, it is logical to develop separate models for the two different situations.

Linear regression analyses of Kentucky data indicated that population, motor vehicle registration, dwelling units, and dwelling units per square mile were all intercorrelated with multiple correlation coefficients (R) greater than 0.95. Since a regression analysis becomes invalid and the effects of the independent variables become obscured when a high linear correlation exists between independent variables *(27)*, three of these four variables had to be eliminated. Since population was most highly correlated with productions in both Kentucky and out-of-state data, population along with income and accessibility were the independent variables to be further evaluated.

Linear and nonlinear multiple regression analyses were performed on the equations shown in Table 2. These equations were intuitively thought to have the best chance of simulating productions. In light of the poor results obtained for Kentucky productions, it was questioned whether an optimal equation had been examined. Therefore, the following second degree polynomial equation was examined in hope that additional terms would explain a greater proportion of variation:

$$P = a_1 + a_2 POP + a_3 I + a_4 S + a_5 POP(I) + a_6 POP(S) + a_7 I(S) + a_8 (POP)^2 + a_9 (I)^2 + a_{10} (S)^2 \quad (15)$$

where P = productions of a Kentucky origin zone,

POP = population of a Kentucky origin zone,

I = effective buying income per household of a Kentucky origin zone,

S = accessibility of a Kentucky origin zone to recreation areas in Kentucky, and

a_i = constants.

The polynomial equation yielded little increase in accuracy. Thus, the equation

$$P = 803.1 \, (POP)^{1.05} \, (I)^{4.19} \, (S)^{1.03} \quad (16)$$

was used to estimate out-of-state productions, and the equation

$$P = 4050.3 (POP)^{0.93} \, (S)^{0.54} \quad (17)$$

was used to estimate Kentucky productions,

where P = productions of an origin zone,

POP = population of an origin zone (millions of people),

I = effective buying income per household of an origin zone (ten thousands of dollars), and

S = accessibility of an origin zone to Kentucky recreation areas (millions of accessibility units).

TABLE 2

PRODUCTION EQUATIONS INVESTIGATED

Equation[a]	Squared Correlation Coefficient	
	Kentucky	Out of State
$P = a_1 + a_2 POP + a_3 S$	0.67	0.10
$P = a_1 + a_2 POP^{a_3} + a_4 I^{a_5} + a_6 S^{a_7}$	0.71	
$P = a_1 POP^{a_2} I^{a_3} S^{a_4}$	0.71	0.84
$P = (a_1 + a_2 S)^{a_3} (1 - e^{-a_4 POP}) I^{a_5}$	0.74	0.83
$P = a_1 POP^{a_2} S^{a_3}$	0.70	0.71

a
P = productions of an origin zone
POP = population of an origin zone
I = effective buying income per household of an origin zone
S = accessibility of an origin zone to recreation areas
a_i = constants
e = base of natural logarithms

The estimating equations were chosen on the basis of their reasonableness (i.e., an inverse relationship of productions with population would not be reasonable), simplicity (i.e., fewer variables and simple form), and accuracy (R^2). The production equations are illustrated in Figures 4 and 5. The data points on these figures represent O&D survey productions assembled by a cross-classification analysis and are plotted at the midpoints of each cell of the cross-classification matrix. The lines represent Equations 16 and 17. Figures 4 and 5 illustrate that Equations 16 and 17 generally simulate the O&D survey productions but still leave some variability unexplained.

Testing

Calibration is accomplished using the best possible values for the independent variables. However, when using the estimating equations for predictive purposes, such ideal data will not be available. Complete testing of the equations cannot be done at this time because it would be necessary to compare the predicted productions to productions obtained from a future O&D survey.

However, it is possible to test the equations using estimated attractions (see "Estimating Attractions") in the accessibility term, indicating the error due to the limitations of the attraction estimating process (estimated attractions must be used in prediction). The equations when tested yielded a squared correlation coefficient (R^2) of 0.81 for out-of-state origin zones and a squared correlation coefficient of 0.68 for Kentucky origin zones, indicating that little accuracy is lost when using estimated attractions instead of actual attractions in the accessibility term.

Prediction

The calibrated equations can be used to predict the productions of each origin zone at some future time provided valid projections are available of future population and income. Accessibility, too, may change with time by the addition or elimination of recreation areas or by a change in predicted attractions to each recreation area. Therefore, new accessibility terms must be calculated using the future number of recreation areas, their distances to each origin zone, and projected attractions of each recreation area. Predictions of future productions are, therefore, sensitive not only to the evolving nature of the origin zones but also to changes in the nature of the recreation and highway systems. In addition, there will be a future increase in per capita recreational travel due to such things as increased leisure time. Equations 16 and 17, combined with projections of future per capita recreational travel *(28)*, enable suitable predictions of future productions.

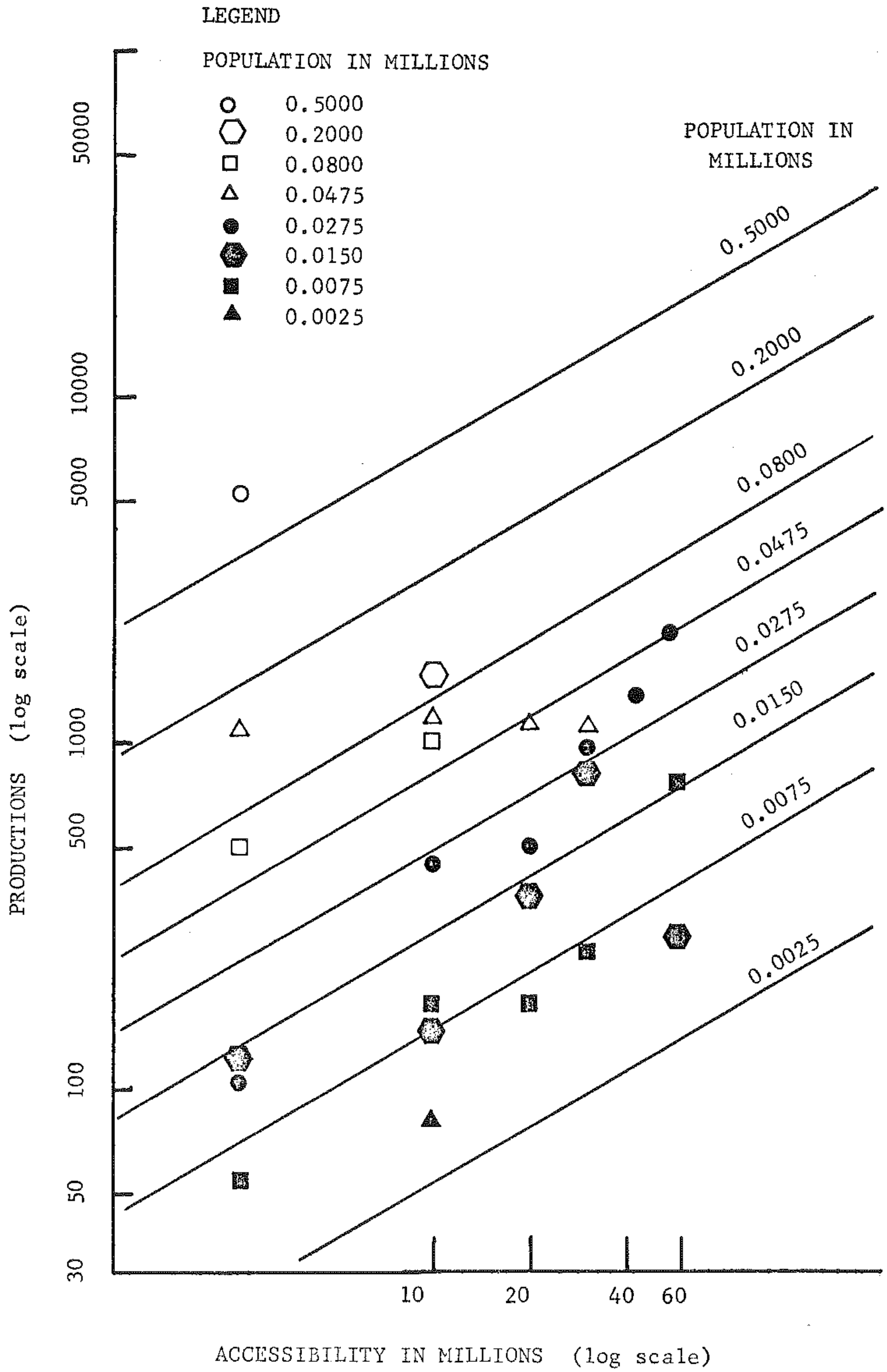

Fig. 4.--Kentucky production equation

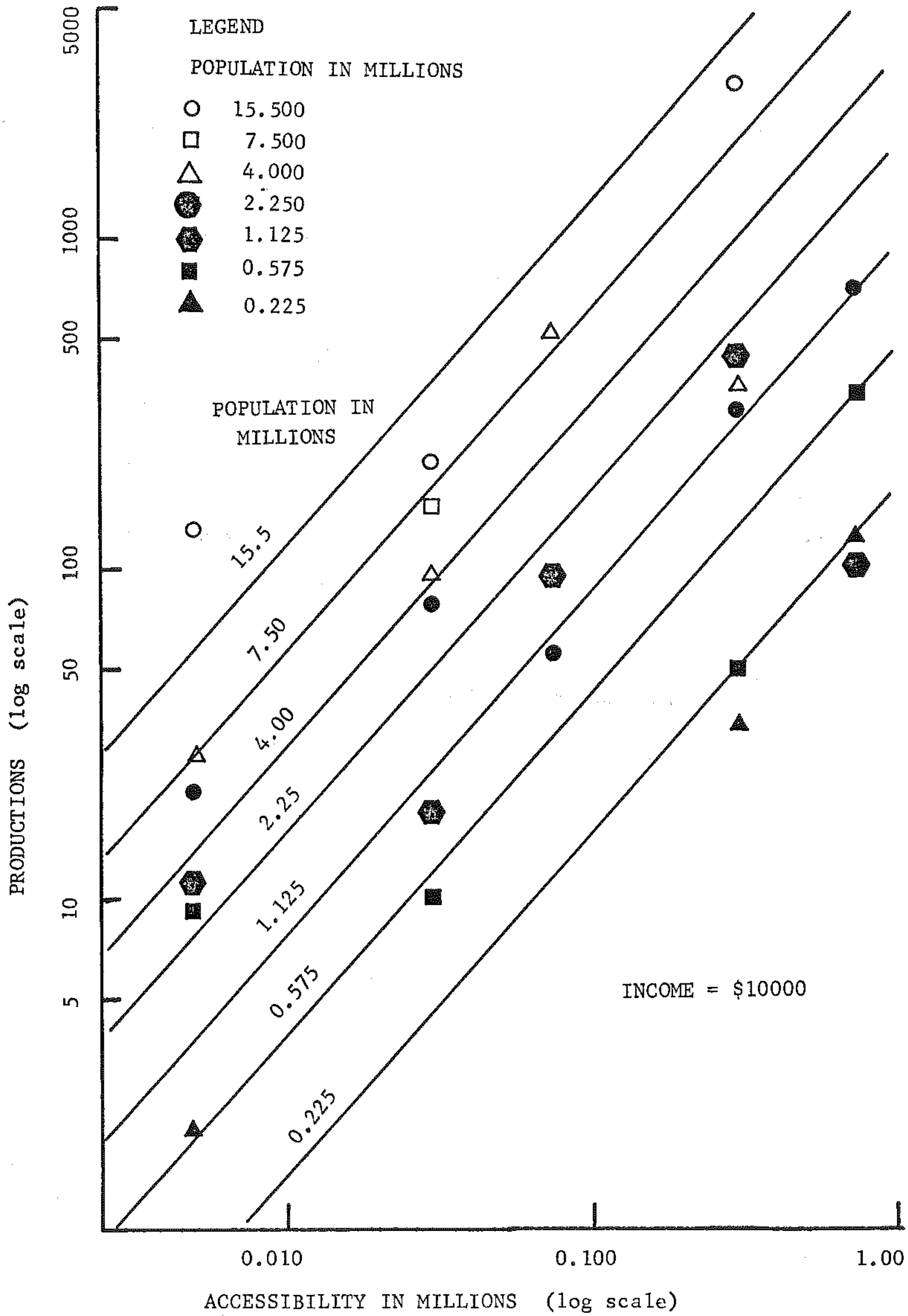

Fig. 5.--Out-of-state production equation

ESTIMATING ATTRACTIONS

Nature of the Problem

Both the gravity and intervening opportunities models require as input the number of trips attracted to each recreation area from all origin zones. Therefore, it is necessary to develop a method for estimating the attractions of each recreation area.

The estimating method must simulate the existing 1970 attractions (known from the O&D survey) and must be able to predict attractions at future times. The nature of facilities offered at each area is likely to change with time as is the number of recreation areas. Knowing the nature of facilities at a recreational area, the attractions of that area can be predicted.

Choice of Variables

A majority of the 42 recreation areas are water oriented. However, there are several of these areas which have other facilities as their main attractions. Therefore, a wide range of variables describing the facilities available at the recreation areas are needed. The variables identified by Pigman *(1)* (see "Trip Generation") were among those evaluated herein.

In addition, it was thought that recreation areas located near large population centers would attract more trips than those isolated from population centers. A "load concept" was thus introduced to represent a greater usage of facilities which are located near large population centers. The following equation was developed to represent this load concept:

$$LOAD_j = \sum_i (POP_i)\ F_{ij} \qquad (18)$$

where $LOAD_j$ = accessibility of recreation area j to population,

POP_i = population of origin zone i, and

F_{ij} = gravity model "F" factors corresponding to the distance between i and j.

Variables describing the type and extent of available recreational facilities as well as the location of population centers with respect to the recreation areas were thus investigated in attempts to estimate attractions.

Calibration

The calibration phase attempts to simulate the 1970 attractions of each recreation area as obtained from the O&D survey. Since there were only 42 recreation areas and since there were numerous variables needed to describe attractions, the situation did not lend itself to cross-classification analysis. Therefore, investigation was limited to regression analyses.

A typical linear multiple regression analysis of the nine variables describing recreational facilities yielded some negative coefficients. This would indicate that some types of facilities detract from the area's attractive power; such a conclusion seems unreasonable. More likely, the negative coefficients resulted from the great range of attractiveness due to water-based facilities, thereby weighting the analysis heavily toward water-based facilities. When the constant term of the linear regression equation was eliminated -- that is, the equation was forced through the origin -- there were no negative regression coefficients. The accuracy of this equation was also reasonably good as evidenced by a squared correlation coefficient of 0.88. Attempts to add a term representing "load" (Equation 18) were disappointing. Addition of the "load" variable increased the squared correlation coefficient from 0.88 to 0.92 but was considered to be unacceptable because the "load" term was assigned a negative coefficient in the additive equation forms and a negative exponent in the multiplicative equation forms.

Although investigations of this study did not so indicate, the author is of the opinion that attractions should be positively correlated with "load". The fact that a linear correlation between attractions and "load" yields a multiple correlation coefficient of 0.36 is evidence of this assertion. However, interrelationships among "load" and the other independent variables in the equations investigated destroyed the positive correlation. In light of these facts, the author suggests that future studies should investigate the "load" term in greater detail than has been possible to date.

Because of its reasonableness and relatively good simulative power, the following equation was chosen to estimate attractions:

$$A_j = 10.23(GH) + 3.283(PIC) + 0.3238(ON) + 0.06430(DRAM) + 2.246(HIK) + 8.171(HB) + 0.2394(BEA) + 0.2268(POOL) + 0.09865(LAKE) \qquad (19)$$

where A_j = attractions of recreation area j,

GH = number of golf holes,

PIC = number of picnic tables,

ON = number of overnight accommodations,

DRAM = number of drama seats,

HIK = miles of hiking trails,

HB = miles of horseback trails,

BEA = lineal feet of beach,

POOL = square feet of swimming pool, and

LAKE = water acreage.

Table 3 compares actual attractions at the 42 recreation areas with attractions estimated from Equation 19. Although this equation seems to yield good results, it cannot accurately estimate attractions of some areas for which the area's major feature was not reflected in the equation. For example, the attractions of Mammoth Cave National Park (Area 10 of Table 3) cannot be accurately estimated because there is no variable representing the scenic attractions of the cave. In cases where Equation 19 does not reflect the major feature, attractions can be estimated more accurately by projections from past

TABLE 3

COMPARISON OF ACTUAL AND ESTIMATED ATTRACTIONS

Area	Attractions		
	Observed	Estimated	Difference
1	703	432	271
2	18220	17108	1112
3	552	1148	596
4	1934	907	1027
5	1245	1009	236
6	2542	1914	628
7	107	773	666
8	752	1727	975
9	1593	760	833
10	1967	272	1695
11	45	10	35
12	1636	2733	1097
13	1133	811	322
14	2416	875	1514
15	601	631	30
16	6904	9376	2472
17	285	182	103
18	3548	2116	1432
19	66	17	49
20	1185	2036	851
21	321	169	152
22	139	17	122
23	130	32	98
24	2451	1817	634
25	60	14	46
26	60	13	47
27	670	490	180
28	126	30	96
29	679	1140	461
30	2306	535	1171
31	3412	2128	1284
32	486	940	454
33	545	1846	1301
34	1930	1234	696
35	286	227	59
36	800	1594	794
37	941	1102	161
38	1146	538	608
39	1224	673	551
40	2857	2029	828
41	189	197	8
42	1260	128	1132

trends or, in the case of new areas, by comparison with similar existing areas.

Prediction

The equation developed in the aforedescribed calibration phase explains approximately 88 percent of the variance in attractions. However, this study cannot evaluate the predictive powers of the equation since no data are available for years other than 1970.

It is likely that growth of nearby population centers will increase the attractions of a recreation area. It is this concept that places additional emphasis on the desirability of using a "load" term in the predictive equation. It is also probable that improvement or construction of highways leading to recreation areas and an increase of propensity for recreational travel (due to such things as increasing leisure time) will increase the attractions of the recreation areas. These possibilities should be investigated in future studies utilizing future O&D survey data or by considering the predictions of future per capita recreation usage made by the Outdoor Recreation Resources Review Commission *(28)*. Equation 19, combined with such predictions, should be able to predict future attractions, except in cases where the major attractive feature of the area is not reflected in Equation 19. As previously mentioned, projections made from past trends should be useful in such exceptions.

GRAVITY MODEL

Nature of the Problem

The gravity model is a distribution model. In other words, once the numbers of trips produced by all origin zones (productions) and the numbers of trips attracted to all recreation areas (attractions) are known or estimated, the gravity model will yield the number of trips from each origin zone to each recreation area (trip interchanges).

The gravity model used in this study is of the form:

$$T_{ij} = P_i A_j F_{ij} / \sum_j A_j F_{ij} \tag{20}$$

where T_{ij} = trips from origin zone i to recreation area j,

P_i = productions at origin zone i,

A_j = attractions at recreation area j, and

F_{ij} = factors corresponding to the distance between origin area i and recreation area j as developed in the calibration phase.

The calibration phase requires an O&D survey from which T_{ij}, P_i, and A_j can be determined. In addition, distances between origin zones i and recreation areas j must be known. Given this information, the model can be calibrated, that is, "F" factors can be determined. The calibrated model can be used for prediction given as input estimated future A_j, P_i, and D_{ij}.

Calibration

Calibration of the gravity model attempts to simulate the O&D survey trip interchanges using known attractions and productions from the survey. Calibration produces a series of "F" factors corresponding to various distance intervals.

The "F" factors are friction factors expressing the inverse of the cost (in this case, cost or impedence is measured by distance) of travel. The "F" factors are a monotonically decreasing function of distance. Therefore, "F" factors are large for small distances and decrease with increasing distance. The "F" factors replace the commonly used function:

$$G_{ij} = 1/D_{ij}^{c} \tag{21}$$

where G_{ij} = measure of travel impedence between origin zone i and destination area j,

D_{ij} = distance from i to j, and

c = a constant exponent.

The "F" factor procedure is more reasonable because it is not constrained to a fixed functional form. In addition, the modern computer allows the "F" factors to be developed numerically with little difficulty. Ideally, "F" is a continuous function of distance. However, it is impractical to determine "F" factors for every mile of distance, since distances range from a few miles to nearly 3,000 miles. Furthermore, the accuracy of measuring distances *(1)* is insufficient to justify such a detailed procedure. On the other hand, too few "F" factor groups would not permit a sufficiently accurate approximation of the true effects of distance. This was verified in several preliminary calibration attempts. In this investigation, it was found that 19 "F" factors, corresponding to 19 distance intervals, were adequate. Determining the number of distance intervals depends on whether a suitable trip length frequency distribution can be obtained in a reasonable number of iterations, as explained later.

Two criteria were used in determining the adequacy of the "F" factors in the calibration phase. First, the average trip length estimated by the model was required to be within 3 percent of the average trip length obtained from the O&D survey. Second, the percentage of the total trips occurring within each of the 19 distance intervals as determined by the model was required to be within 5 percent of the corresponding value obtained by survey. These criteria were developed to conform with the Bureau of Public Roads *(15)* suggestion that the model and O&D survey trip length frequency curves reasonably agree and that the model and O&D survey average trip lengths agree within 3 percent. The "F" factors were adjusted (as subsequently explained) until these criteria were met. The number of adjustments required depends on the accuracy of initial estimates of each "F" factor. However, in most cases 10 iterations were found to be sufficient.

The calibration process, which required a digital computer, proceeded as follows:

1. The average O&D trip length and the percentage of actual O&D trips in each distance interval were determined.
2. Initial estimates of the 19 "F" factors were made. Initial "F" factors in this study were based on values reported in a Kansas study *(7)*. The initial estimates are not critical; however, convergence is facilitated by making good initial estimates.
3. An "F" factor was determined for each possible trip interchange according to the corresponding distance.
4. Using O&D attractions and productions and the initial "F" factors, all trip interchanges (T_{ij}) were computed using Equation 20.
5. The O&D attractions were adjusted in the following manner:

$$I_j = A_j^2 / \sum_i T_{ij} \qquad (22)$$

where I_j = adjusted attractions,
A_j = O&D attractions, and
T_{ij} = trip interchanges from Step 4.

6. Using O&D productions, I_j instead of A_j, and the initial "F" factors, all T_{ij} were recomputed

using Equation 20.

7. New adjusted attractions ($I_{j(new)}$) were calculated as follows:

$$I_{j(new)} = I_{j(old)}A_j/\sum_i T_{ij} \qquad (23)$$

where T_{ij} = trip interchanges from the last model calculation. Nine iterations were sufficient in this study.

8. Steps 6 and 7 were repeated until the following equality was satisfied:

$$A_j = \sum_i T_{ij} \qquad (24)$$

where T_{ij} = trip interchanges from the last model calculation. Nine iterations were sufficient in this study.

9. The trip length frequency distribution and the average trip length were computed from the estimated trip interchanges. If these quantities were in sufficient accord with the actual quantities obtained in Step 1, the process terminated.

10. If the criteria were not met, however, each "F" factor was adjusted by

$$F_{(new)} = F_{(old)} \frac{\text{Percentage of trips in distance interval by O\&D survey}}{\text{Percentage of trips in distance interval by latest gravity model distribution}} \qquad (25)$$

11. The entire process (Steps 3 through 10) was repeated, using new "F" factors from Step 10, until Step 9 was satisfied.

The trip interchanges computed from the last iteration were then compared with the actual O&D survey trip interchanges and a squared correlation coefficient was computed. This squared correlation coefficient can be interpreted as one measure of how well the gravity model distributes trips, assuming that attractions and productions are known, and was equal to 0.89. Table 4 illustrates the distance intervals and corresponding "F" factors. Figure 6 depicts graphically the relationships between "F" factors and distance. Calculations made from Figure 6 indicate that the following expression approximates "F" factors:

$$F_{ij} = k/D_{ij}^{2.4} \qquad (26)$$

where F_{ij} = "F" factor corresponding to D_{ij},
D_{ij} = distance between i and j, and
k = constant.

TABLE 4

"F" FACTORS FOR GRAVITY MODEL

Distance (miles)	"F" Factors
0 — 10	10735.62
11 — 20	3400.18
21 — 30	917.27
31 — 40	483.68
41 — 60	162.22
61 — 80	90.21
81 — 100	36.09
101 — 125	21.01
126 — 150	11.60
151 — 200	8.86
201 — 250	5.07
251 — 325	3.11
326 — 400	1.40
401 — 550	0.65
551 — 700	0.29
701 — 1000	0.20
1001 — 1300	0.12
1301 — 1700	0.08
1701 — 3000	0.05

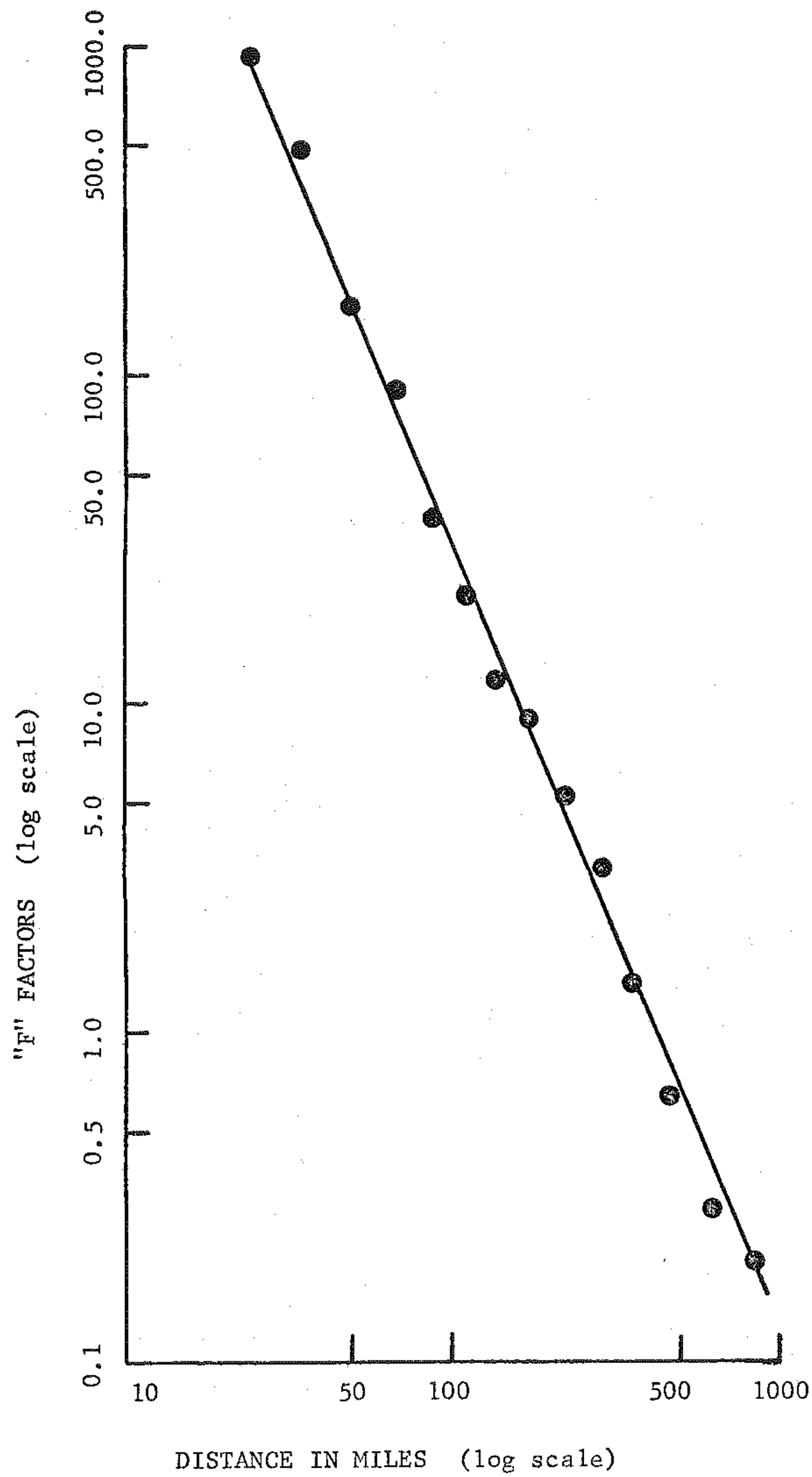

Fig. 6.--"F" factors versus distance

However, Figure 6 is a logarithmic plot, and therefore much of the variation between data points and the curve is masked. It is thus doubtful that the use of Equation 26 instead of "F" factors would add additional accuracy. Table 5 summarizes actual versus computed average trip lengths and trip length frequency distributions. It is evident that the gravity model distributes O&D productions and attractions and duplicates the O&D trip length frequency distribution quite accurately.

Testing

Although the gravity model distributes known attractions and productions quite well, it is unknown how well it distributes attractions and productions estimated from the trip generation models. Testing requires a comparison of actual O&D trip interchanges with the gravity model distribution using estimated attractions and productions. The gravity model requires that

$$\sum_j A_j = \sum_i P_i. \qquad (27)$$

However, techniques for estimating attractions and productions do not guarantee that the sum of estimated productions will equal the sum of estimated attractions. Since the technique for estimating attractions was statistically better than that for estimating productions, it was decided to adjust the estimated productions so that their sum would equal to the sum of estimated attractions. This was accomplished by

$$P_{i(adjusted)} = P_{i(estimated)} \times \sum_i P_{i(estimated)} / \sum_j A_{j(estimated)}. \qquad (28)$$

Testing the gravity model proceeded as follows:

1. Attractions and productions were estimated using 1970 socio-economic and recreation data and the trip generation models.
2. Estimated productions were adjusted by means of Equation 28.
3. An "F" factor was determined for each possible trip interchange according to the corresponding distance.
4. Trip Interchanges (T_{ij}) were computed using Equation 20.
5. Adjusted attractions (I_j) were computed using Equation 22.
6. Using I_j instead of A_j, all T_{ij} were recomputed using Equation 20.
7. New adjusted attractions ($I_{j(new)}$) were calculated using Equation 23, where the T_{ij}'s were the trip interchanges computed in Step 6.
8. Steps 6 and 7 were repeated until Equation 24 was satisfied.

The gravity model test in this study yielded a squared correlation coefficient of 0.52 when using estimated productions and attractions. APPENDIX IV contains a summary of the gravity model test. The squared correlation coefficient of the calibration was 0.89, indicating that the gravity model can

TABLE 5

TRIP LENGTH FREQUENCY DISTRIBUTION

Trip Length (miles)	Percentage of Trips	
	Observed	Calculated from Gravity Model
0 — 10	17.70	17.62
11 — 20	17.08	16.98
21 — 30	7.29	7.25
31 — 40	10.22	10.15
41 — 60	9.74	9.72
61 — 80	6.49	6.50
81 — 100	3.66	3.67
101 — 125	4.01	4.04
126 — 150	2.09	2.10
151 — 200	5.04	5.09
201 — 250	2.78	2.29
251 — 325	5.71	5.74
326 — 400	3.14	3.21
401 — 550	2.23	2.31
551 — 700	0.61	0.64
701 — 1000	1.58	1.61
1001 — 1300	0.27	0.27
1301 — 1700	0.03	0.03
1701 — 3000	0.32	0.32
Average Trip Length (miles)	109.00	111.50

distribute trips quite well given correct attractions and productions. The reduction in the squared correlation coefficient in testing the model emphasizes the importance of correctly estimating attractions and productions. It is concluded, therefore, that the greater problem in modeling recreational travel is in the trip generation phase and not in the trip distribution phase.

Prediction

Predicting future trips with the gravity model can be accomplished in the same manner as testing the gravity model. It is probable that the "F" factors would vary little from year to year unless there was a major change in the transportation network or travel mode. Future trip interchanges can be predicted using the equations for estimating productions and attractions, modifying the results using information regarding an increase in per capita recreation demand *(28)*, and distributing the trips as in testing.

INTERVENING OPPORTUNITIES MODEL

Nature of the Problem

Like the gravity model, the intervening opportunities model is a distribution model. In other words, given the productions of all origin zones and the attractions of all recreation areas, the model computes trip interchanges. The model is based in part on the assumption that a tripmaker wants to make the shortest possible trip. However, if the shortest trip does not satisfy his needs, the tripmaker must consider more distant destinations. The model is based on probability. That is, the probability that a trip from an origin zone will find a destination in a recreation area is equal to the probability that an acceptable destination exists there times the probability that an acceptable destination has not been found elsewhere *(17)*. The model can be stated mathematically as

$$T_{ij} = P_i[\exp(-LA) - \exp(-L \{A + A_j\})] \qquad (29)$$

where exp = expotential function,

L = probability that a random destination will satisfy the needs of a particular trip,

A = sum of attractions of all recreation areas closer to origin i than recreation area j, and

P_i, A_j, T_{ij} are as defined in the gravity model.

As in the gravity model, the opportunities model does not guarantee that

$$A_j = \sum_i T_{ij}. \qquad (30)$$

Pyers *(29)* found that attractions could be adjusted in exactly the same way as described in the gravity model to force a balance in trip ends (Equation 30) by an iterative process. Perhaps a more important problem, and one that was not encountered in the gravity model, is the "decay" of the opportunities model. An examination of the opportunities model reveals that, in order for the model to distribute all of the productions, the sum over j of $[\exp(-LA) - \exp(-L \{A + A_j\})]$ for each origin zone must equal one. The following will illustrate *(29)*:

$$T_{ij} = P_i[\exp(-LA) - \exp(-L \{A + A_j\})] \qquad (31)$$

$$\sum_j T_{ij} = P_i \sum_j [\exp(-LA) - \exp(-L \{A + A_j\})] \qquad (32)$$

$$\sum_j T_{ij}/P_i = \sum_j [\exp(-LA) - \exp(-L \{A + A_j\})] \qquad (33)$$

where $\sum_j T_{ij}/P_i$ should be equal to one if all the productions originating from origin zone i are to be distributed. If A_j is ordered from closest to furthest from the origin zone, A_1 becomes the closest recreation area, A_2 becomes the next closest, etc. Then, evaluating A in terms of A_j, and expanding the right side of Equation 33, the first term becomes unity, the middle terms cancel out in pairs, and the last term becomes $\exp(-L\sum_j A_j)$. Therefore

$$\sum_j [\exp(-LA) - \exp(-L \{A + A_j\})] = 1 - \exp(-L\sum_j A_j). \tag{34}$$

If the quantity $L\sum_j A_j$ is large, $[1 - \exp(-L\sum_j A_j)]$ approaches unity and all productions are distributed. Otherwise a correction constant must be added to the basic model as follows:

$$T_{ij} = NP_i[\exp(-LA - \exp(-L \{A + A_j\})] \tag{35}$$

where N = correction constant.

If $\sum_j T_{ij}/P_i$ is to be equal to one, then

$$N[1 - \exp(-L\sum_j A_j)] = 1 \tag{36}$$

and

$$N = 1/[1 - \exp(-L\sum_j A_j)]. \tag{37}$$

Equation 37 is the equation for computing the correction factor N. This correction term can be determined before computing the trip interchanges, and its use will assure that all productions are distributed.

The opportunities model as expressed by Equation 35 can be used to predict trip interchanges given attractions, productions, the probability parameter L, and relative distances to recreation areas from each origin zone. Since distances, attractions, and productions are estimated as previously described, the unknown remaining to be determined is L. Calibration uses O&D survey data to determine this probability parameter.

Calibration

Calibration determines the value of the probability parameter L which best simulates the O&D interchanges. Smith and Landman *(7)* suggested that an initial value for L could be calculated by solving the opportunities model equation for one trip interchange. Then the optimum value for L could be calculated by an iterative process which adjusts L in such a way that the calculated average trip length would be nearly equal to the actual average trip length. For each iteration, a new and better L would be calculated as follows:

$$L_{(new)} = L_{(old)}\ (CATL/ATL) \tag{38}$$

where ATL = actual (O&D) average trip length, and

CATL = calculated average trip length from prior iteration.

This method was used initially to revise the first estimate of L. When it appeared that an excessive number of iterations would be required to make the simulated and actual (O&D) average trip lengths agree, the author devised a new scheme. This scheme determined L on the basis of the best squared correlation coefficient when using the opportunities model to simulate O&D trip interchanges with O&D attractions and productions instead of determining L on the basis of average trip lengths.

The calibration process proceeds as follows:

1. Make an initial estimate of L.
2. Calculate N using Equation 37.
3. Calculate trip interchanges using Equation 35.
4. Adjust attractions by

$$I_j = A_j^2/\sum_i T_{ij} \tag{39}$$

where I_j = adjusted attractions.

5. Recalculate N by Equation 37 using I_j instead of A_j.
6. Recalculate the trip interchanges by Equation 35 using I_j instead of A_j.
7. Readjust attractions by

$$I_{j(new)} = A_j I_{j(old)}/\sum_i T_{ij}. \tag{40}$$

8. Repeat Steps 5, 6 and 7 until

$$A_j = \sum_i T_{ij}. \tag{41}$$

where T_{ij} = trip interchanges from Step 6.

9. Compare the last calculated trip interchanges with the O&D trip interchanges and compute the squared correlation coefficient. Increase L by 0.00004. Repeat Steps 2 through 8. If the squared correlation coefficient is increased, again increase L by 0.00004. But if the squared correlation coefficient is decreased, repeat Steps 2 through 8 using L decreased by 0.00004. Terminate when the L yielding the best squared correlation coefficient is found.

Through this process, the best value of L was found to be 0.00033. The calibrated model was able to distribute O&D attractions and productions with a squared correlation coefficient of 0.70.

Being somewhat disappointed with this accuracy, an evaluation was made using the calibrated L, but not adjusting attractions (i.e., eliminating Steps 4-8 in the aforedescribed sequence). This analysis yielded a squared correlation coefficient of 0.79, pointing out still another problem of the intervening opportunities model. It is not reasonable to expect recreation areas of extremely different attractiveness to attract trips in the same manner. This problem is thought to have caused the difficulty encountered in Step 8. To help solve this problem, Peyers *(29)* suggested the use of two different values of L -- one for small trip generators and one for large trip generators. This method would require trips to be distributed by two models stratified by the attractiveness of the recreation areas. In light of the time and expense (computer time) that would be required to apply this method, it could not be further pursued. Considering the relatively low squared correlation coefficient obtained in calibration and the difficulty in distributing trips to recreation areas of large attractiveness, an intervening opportunities model utilizing only one value of L is not recommended.

Testing

The calibration process is used to determine the probability parameter L and to evaluate the accuracy of the intervening opportunities model given actual attractions and productions. However, when using the model for prediction, actual attractions and productions will not be known but will have to be estimated. Therefore, to test the model, the 1970 estimated attractions and productions (developed earlier and adjusted by Equation 28) were used in the model, and the resulting trip interchanges were compared with the O&D trip interchanges. This method simulates 1970 trip interchanges and is the same process which would be used for predicting future trip interchanges.

Testing the intervening opportunities model proceeds as follows:

1. Calculate N using Equation 37.
2. Calculate trip interchanges using Equation 35.
3. Calculate adjusted attractions (I_j) using Equation 39.
4. Recalculate N by Equation 37 using I_j instead of A_j.
5. Recalculate the trip interchanges by Equation 35 using I_j instead of A_j.
6. Calculate new adjusted attractions ($I_{j(new)}$) using Equation 40.
7. Repeat Steps 4, 5 and 6 until the requirement of Equation 41 is met. Because of the problems caused by using only one value for L, this requirement could not be met in a reasonable number of iterations.
8. Compare the computed trip interchanges with the O&D trip interchanges and compute the squared correlation coefficient.

The squared correlation coefficient decreased from 0.70 in calibration to 0.40 in testing, indicating once again that the estimated attractions and productions were in considerable error. APPENDIX V summarizes the opportunities model test.

In light of the problem caused by using only one value of L as described in calibration, an evaluation was made computing trip interchanges but not adjusting attractions. The resulting squared correlation coefficient of 0.46 further illustrates that a more elaborate model may be necessary to distribute trips when attractions of greatly different magnitudes are considered. In addition, use of more than one value of L should allow the requirement of Step 7 to be better met. However, the large drop in the squared correlation coefficient from calibration to testing confirms that estimation of productions and attractions is a greater problem in recreational travel modeling than is trip distribution.

Prediction

Predicting future trip interchanges with the intervening opportunities model may be accomplished in the same manner as testing the model. Attractions and productions for the year desired are obtained from trip generation equations. The calibrated L would be assumed to remain constant over time unless there was a great change in either the transportation network or travel mode. In that case, another calibration of the model would be required. However, in light of the previously described problems associated with a model using only one value for L, the use of such a model would not be recommended.

COMPARISON OF THE GRAVITY AND INTERVENING OPPORTUNITIES MODELS

Both the gravity and intervening opportunities models were applied to the same data base and the same estimated attractions and productions were used in testing both models. Therefore, a valid comparison of the models can be made. Figures 7 through 11 illustrate the cumulative trip length distributions for five recreation areas as determined from the O&D survey, the gravity model, and the intervening opportunities model. Neither model simulates the actual distribution for a particular recreation area exactly, although in most cases both models generally follow the trends of the actual distribution curve. Small changes in curvature of the actual trip length frequency distribution curve are not reflected by either model.

Both models were calibrated to duplicate O&D trip interchanges. The O&D survey indicates that most trips were shorter than 200 miles. Therefore, both prediction models showed less variation from the actual data with increasing trip length.

The opportunity model is sensitive only to the order of trip distance, not to distance as such. The gravity model is sensitive to trip distance. The models therefore distribute trips differently. This is illustrated by the fact that the distribution curves of Figures 7 through 11 for the two models differ.

The models were calibrated to simulate average conditions. Actually, none of the recreation areas can be called average. Figures 7 through 11 and Appendices IV and V indicate that, for recreation areas which have significant day-use activity, the models predict a longer than actual average trip length. Examples of such areas are Lake Cumberland, Lake Barkley, and Kentucky Lake. On the other hand, for areas of primarily national interest, such as Mammoth Cave, the models predict a shorter than actual average trip length. On the basis of an analysis of cumulative trip length frequency distributions, neither model can be judged to be superior. Therefore, evaluation of the accuracy of the models must come from a statistical comparison of the actual and predicted trip interchanges.

The models distributed actual productions and attractions (calibration) with different degrees of accuracy. The gravity model (R^2 = 0.89) did a much better job than the opportunities model (R^2 = 0.70). In addition, the opportunities model actually became more accurate when attractions were not adjusted, suggesting the possible need for a model utilizing two values of L. The gravity model did not have this problem, distributing trips to recreation areas of widely differing attractiveness with near equal accuracy. When calibrating the models, the opportunities model requires an initial estimate of one value for L. On the other hand, the gravity model requires selection of the number and size of distance intervals, and initial estimates of corresponding "F" factors for each interval. During each iteration, the opportunities model requires just one adjustment of L but the gravity model requires each "F" factor to be adjusted. Both models require adjustment of attractions, but only the opportunities model requires productions to be adjusted (calculation of the correction factor N) to guarantee that all trips are distributed. Perhaps the cost in computer time is a good measure of the number of calculations done by each model. In general, the opportunities model costs about three to four times as much as the

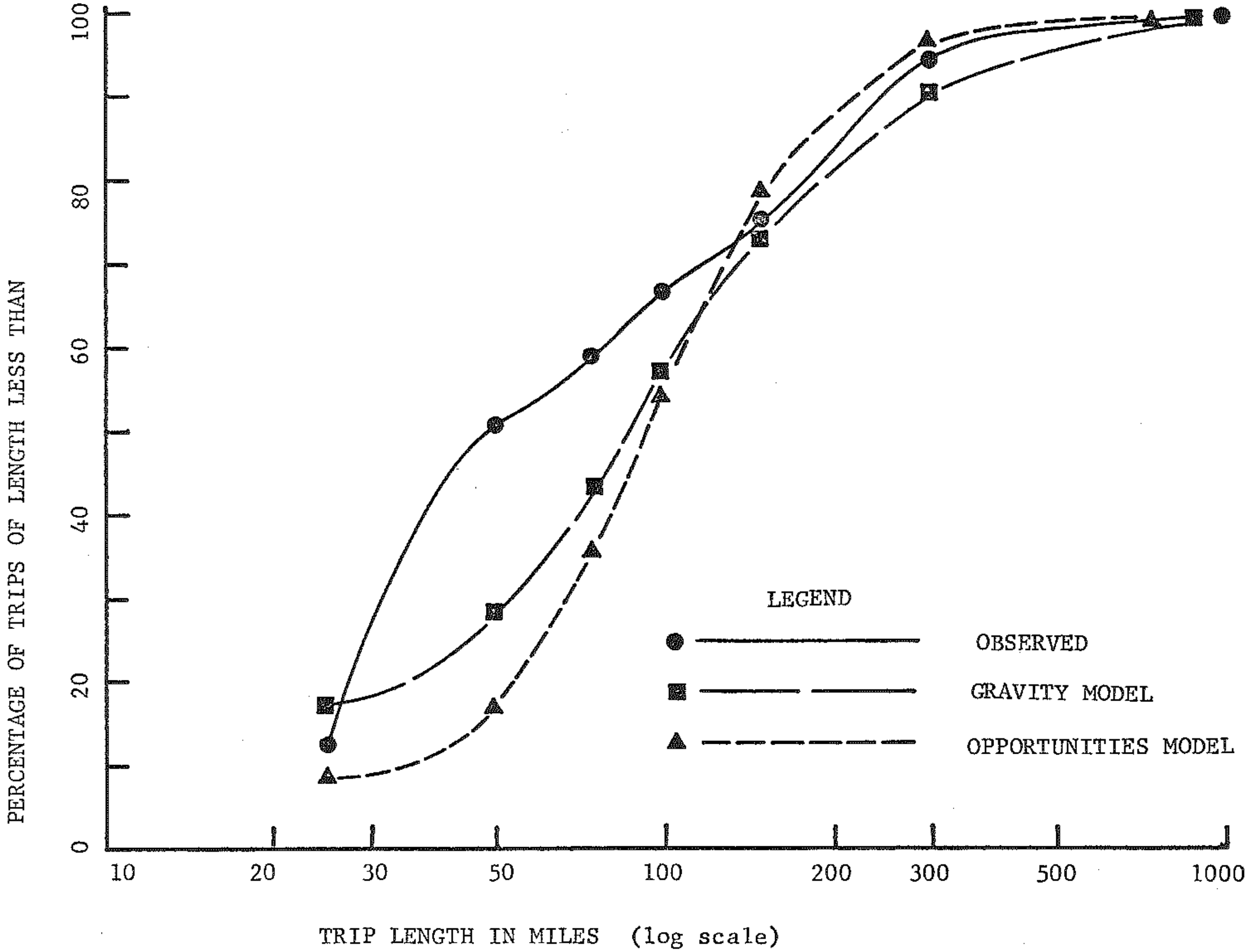

Fig. 7.--Lake Cumberland cumulative trip length frequency distribution

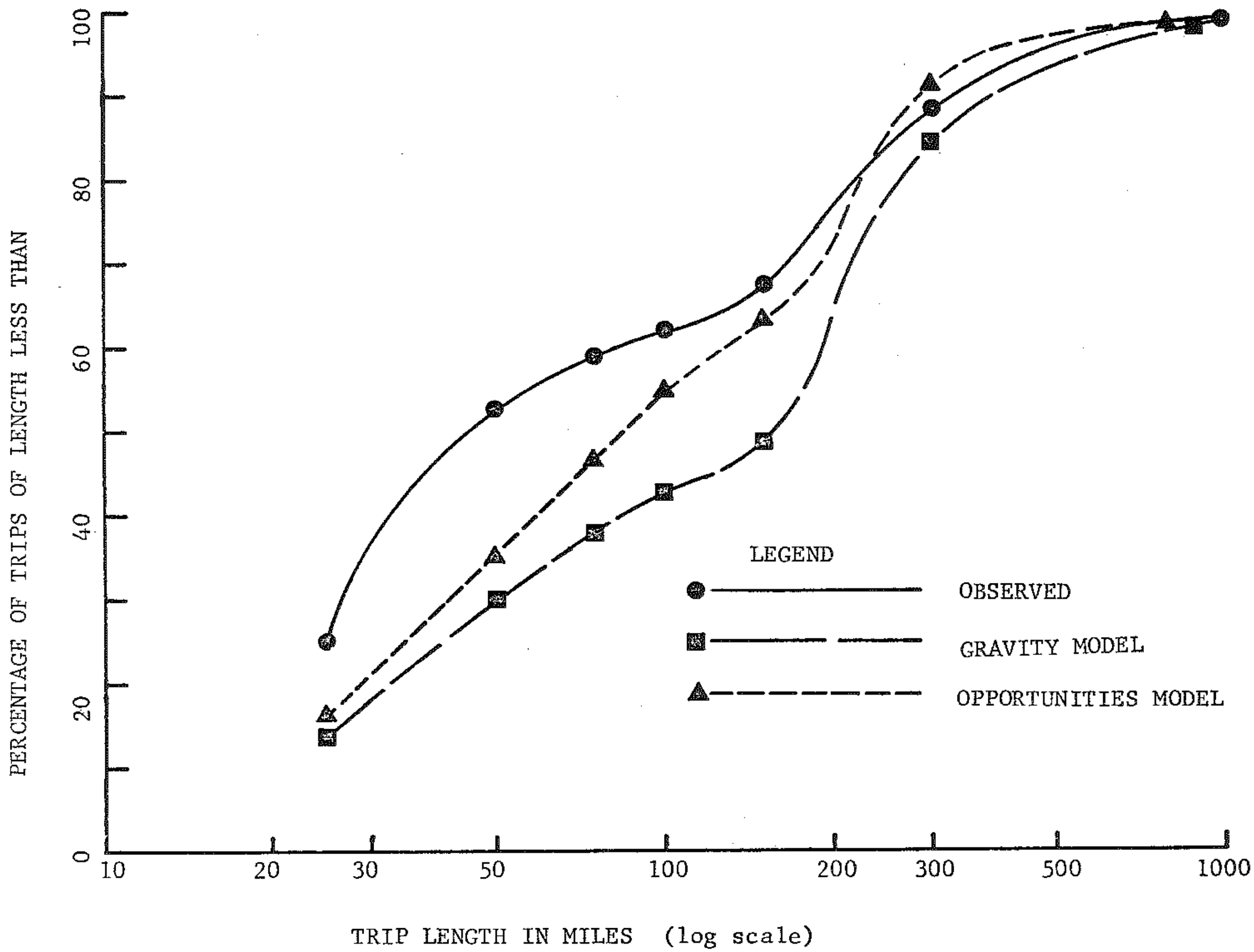

Fig. 8.--Kentucky Lake-Lake Barkley cumulative trip length frequency distribution

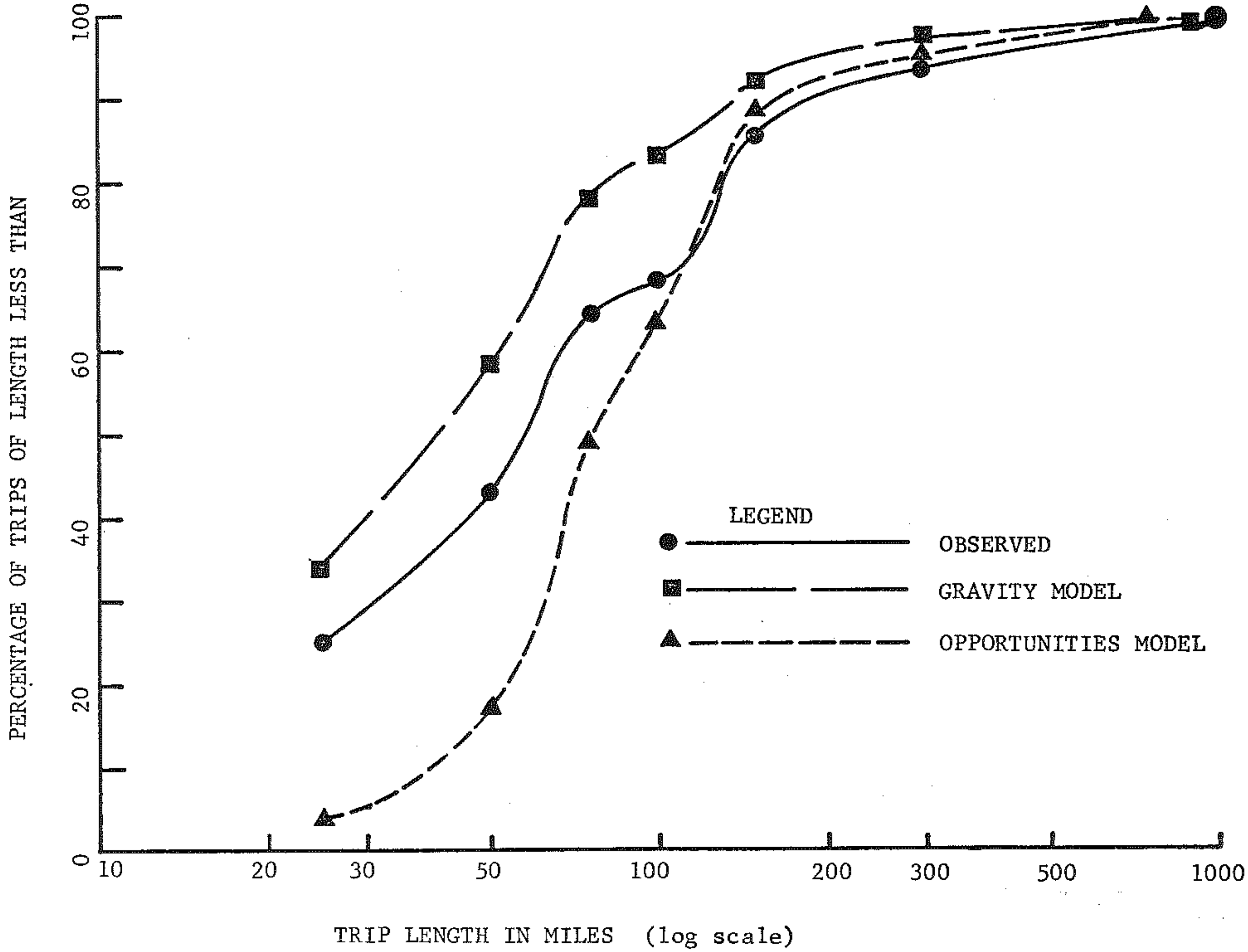

Fig. 9.--Natural Bridge State Park cumulative trip length frequency distribution

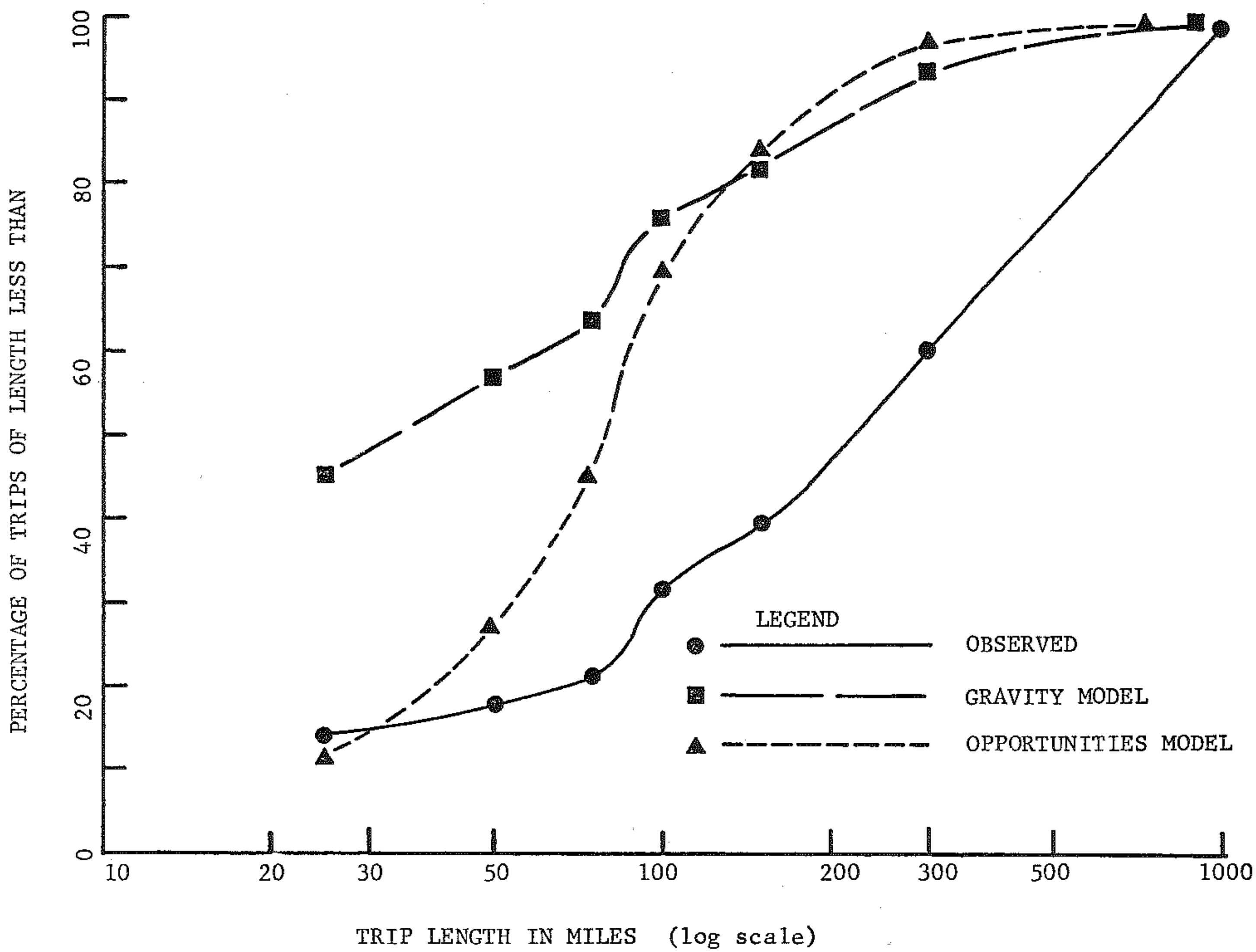

Fig. 10.--Mammoth Cave National Park cumulative trip length frequency distribution

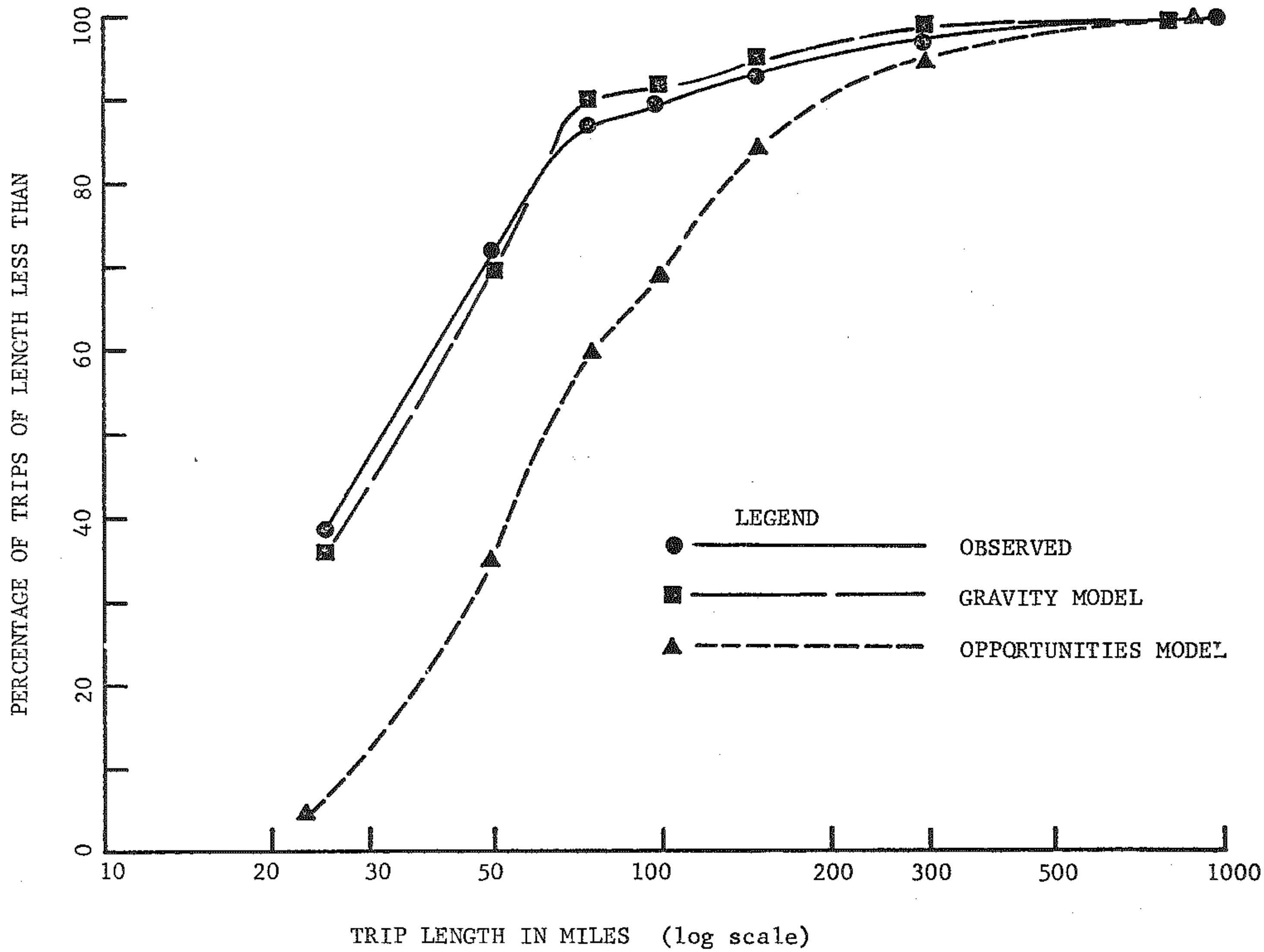

Fig. 11.--General Butler State Park cumulative trip length frequency distribution

gravity model. Although the gravity model requires more initial decisions than the opportunities model, the problems and cost of the opportunities model indicate the calibration process of the gravity model is superior. Once the models have been calibrated, no initial estimates of parameters are necessary. The models, with their constants already determined, require only attractions, productions, and distances as input. As before, the opportunities model will have problems distributing trips to recreation areas of widely differing attractiveness and will be expensive to handle on the computer. When estimated attractions and productions were used (testing), accuracy of both models was reduced but the gravity model yielded the best squared correlation coefficient (0.52 for the gravity model compared with 0.40 for the opportunities model). The models should be able to predict future trips with the same accuracy as noted in testing. However, if better estimating techniques for attractions and productions are developed, the accuracy of both models should be increased.

CONCLUSIONS

The application of the gravity and intervening opportunities models to 1970 outdoor recreational travel in Kentucky leads to the following conclusions:

1. Population and accessibility are valuable indicators of outdoor recreational trip productions of Kentucky origin zones.
2. Income, population, and accessibility are valuable indicators of outdoor recreational trips destined to Kentucky recreation areas from out-of-state origin zones.
3. Accessibility, as defined by Equation 14, should be considered in all future studies of outdoor recreational travel.
4. The methods developed to estimate outdoor recreational trip productions of an origin zone give relatively poor results and require more study.
5. The number of dwelling units, the number of dwelling units per square mile, motor vehicle registration, and population are highly intercorrelated in the 120 Kentucky counties.
6. The nature and extent of the facilities of an outdoor recreation area are suitable indicators of its attractiveness.
7. A measure of nearness of population to a recreation area could not be used in this study to explain the area's attractiveness.
8. The linear equations developed for estimating attractions of Kentucky's outdoor recreation areas can explain approximately 89 percent of the variance.
9. Future attractions and productions predicted by the equations developed in this study should be modified by estimates of future per capita recreation demand.
10. Attractions of recreation areas which have major attractive features not reflected in the estimating equations can probably be predicted more accurately from extensions of past trends.
11. The "F" factors developed in the gravity model are a convenient and useful means of explaining distance effects in trip distribution.
12. The gravity model can distribute O&D attractions and productions quite accurately with little cost.
13. Adjusting L to best simulate O&D trip interchanges is a useful method of calibrating the intervening opportunities model.
14. The intervening opportunities model cannot give satisfactory results with only one value of the probability parameter L when recreation areas of widely differing attractiveness are present in the study area.
15. The intervening opportunities model is less accurate, has more problems, and costs more to apply than the gravity model.
16. Trip generation rather than trip distribution is the greater problem in outdoor recreational travel modeling.

APPENDIX I

MAJOR PHASES OF STUDY

I. Trip Generation

A. Develop a method for predicting trip productions of each origin zone.

1. Simulate present trip productions (calibration).
2. Test predictive method against present trip productions.
3. Explain method for use in prediction.

B. Develop a method of predicting trip attractions of each recreation area.

1. Simulate present trip attractions (calibration).
2. Test predictive method against present trip attractions.
3. Explain method for use in prediction.

II. Trip Distribution (Gravity and Intervening Opportunities Models)

A. Calibrate distribution models using origin and destination survey data to evaluate model constants.

B. Test calibrated models against O&D trip interchanges using actual O&D attractions and productions.

C. Test calibrated models against O&D trip interchanges using attractions and productions obtained from the predictive methods.

D. Explain methods of using models for prediction.

APPENDIX II

NOTATION

a, b, c, k	=	constants
A	=	Sum of attractions of all destination or recreation areas closer to origin zone i than destination area j
A_j	=	attractions of recreation or destination area j
BEA	=	lineal feet of beach
DRAM	=	number of drama seats
D_{ij}	=	distance between origin zone i and recreation or destination area j
exp	=	expotential function
F_i and F_j	=	growth factors
F_{ij}	=	gravity model "F" factors
G_{ij}	=	measure of travel impedence
GH	=	number of golf holes
HB	=	miles of horseback trails
HIK	=	miles of hiking trails
i	=	subscript denoting origin zone number
I	=	income
I_j	=	adjusted attractions of destination or recreation area j
j	=	subscript denoting destination or recreation area number
L	=	intervening opportunities model probability that a random destination will satisfy a tripmaker's needs
LAKE	=	water acreage
$LOAD_j$	=	accessibility of recreation area j to population
N	=	intervening opportunities model correction factor
ON	=	number of overnight accommodations
P_i	=	productions of origin zone i
PIC	=	number of picnic tables
POOL	=	square feet of swimming pool
POP	=	population
R	=	multiple correlation coefficient
R^2	=	squared correlation coefficient
R_j	=	number of jobs available in zone j
S_i	=	accessibility of an origin zone i to Kentucky outdoor recreation areas
t_i	=	present trips originating in zone i
t_j	=	present trips ending in zone j
t_{ij}	=	present trips originating in zone i and ending in zone j (trip interchanges)
T_{ij}	=	calculated trips originating in origin zone i and ending in destination or recreation area j (trip interchanges)

W_i = workers residing in zone i

APPENDIX III

A NOTE ON STATISTICS AND REGRESSION ANALYSIS

One method of determining how well computed data simulates actual data is the squared correlation coefficient (R^2). The squared correlation coefficient may be defined as

$$R^2 = 1 - (SE/SD)^2$$

where R^2 = the squared correlation coefficient,

SE = the standard error of the estimate, and

SD = the standard deviation of the data.

The squared correlation coefficient may be interpreted as the fraction of variation of the dependent variable which is explained by the independent variables in a particular equation. The standard error of the estimate may be defined as:

$$SE = \sqrt{\Sigma\ (X-x)^2/(n-u)}$$

where X = actual data values,

x = values estimated by a regression equation,

n = number of observations, and

u = number of constants in the regression equation.

Linear multiple regression analyses fit linear equations to data sets. An analysis evaluates the constants of the equation by the method of least squares. Nonlinear regression analyses fit nonlinear equations to sets of data and similarly evaluate constants. The biggest problem in using regression analyses is finding the best and most logical equation form to fit to the data. It may be noted that the equation with the greatest squared correlation coefficient and the smallest standard error may not be logical (no cause-effect relationship or an illogical relationship) and therefore its use may be meaningless or misleading.

APPENDIX IV

RESULTS OF GRAVITY MODEL TEST

1970 KENTUCKY RECREATIONAL TRAVEL STUDY
KENTUCKY DEPARTMENT OF HIGHWAYS
MODEL EVALUATION

GRAVITY MODEL EVALUATION

REC. ZONE		TOTAL TRIPS	MEAN TRIPS PER ORIGIN	STD. DEV. TRIPS PER ORIGIN	STD. ERROR	SQ. CORR. INDEX	MEAN TRIP LENGTH	STD. DEV. TRIP LENGTH	PERCENTAGE OF TRIPS HAVING LENGTHS LESS THAN OR EQUAL TO 25	50	75	100	150	300	1000	3000
1	ACTUAL	703.	3.70	24.42			63.4	196.8	70.1	82.2	86.6	86.9	87.6	93.6	99.4	100.0
	PREDICTED	431.	2.27	8.57	20.08	0.32	163.6	238.6	39.8	53.0	55.1	55.7	58.8	84.5	98.3	100.0
2	ACTUAL	18220.	95.89	297.95			140.5	200.0	25.1	53.1	59.0	62.3	67.6	88.5	99.2	100.0
	PREDICTED	17100.	90.00	208.41	181.98	0.63	202.6	234.0	13.6	29.9	37.9	43.2	48.4	84.3	98.1	100.0
3	ACTUAL	552.	2.91	16.26			92.5	166.5	59.6	64.9	69.2	79.9	84.1	92.2	98.9	100.0
	PREDICTED	1148.	6.04	23.54	12.33	0.43	122.2	186.2	42.7	52.2	62.3	65.8	73.9	90.5	99.1	100.0
4	ACTUAL	1934.	10.18	98.64			78.9	266.1	74.5	85.0	85.2	86.1	87.5	94.6	99.0	100.0
	PREDICTED	906.	4.77	37.44	62.71	0.60	66.5	148.0	68.4	76.2	77.0	78.9	85.5	96.4	99.8	100.0
5	ACTUAL	1245.	6.55	41.46			48.4	121.2	69.8	82.6	88.5	90.0	94.2	96.1	99.8	100.0
	PREDICTED	1008.	5.31	25.19	19.72	0.77	89.7	161.2	49.0	62.9	68.7	73.8	82.0	91.8	99.7	100.0
6	ACTUAL	2542.	13.38	79.79			104.0	235.5	21.9	43.0	86.4	88.5	90.1	94.4	98.9	100.0
	PREDICTED	1913.	10.07	43.01	46.96	0.65	87.4	141.0	30.4	48.1	76.2	78.9	83.4	95.9	99.8	100.0
7	ACTUAL	107.	0.56	4.15			68.9	142.4	43.0	86.9	86.9	86.9	92.5	94.4	100.0	100.0
	PREDICTED	773.	4.07	29.61	25.90	-38.01	54.0	96.2	33.9	83.9	87.9	90.8	94.1	96.9	99.9	100.0
8	ACTUAL	752.	3.96	27.52			193.1	337.0	15.2	64.6	68.2	69.1	71.1	76.3	97.9	100.0
	PREDICTED	1726.	9.08	57.77	36.57	-0.77	44.7	85.4	49.1	87.1	90.6	92.8	95.4	97.7	99.9	100.0
9	ACTUAL	1593.	8.38	63.67			61.5	89.0	24.8	37.2	91.5	94.0	95.4	98.5	99.9	100.0
	PREDICTED	760.	4.00	15.93	51.65	0.34	86.5	138.9	22.6	50.0	75.0	80.1	83.8	93.7	99.8	100.0
10	ACTUAL	1967.	10.35	22.60			299.7	334.1	14.2	17.9	21.1	31.5	39.7	60.3	98.2	100.0
	PREDICTED	272.	1.43	5.08	21.94	0.06	90.8	153.4	45.4	56.7	63.8	76.1	82.0	93.6	99.8	100.0
11	ACTUAL	45.	0.24	1.90			40.0	80.3	75.6	80.0	82.2	88.9	95.6	97.8	100.0	100.0
	PREDICTED	10.	0.06	0.44	1.48	0.39	48.8	115.6	70.2	79.4	83.6	89.0	91.5	96.7	99.9	100.0
12	ACTUAL	1636.	8.61	61.10			39.3	78.0	55.3	85.0	88.0	88.8	95.9	98.0	100.0	100.0
	PREDICTED	2732.	14.38	67.26	19.95	0.89	85.6	156.9	44.1	63.2	69.1	73.4	83.8	93.5	99.8	100.0
13	ACTUAL	1133.	5.96	28.32			140.9	213.6	36.1	60.3	64.7	66.0	72.2	78.8	99.6	100.0
	PREDICTED	811.	4.27	21.07	11.90	0.82	49.9	99.7	54.2	77.7	86.2	88.7	94.2	96.7	99.9	100.0
14	ACTUAL	2416.	12.72	92.33			41.0	103.3	74.5	79.1	82.5	94.7	95.9	98.0	99.8	100.0
	PREDICTED	874.	4.60	16.26	78.30	0.28	83.2	139.1	40.0	51.3	61.6	81.3	86.8	94.7	99.8	100.0

1970 KENTUCKY RECREATIONAL TRAVEL STUDY
KENTUCKY DEPARTMENT OF HIGHWAYS
MODEL EVALUATION

GRAVITY MODEL EVALUATION

REC. ZONE		TOTAL TRIPS	MEAN TRIPS PER ORIGIN	STD. DEV. TRIPS PER ORIGIN	STD. ERROR INDEX	SQ. CORR. INDEX	MEAN TRIP LENGTH	STD. DEV. TRIP LENGTH	PERCENTAGE OF TRIPS HAVING LENGTHS LESS THAN OR EQUAL TO 25	50	75	100	150	300	1000	3000
15	ACTUAL	601.	3.16	16.35			90.7	149.4	49.9	56.7	60.2	62.7	83.7	94.5	99.8	100.0
	PREDICTED	631.	3.32	7.42	12.48	0.42	147.4	197.2	17.7	27.3	39.9	50.5	70.3	89.7	99.6	100.0
16	ACTUAL	6904.	36.34	190.43			105.4	153.6	12.7	50.8	58.8	66.8	75.6	94.4	99.8	100.0
	PREDICTED	9375.	49.34	102.78	171.67	0.19	131.8	176.4	17.3	28.5	43.5	57.0	73.5	90.6	99.7	100.0
17	ACTUAL	285.	1.50	6.78			124.6	143.7	37.9	49.5	50.9	55.8	58.6	91.6	100.0	100.0
	PREDICTED	182.	0.96	3.60	6.42	0.10	112.5	168.1	36.8	42.9	51.2	62.9	79.0	91.8	99.8	100.0
18	ACTUAL	3548.	18.67	42.81			182.0	211.0	16.4	28.2	35.7	39.1	54.3	81.5	99.6	100.0
	PREDICTED	2117.	11.14	48.86	35.02	0.33	99.7	166.1	41.8	51.5	60.9	66.4	80.5	92.5	99.8	100.0
19	ACTUAL	66.	0.35	3.49			18.7	30.5	74.2	90.9	90.9	92.4	100.0	100.0	100.0	100.0
	PREDICTED	17.	0.09	0.60	2.93	0.30	35.6	82.3	64.7	83.7	86.9	93.6	96.4	98.6	100.0	100.0
20	ACTUAL	1185.	6.24	31.71			60.6	175.2	71.6	78.9	82.0	88.3	92.8	96.0	99.6	100.0
	PREDICTED	2035.	10.71	48.81	21.93	0.52	38.1	81.3	69.9	83.3	87.2	93.8	96.4	98.1	100.0	100.0
21	ACTUAL	321.	1.69	5.23			140.8	264.5	14.3	30.5	55.1	64.8	78.8	89.1	99.1	100.0
	PREDICTED	170.	0.89	3.96	4.54	0.25	39.3	80.0	50.4	80.3	90.0	94.2	96.6	98.2	100.0	100.0
22	ACTUAL	139.	0.73	4.50			60.7	156.0	41.7	89.9	89.9	91.4	92.8	95.7	100.0	100.0
	PREDICTED	17.	0.09	0.37	4.27	0.10	41.7	78.1	44.9	83.4	90.1	94.9	96.7	97.9	100.0	100.0
23	ACTUAL	130.	0.68	6.43			53.2	133.1	21.5	94.6	96.2	96.2	96.9	96.9	100.0	100.0
	PREDICTED	32.	0.17	0.86	5.77	0.19	40.3	73.3	42.0	84.2	92.2	95.6	97.1	98.2	100.0	100.0
24	ACTUAL	2451.	12.90	63.99			62.3	150.3	38.6	72.2	87.6	89.6	93.2	97.1	99.7	100.0
	PREDICTED	1816.	9.56	32.58	41.32	0.58	52.5	87.1	36.0	72.0	89.9	91.9	94.8	98.1	99.9	100.0
25	ACTUAL	60.	0.32	1.86			34.8	36.1	51.7	73.3	93.3	93.3	98.3	100.0	100.0	100.0
	PREDICTED	14.	0.07	0.30	1.71	0.16	46.4	72.7	32.0	75.9	93.3	94.7	96.6	99.0	100.0	100.0
26	ACTUAL	60.	0.32	1.89			45.5	74.3	56.7	83.3	86.7	88.3	95.0	98.3	100.0	100.0
	PREDICTED	13.	0.07	0.58	1.43	0.43	27.3	49.4	76.8	93.0	94.6	97.9	98.6	99.6	100.0	100.0
27	ACTUAL	670.	3.53	21.24			54.6	174.5	70.7	82.2	84.5	89.9	93.4	96.6	99.6	100.0
	PREDICTED	490.	2.58	23.67	10.20	0.77	14.3	29.8	93.1	97.4	98.1	99.3	99.5	99.9	100.0	100.0
28	ACTUAL	126.	0.66	3.92			90.7	315.6	29.4	87.3	88.1	93.7	96.0	96.8	98.4	100.0
	PREDICTED	30.	0.16	0.79	3.57	0.17	34.6	62.8	58.5	88.9	91.3	96.7	97.8	99.3	100.0	100.0

1970 KENTUCKY RECREATIONAL TRAVEL STUDY
KENTUCKY DEPARTMENT OF HIGHWAYS
MODEL EVALUATION

GRAVITY MODEL EVALUATION

REC. ZONE		TOTAL TRIPS	MEAN TRIPS PER ORIGIN	STD. DEV. TRIPS PER ORIGIN	STD. ERROR	SQ. CORR. INDEX	MEAN TRIP LENGTH	STD. DEV. TRIP LENGTH	PERCENTAGE OF TRIPS HAVING LENGTHS LESS THAN OR EQUAL TO 25	50	75	100	150	300	1000	3000
29	ACTUAL	679.	3.57	14.83			40.9	164.8	68.8	87.0	92.5	94.3	97.9	99.1	99.6	100.0
	PREDICTED	1140.	6.00	18.61			48.9	83.0	50.2	68.9	82.9	91.7	95.9	98.7	100.0	100.0
					12.60	0.28										
30	ACTUAL	2306.	12.14	63.15			70.9	167.7	64.4	77.6	80.5	85.6	89.8	95.1	99.2	100.0
	PREDICTED	535.	2.82	20.54			29.7	64.1	82.1	89.1	91.1	96.3	97.8	99.1	100.0	100.0
					44.61	0.50										
31	ACTUAL	3412.	17.96	122.35			91.1	208.4	55.6	69.1	72.4	76.3	80.8	91.6	99.2	100.0
	PREDICTED	2129.	11.20	51.37			71.2	135.4	49.7	61.7	72.3	80.3	89.4	95.2	99.9	100.0
					77.59	0.60										
32	ACTUAL	486.	2.56	14.24			144.9	231.4	52.7	55.3	57.0	58.4	63.6	82.1	99.0	100.C
	PREDICTED	941.	4.95	23.67			84.0	159.2	54.5	63.5	69.6	74.0	80.3	93.8	99.8	100.0
					11.84	0.31										
33	ACTUAL	545.	2.87	10.19			257.3	310.1	23.3	25.3	35.8	36.7	41.5	64.4	98.5	100.0
	PREDICTED	1848.	9.72	51.80			98.5	170.8	46.9	55.2	66.4	71.6	77.3	92.3	99.8	100.0
					44.65	-18.20										
34	ACTUAL	1930.	10.16	29.13			101.1	181.8	24.8	42.8	64.1	68.1	86.5	94.1	99.2	100.0
	PREDICTED	1235.	6.50	16.18			65.6	113.2	34.1	58.2	78.5	83.4	92.6	97.0	99.9	100.0
					20.12	0.52										
35	ACTUAL	286.	1.51	4.18			109.2	149.3	19.2	35.7	54.2	60.1	85.3	95.1	99.3	100.0
	PREDICTED	227.	1.19	2.96			67.6	113.7	32.4	57.1	77.4	84.1	92.8	96.4	99.9	100.0
					3.23	0.40										
36	ACTUAL	800.	4.21	17.19			104.8	162.0	26.9	44.9	48.4	74.6	85.1	94.3	99.4	100.0
	PREDICTED	1597.	8.40	40.63			55.4	103.8	51.2	73.6	79.2	86.5	92.8	96.9	99.9	100.0
					32.30	-2.53										
37	ACTUAL	941.	4.95	30.43			66.0	204.7	60.5	66.5	86.7	88.7	92.7	96.6	99.3	100.0
	PREDICTED	1105.	5.82	50.75			20.7	60.1	90.3	92.4	94.6	95.5	97.9	99.1	100.0	100.0
					28.38	0.13										
38	ACTUAL	1146.	6.03	36.26			47.1	116.5	58.9	81.6	84.0	92.1	94.5	98.3	99.7	100.0
	PREDICTED	539.	2.83	9.57			63.2	113.1	43.2	69.6	77.2	83.5	91.1	97.1	99.9	100.0
					29.64	0.33										
39	ACTUAL	1224.	6.44	49.10			71.0	199.7	71.2	77.9	80.6	81.9	86.1	96.2	99.4	100.0
	PREDICTED	674.	3.54	12.22			73.2	129.8	48.1	62.4	75.5	81.6	87.6	95.0	99.9	100.0
					39.54	0.35										
40	ACTUAL	2857.	15.04	97.94			57.3	173.4	75.7	79.3	81.1	82.3	89.6	95.3	99.6	100.0
	PREDICTED	2035.	10.71	75.29			25.6	73.2	88.2	91.1	93.6	94.7	96.5	98.9	100.0	100.0
					33.49	0.88										
41	ACTUAL	189.	0.99	8.86			95.5	223.4	75.1	75.1	76.7	76.7	79.4	92.1	99.5	100.0
	PREDICTED	197.	1.04	4.76			87.8	154.2	45.3	62.3	72.2	75.2	80.9	93.6	99.8	100.0
					8.49	0.08										
42	ACTUAL	1260.	6.63	78.55			48.6	122.8	86.0	88.7	89.2	89.9	91.9	95.2	100.0	100.0
	PREDICTED	128.	0.68	6.87			50.8	119.5	73.7	83.0	85.9	87.8	90.8	97.1	99.9	100.0
					72.14	0.16										

STATISTICAL ACCURACY OF TOTAL PREDICTION

STANDARD ERROR	STANDARD DEVIATION	SQUARED CORRELATION INDEX
50.133	72.316	0.519

MEAN TRIPS PER INTERCHANGE 8.703

APPENDIX V

RESULTS OF INTERVENING OPPORTUNITIES MODEL

1970 KENTUCKY RECREATIONAL TRAVEL STUDY
KENTUCKY DEPARTMENT OF HIGHWAYS
MODEL EVALUATION

OPPORTUNITY MODEL EVALUATION

REC. ZONE		TOTAL TRIPS	MEAN TRIPS PER ORIGIN	STD. DEV. TRIPS PER ORIGIN	STD. ERROR	SQ. CORR. INDEX	MEAN TRIP LENGTH	STD. DEV. TRIP LENGTH	25	50	75	100	150	300	1000	3000
									PERCENTAGE OF TRIPS HAVING LENGTHS LESS THAN OR EQUAL TO							
1	ACTUAL	703.	3.70	24.42			63.4	196.8	70.1	82.2	86.6	86.9	87.6	93.6	99.4	100.0
	PREDICTED	432.	2.27	18.02			247.6	333.3	8.1	31.4	31.4	31.4	31.4	87.4	97.4	100.0
					28.14	-0.33										
2	ACTUAL	18220.	95.89	297.95			140.5	200.0	25.1	53.1	59.0	62.3	67.6	88.5	99.2	100.0
	PREDICTED	15307.	80.56	205.78			155.1	217.2	15.4	34.8	46.5	54.7	63.3	91.1	99.1	100.0
					166.77	0.69										
3	ACTUAL	552.	2.91	16.26			92.5	166.5	59.6	64.9	69.2	79.9	84.1	92.2	98.9	100.0
	PREDICTED	1239.	6.52	15.34			114.8	118.1	19.2	31.2	47.4	57.5	75.2	93.8	99.7	100.0
					15.42	0.10										
4	ACTUAL	1934.	10.18	98.64			78.9	266.1	74.5	85.0	85.2	86.1	87.5	94.6	99.0	100.0
	PREDICTED	964.	5.07	16.38			155.6	126.5	11.6	27.2	31.8	39.4	54.6	96.2	99.9	100.0
					95.56	0.06										
5	ACTUAL	1245.	6.55	41.46			48.4	121.2	69.8	82.6	88.5	90.0	94.2	96.1	99.8	100.0
	PREDICTED	1082.	5.70	12.97			106.3	109.5	9.7	30.7	51.1	60.6	78.4	97.0	99.9	100.0
					38.37	0.14										
6	ACTUAL	2542.	13.38	79.79			104.0	235.5	21.9	43.0	86.4	88.5	90.1	94.4	98.9	100.0
	PREDICTED	2004.	10.55	33.70			103.5	97.4	4.7	21.3	60.3	66.4	77.5	96.4	100.0	100.0
					50.87	0.59										
7	ACTUAL	107.	0.56	4.15			68.9	142.4	43.0	86.9	86.9	86.9	92.5	94.4	100.0	100.0
	PREDICTED	799.	4.20	13.94			104.5	116.9	12.6	39.1	50.0	65.6	82.0	95.2	99.9	100.0
					11.29	-6.42										
8	ACTUAL	752.	3.96	27.52			193.1	337.0	15.2	64.6	68.2	69.1	71.1	76.3	97.9	100.0
	PREDICTED	1780.	9.37	30.96			102.8	116.7	12.4	38.7	51.6	65.6	82.1	95.2	99.9	100.0
					13.18	0.77										
9	ACTUAL	1593.	8.38	63.67			61.5	89.0	24.8	37.2	91.5	94.0	95.4	98.5	99.9	100.0
	PREDICTED	791.	4.16	12.51			99.7	97.6	4.5	26.5	59.2	68.2	77.2	96.9	99.9	100.0
					52.84	0.31										
10	ACTUAL	1967.	10.35	22.60			299.7	334.1	14.2	17.9	21.1	31.5	39.7	60.3	98.2	100.0
	PREDICTED	287.	1.51	4.26			101.7	99.5	11.9	27.0	45.1	69.9	82.4	96.9	99.9	100.0
					22.30	0.03										
11	ACTUAL	45.	0.24	1.90			40.0	80.3	75.6	80.0	82.2	88.9	95.6	97.8	100.0	100.0
	PREDICTED	11.	0.06	0.17			101.7	100.2	6.3	30.3	49.4	70.4	80.9	96.8	99.9	100.0
					1.87	0.03										
12	ACTUAL	1636.	8.61	61.10			39.3	78.0	55.3	85.0	88.0	88.8	95.9	98.0	100.0	100.0
	PREDICTED	2896.	15.24	43.42			108.8	106.1	10.6	24.6	41.5	52.3	80.9	96.1	99.9	100.0
					57.39	0.12										
13	ACTUAL	1133.	5.96	28.32			140.9	213.6	36.1	60.3	64.7	66.0	72.2	78.8	99.6	100.0
	PREDICTED	833.	4.38	11.52			99.4	117.2	10.2	39.9	58.8	66.5	85.3	94.9	99.9	100.0
					23.33	0.32										
14	ACTUAL	2416.	12.72	92.33			41.0	103.3	74.5	79.1	82.5	94.7	95.9	98.0	99.8	100.0
	PREDICTED	904.	4.76	10.57			106.7	107.9	6.0	21.6	39.5	69.0	82.6	96.3	99.9	100.0
					90.79	0.03										

1970 KENTUCKY RECREATIONAL TRAVEL STUDY
KENTUCKY DEPARTMENT OF HIGHWAYS
MODEL EVALUATION

OPPORTUNITY MODEL EVALUATION

REC. ZONE		TOTAL TRIPS	MEAN TRIPS PER ORIGIN	STD. DEV. TRIPS PER ORIGIN	STD. ERROR	SQ. CORR. INDEX	MEAN TRIP LENGTH	STD. DEV. TRIP LENGTH	PERCENTAGE OF TRIPS HAVING LENGTHS LESS THAN OR EQUAL TO 25	50	75	100	150	300	1000	3000
15	ACTUAL	601.	3.16	16.35			90.7	149.4	49.9	56.7	60.2	62.7	83.7	94.5	99.8	100.0
	PREDICTED	686.	3.61	6.85			116.2	113.6	6.6	23.3	37.6	57.6	78.9	96.0	99.9	100.0
					14.71	0.19										
16	ACTUAL	6904.	36.34	190.43			105.4	153.6	12.7	50.8	58.8	66.8	75.6	94.4	99.8	100.0
	PREDICTED	9970.	52.48	98.16			112.7	108.8	8.6	17.0	38.5	56.8	78.8	96.2	99.9	100.0
					182.68	0.08										
17	ACTUAL	285.	1.50	6.78			124.6	143.7	37.9	49.5	50.9	55.8	58.6	91.6	100.0	100.0
	PREDICTED	194.	1.02	1.76			119.5	125.7	9.5	22.6	39.1	55.1	81.2	93.5	100.0	100.0
					6.26	0.15										
18	ACTUAL	3548.	18.67	42.81			182.0	211.0	16.4	28.2	35.7	39.1	54.3	81.5	99.6	100.0
	PREDICTED	2246.	11.82	19.81			123.3	133.6	11.2	24.2	39.4	49.9	78.6	92.7	100.0	100.0
					35.43	0.32										
19	ACTUAL	66.	0.35	3.49			18.7	30.5	74.2	90.9	90.9	92.4	100.C	100.0	100.0	100.0
	PREDICTED	18.	0.09	0.20			101.4	117.4	8.4	28.9	41.1	74.8	89.5	95.9	100.0	100.0
					3.46	0.01										
20	ACTUAL	1185.	6.24	31.71			60.6	175.2	71.6	78.9	82.0	88.3	92.8	96.0	99.6	100.0
	PREDICTED	2085.	10.98	24.41			101.2	117.9	14.4	26.3	41.4	70.5	89.4	94.7	100.0	100.0
					29.05	0.16										
21	ACTUAL	321.	1.69	5.23			140.8	264.5	14.3	30.5	55.1	64.8	78.8	89.1	99.1	100.0
	PREDICTED	174.	0.91	2.10			100.4	117.7	8.2	27.7	54.7	73.0	88.9	94.8	100.0	100.0
					3.63	0.52										
22	ACTUAL	139.	0.73	4.50			60.7	156.0	41.7	89.9	89.9	91.4	92.8	95.7	100.0	100.0
	PREDICTED	17.	0.09	0.24			97.3	119.1	5.1	43.1	59.9	74.1	90.5	94.2	100.0	100.0
					4.47	0.01										
23	ACTUAL	130.	0.68	6.43			53.2	133.1	21.5	94.6	96.2	96.2	96.9	96.9	100.0	100.0
	PREDICTED	33.	0.17	0.50			96.9	119.3	3.5	39.8	61.3	74.0	89.1	94.2	100.0	100.0
					6.05	0.11										
24	ACTUAL	2451.	12.90	63.99			62.3	150.3	38.6	72.2	87.6	89.6	93.2	97.1	99.7	100.0
	PREDICTED	1857.	9.77	28.84			108.6	131.9	3.9	35.2	60.2	68.9	84.5	96.2	100.0	100.0
					53.28	0.31										
25	ACTUAL	60.	0.32	1.86			34.8	36.1	51.7	73.3	93.3	93.3	98.3	100.0	100.0	100.0
	PREDICTED	14.	0.07	0.20			104.8	130.5	3.3	29.2	62.8	69.6	85.7	96.4	100.0	100.0
					1.84	0.03										
26	ACTUAL	60.	0.32	1.89			45.5	74.3	56.7	83.3	86.7	88.3	95.0	98.3	100.0	100.0
	PREDICTED	14.	0.07	0.19			106.7	131.4	10.5	35.5	45.6	69.6	85.7	95.9	100.0	100.0
					1.84	0.05										
27	ACTUAL	670.	3.53	21.24			54.6	174.5	70.7	82.2	84.5	89.9	93.4	96.6	99.6	100.0
	PREDICTED	501.	2.64	7.24			112.9	136.0	13.6	25.9	42.3	65.7	82.9	95.5	100.0	100.0
					19.22	0.18										
28	ACTUAL	126.	0.66	3.92			90.7	315.6	29.4	87.3	88.1	93.7	96.0	96.8	98.4	100.0
	PREDICTED	31.	0.16	0.42			108.5	131.6	9.0	36.0	46.0	71.0	85.7	95.9	100.0	100.0
					3.81	0.05										

1970 KENTUCKY RECREATIONAL TRAVEL STUDY
KENTUCKY DEPARTMENT OF HIGHWAYS
MODEL EVALUATION

OPPORTUNITY MODEL EVALUATION

REC. ZONE		TOTAL TRIPS	MEAN TRIPS PER ORIGIN	STD. DEV. TRIPS PER ORIGIN	STD. ERROR	SQ. CORR. INDEX	MEAN TRIP LENGTH	STD. DEV. TRIP LENGTH	PERCENTAGE OF TRIPS HAVING LENGTHS LESS THAN OR EQUAL TO 25	50	75	100	150	300	1000	3000
29	ACTUAL	679.	3.57	14.83			40.9	164.8	68.8	87.0	92.5	94.3	97.9	99.1	99.6	100.0
	PREDICTED	1164.	6.13	14.13			112.7	130.6	4.8	21.8	44.4	62.7	86.8	95.6	100.0	100.0
					18.93	-0.63										
30	ACTUAL	2306.	12.14	63.15			70.9	167.7	64.4	77.6	80.5	85.6	89.8	95.1	99.2	100.0
	PREDICTED	548.	2.88	6.30			100.9	117.9	14.4	28.1	38.3	75.3	88.9	95.6	100.0	100.0
					60.98	0.07										
31	ACTUAL	3412.	17.96	122.35			91.1	208.4	55.6	69.1	72.4	76.3	80.8	91.6	99.2	100.0
	PREDICTED	2204.	11.60	20.11			116.9	131.1	8.1	22.3	40.3	59.9	85.2	93.6	100.0	100.0
					116.84	0.09										
32	ACTUAL	486.	2.56	14.24			144.9	231.4	52.7	55.3	57.0	58.4	63.6	82.1	99.0	100.0
	PREDICTED	996.	5.24	10.66			117.2	139.5	20.6	34.0	41.6	55.9	74.5	93.3	100.0	100.0
					11.44	0.35										
33	ACTUAL	545.	2.87	10.19			257.3	310.1	23.3	25.3	35.8	36.7	41.5	64.4	98.5	100.0
	PREDICTED	1953.	10.28	21.73			126.4	152.1	12.2	30.5	40.9	58.0	76.3	92.0	100.0	100.0
					20.19	-2.93										
34	ACTUAL	1930.	10.16	29.13			101.1	181.8	24.8	42.8	64.1	68.1	86.5	94.1	99.2	100.0
	PREDICTED	1267.	6.67	12.29			110.2	124.9	3.9	16.7	48.9	62.5	87.5	94.5	100.0	100.0
					23.78	0.33										
35	ACTUAL	286.	1.51	4.18			109.2	149.3	19.2	35.7	54.2	60.1	85.3	95.1	99.3	100.0
	PREDICTED	233.	1.23	2.30			115.4	131.9	3.7	17.8	49.8	62.9	87.8	93.8	100.0	100.0
					3.14	0.44										
36	ACTUAL	800.	4.21	17.19			104.8	162.0	26.9	44.9	48.4	74.6	85.1	94.3	99.4	100.0
	PREDICTED	1637.	8.61	17.77			135.2	148.3	8.6	18.6	32.7	53.0	79.4	90.5	100.0	100.0
					19.71	-0.32										
37	ACTUAL	941.	4.95	30.43			66.0	204.7	60.5	66.5	86.7	88.7	92.7	96.6	99.3	100.0
	PREDICTED	1136.	5.98	12.65			145.0	158.5	14.9	19.4	33.1	44.0	76.3	88.8	100.0	100.0
					26.49	0.24										
38	ACTUAL	1146.	6.03	36.26			47.1	116.5	58.9	81.6	84.0	92.1	94.5	98.3	99.7	100.0
	PREDICTED	554.	2.92	5.83			131.0	146.4	5.9	26.2	38.5	53.2	79.0	91.4	100.0	100.0
					35.13	0.06										
39	ACTUAL	1224.	6.44	49.10			71.0	199.7	71.2	77.9	80.6	81.9	86.1	96.2	99.4	100.0
	PREDICTED	695.	3.66	6.73			121.1	134.3	6.0	17.9	42.3	60.6	81.0	92.5	100.0	100.0
					48.86	0.01										
40	ACTUAL	2857.	15.04	97.94			57.3	173.4	75.7	79.3	81.1	82.3	89.6	95.3	99.6	100.0
	PREDICTED	2097.	11.04	22.07			134.3	159.6	17.5	25.7	43.3	54.6	75.9	90.4	100.0	100.0
					87.13	0.21										
41	ACTUAL	189.	0.99	8.86			95.5	223.4	75.1	75.1	76.7	76.7	79.4	92.1	99.5	100.0
	PREDICTED	206.	1.08	2.14			140.8	162.8	7.1	22.3	44.9	52.3	76.1	88.8	100.0	100.0
					8.73	0.03										
42	ACTUAL	1260.	6.63	78.55			48.6	122.8	86.0	88.7	89.2	89.9	91.9	95.2	100.0	100.0
	PREDICTED	134.	0.70	1.61			152.0	176.1	9.0	25.1	34.0	55.4	73.0	89.5	100.0	100.0
					78.15	0.01										

STATISTICAL ACCURACY OF TOTAL PREDICTION   L= 0.00033000

STANDARD ERROR	STANDARD DEVIATION	SQUARED CORRELATION INDEX
56.186	72.316	0.396

MEAN TRIPS PER INTERCHANGE   8.703

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