MODELS OF OUTDOOR RECREATIONAL TRAVEL

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The purpose of this investigation was to evaluate models of travel flow from population centers throughout the United States to outdoor recreational areas in Kentucky. Data were obtained by means of a license-plate, origin-destination survey at 160 sites within 42 recreational areas and by means of a continuous vehicle-counting program at 8 of these sites. Attempts to simulate distributed travel flows concentrated on various single-equation models, a cross-classification model, and gravity and intervening opportunities models. The cross-classification model was found to be an acceptable means for simulating and predicting outdoor recreational travel flows and was decidedly superior to the other models. From the cross-classification model, per capita distributed flows were found to decrease at a decreasing rate with increasing population of the origin zone, increase at a variable rate with increasing attraction of the recreational area, and decrease at a decreasing rate with increasing distance. The intervening opportunities model was found to be unacceptable as a distribution model because it could not effectively accommodate the widely differing sizes of the 42 recreational areas. The gravity model was quite effective in distributing actual productions and attractions. Problems associated with the gravity model were limited to difficulties in accurately estimating trip productions and attractions in the trip generation phase of analysis.

•THIS paper describes a comprehensive evaluation of several models of travel flow from population centers throughout the United States to outdoor recreational areas in Kentucky. Particular attention is focused on the information needs of highway planners. They require information such as simulation of the flow of vehicles within a short time period such as a day; simulation of distributed flows, that is, the flow from each origin zone to each recreational area; and consideration of all major recreational areas within the geographic bounds of interest regardless of type, function, or ownership.

NATURE OF PROBLEM

Conceptually, recreational travel flow is related to various factors determining that flow as follows:

$$V_{ij} = f(D_i, S_j, PR_{ij}, T, \overline{S}_{ij}, \overline{D}_{ij}, M) \quad (1)$$

where

- V = distributed recreational travel flow from origin zone i to recreational area j,
- f = some function,
- D_i = recreational demand at zone i,
- S_j = recreational supply at area j,
- PR_{ij} = average price of the recreational experience,
- T = time period,
- $\overline{S}_{ij}$ = supply of other recreational areas and facilities that competes with recreational area j for the limited demand at zone i,
- $\overline{D}_{ij}$ = demand of other origin zones that competes with origin zone i for the limited recreational supply at area j, and
- M = miscellaneous factors.

Thus, recreational flow may be visualized as a delicate equilibrium among the demand for recreational experiences, supply of recreational opportunities, price of recreation as modified by the competitive nature of the system, and other miscellaneous considerations. Two primary tasks of traffic flow modeling are to identify the most relevant, quantifiable, independent variables of Eq. 1 and to select a suitable function or algorithm for relating the dependent with the independent variables. Figure 1 shows many specific factors that have been used by others to quantify the conceptual variables of Eq. 1.

Recreational travel flow models may be classified in either of two distinct categories. The first includes "total flow" models designed to simulate the total flow produced at an origin zone or the total flow attracted to a recreational area. The second includes "distributed flow" models designed to simulate the flow between each origin zone and each recreational area. Output from distributed flow models can be used, through appropriate summation, to produce total flow simulations for both origin zones and recreational areas. The following are some prior studies in which recreational travel models have been developed: total flow models (18, 19, 22) and distributed flow models (1, 5, 6, 8, 10-14, 18-22).

The literature review failed to identify any distributed flow model that was superior to the other types. Therefore, it was decided to investigate four types, including single-equation, cross-classification, gravity, and intervening opportunities models. Single-equation models, used quite successfully by others (11, 14, 21), are particularly easy to calibrate and apply. Cross-classification models, apparently not used for recreational travel, have been successfully used for other travel not only as a simulation model but also as a means for visual examination of data trends (7). Finally, gravity and intervening opportunities models have been used quite successfully not only for recreational travel but also for travel in urban areas (3, 4, 16).

SURVEY PROCEDURES

Data for calibrating and evaluating the various models were collected by means of a license-plate, origin-destination (O-D) survey at 160 recreational sites in Kentucky during the summer of 1970. These data were supplemented by a traffic volume survey using continuous automatic traffic recorders at eight of the sites.

Peak travel to most outdoor recreational facilities in Kentucky occurs on summer Sundays, excluding from consideration certain holiday periods. The O-D survey was, therefore, conducted on Sundays, and modeling efforts were concentrated on average summer Sunday flows, a flow period suitable for planning and design of both recreational and highway facilities. Surveys were conducted at each site from 10 a.m. to 8 p.m. by one to three persons, depending on the level of travel anticipated. Data recorded for each observed vehicle included direction of movement (arriving or departing), type of vehicle, number of persons in the vehicle, and license-plate identification.

The license-plate identification was used to approximate the origin of the vehicle. A total of 190 origin zones were identified—120 counties in Kentucky, 10 zones in Ohio, 8 zones in Indiana, 6 zones in Tennessee, 3 zones in Michigan, and 1 zone for each of the remaining 43 coterminous states.

Each of the 160 survey sites was associated with 1 of 42 recreational areas. The sites were carefully selected such that the sum of flows passing all the sites associated with a given recreational area accurately represented the total flow to that area.

The 42 areas represent a major part of outdoor recreational activity in Kentucky. Specific areas were chosen to represent a variety of facilities from small fishing lakes to major national scenic attractions, a wide geographic distribution within the state, and a wide variety of operating agencies.

Details concerning the study techniques and other related information can be found elsewhere (15). However, it must be noted here that the license-plate, O-D study was found to be a very efficient way to obtain useful flow data even though certain information, such as trip purpose, could not be obtained and some error was introduced by assuming the point of the trip to be identical with the location of vehicle registration. Concentration on the period of normal peak flow, that is, the summer Sunday, proved extremely efficient and completely compatible with data requirements of this study.

Figure 1. Factors influencing outdoor recreation travel flow.

- A. Origin of Recreational Demand
  - 1. Participant
    - a. Family Characteristics
      - (1) Income of family head
      - (2) Education of family head
      - (3) Occupation of family head
      - (4) Leisure of family head (work week and paid vacation)
      - (5) Race
      - (6) National origin
      - (7) Automobile ownership
      - (8) Location of residence (urban or rural)
    - b. Individual characteristics
      - (1) Leisure
      - (2) Age
      - (3) Marital status
      - (4) Sex
      - (5) Education
  - 2. Origin area
    - a. Total population
    - b. Degree of urbanization
    - c. Median family or percapita income
    - d. Median education
    - e. Percentage of blue- or white-collar employees
    - f. Automobile ownership or registration
    - g. Retail sales
    - h. Property value
    - i. Median age
    - j. Median leisure (work week and paid vacation)
    - k. Race ratio
    - l. Nativity ratio
    - m. Unemployment ratio
    - n. Proportion of various types of employment
    - o. Residential density
    - p. Number of dwelling units
- B. Price of Recreational Experience (monetary and non-monetary)
  - 1. Spatial separation characteristics
    - a. Travel route quality
    - b. Travel time
    - c. Out-of-pocket travel costs
    - d. Distance (airline, road, or other)
  - 2. Charges for use of recreational facilities
  - 3. Cost of equipment rental or ownership
- C. Time Characteristics
  - 1. Holidays
  - 2. Cyclic conditions
    - a. Season
    - b. Month
    - c. Day of week
    - d. Time of day
- D. Competition
  - 1. Supply
    - a. Accessibility to closer recreational areas
    - b. Distance ratio (nearest competing area)
    - c. Sum of attractiveness of closer areas
    - d. Other
  - 2. Demand
    - a. Accessibility to closer origin zones
    - b. Sum of population closer
    - c. Other
- E. Miscellaneous Considerations
  - 1. Regional preferences
  - 2. Other
- F. Supply of Recreational Opportunities
  - 1. Water-oriented facilities
    - a. Lake
      - (1) Total acres
      - (2) Water level, temperature, and quality
      - (3) Miles of shoreline
      - (4) Acres for fishing, water skiing, boating, and sail boating
      - (5) Length or acres acres of beach
      - (6) Swimming areas
      - (7) Number of boat-launching ramps
      - (8) Number of rental boats
      - (9) Number of slips (open and closed)
    - b. Swimming pools
      - (1) Number
      - (2) Size
      - (3) Availability of bath house
  - 2. Intensive-use facilities
    - a. Number of golf holes
    - b. Area available for field sports
    - c. Number of tennis courts
    - d. Number and types of playgrounds
    - e. Availability of shooting range
    - f. Availability of archery range
    - g. Availability of bicycle rentals
    - h. Availability of sky lift
    - i. Availability of amusement park
    - j. Availability of skating rink
    - k. Availability of riding stables
  - 3. Extensive-use facilities
    - a. Trails and paths
      - (1) Miles of bicycling paths
      - (2) Miles of hiking and walking paths
      - (3) Miles of horseback-riding paths
    - b. Area available for hunting
  - 4. Composite size of area
    - a. Total undeveloped acreage
    - b. Total developed acreage
    - c. Total water acreage
  - 5. Eating facilities
    - a. Restaurant (number of seats)
    - b. Concessions
    - c. Picnicking
      - (1) Number of tables or area available
      - (2) Number of grills
      - (3) Number or area of shelters
      - (4) Availability of drinking water
    - d. Distance to nearest inn or store
  - 6. Overnight accommodations
    - a. Camping
      - (1) Number of sites and(or) acres
      - (2) Availability of bathhouse
      - (3) Availability of flush or pit toilets
      - (4) Availability of electricity
      - (5) Availability of laundry facilities
      - (6) Availability of firewood
      - (7) Availability of drinking water
    - b. Other
      - (1) Number of cottages
      - (2) Number of lodge rooms
      - (3) Number of motel rooms
      - (4) Total number of overnight accommodations
  - 7. Quality of physical environment
    - a. Terrain
    - b. Vegetation and shade
    - c. Wildlife
    - d. Water and shoreline
    - e. Climate
    - f. Historic and(or) cultural attractions
  - 8. Activities available
    - a. Wildlife exhibits
    - b. Naturalist service
    - c. Number of drama or concert seats
    - d. Museum
    - e. Lectures
  - 9. Other
    - a. Distance to nearest airport
    - b. Capital investment in recreational facilities

DEPENDENT VARIABLE

The number of vehicles departing a recreational area during the 10-hour survey period (10 a.m. to 8 p.m.) on the average summer Sunday was chosen as the dependent variable of the modeling efforts. The 10-hour period was selected to encompass the hours of primary flow in such a way that the endurance of one survey crew would not be exceeded. Departing flows were chosen to avoid a bias toward day users arriving on Sundays. In all cases, the number of vehicles departing during this period was, for all practical purposes, equal to the number of vehicles arriving during the same period. Use of the average summer Sunday avoided extreme peaks associated with summer holidays. At the same time, summer Sunday flows occur with sufficient frequency to justify their use in planning and design.

The 10-hour departing vehicular flow has little direct use in highway planning and design. However, it may be readily factored to yield estimates of more relevant flow variables. For example, the 10-hour departing flows can be multiplied by a factor ranging from 0.25 to 0.29 (average of 0.27) to estimate peak-hour, two-directional flows. Average summer Sunday, 24-hour, two-directional flows can be estimated by applying similar factors of 2.27 to 2.66 (average of 2.44) to the 10-hour departing flows. Finally, 10-hour departing flows can be multiplied by a factor of 0.58 to 1.13 (average of 0.91) to estimate average daily traffic. Average daily traffic, a two-directional 24-hour flow, is defined as the total annual flow divided by 365. The preceding factors were obtained by analyzing continuous traffic-count data obtained at seven sites located in large part at multipurpose state parks. The eighth site, at which volumes were continuously recorded, was excluded because it was not representative of typical recreational travel in Kentucky.

TOTAL FLOW MODELS

The gravity and intervening opportunities models required, as input, estimates of the number of trips produced at each origin zone that are destined to Kentucky outdoor recreational areas and estimates of the number of trips attracted to each recreational area. Such estimates are usually based on total flow models evaluated using regression techniques.

Productions

Kaltenbach (9) has summarized many independent variables used by others in regression equations for estimating productions. These include total population, urban population, number of dwelling units, median age, median family income, retail sales, sex, race, educational level, various measures of accessibility to recreational opportunities, and others. Chosen for evaluation here were total population, motor vehicle registration, total number of dwelling units, number of dwelling units per square mile, average effective buying income per household, and accessibility to recreational opportunities. Unfortunately, when the Kentucky origin zones were analyzed, very large linear correlations were found among the first four of these independent variables. Accordingly, population was chosen to represent this set of variables in order to avoid potential difficulties. Accessibility to recreational opportunities was expressed as

$$AR_i = \sum_j A_j F_{ij} \qquad (2)$$

where

AR_i = accessibility of origin zone i to recreational opportunities,
A_j = number of trips attracted to recreational area j, and
F_{ij} = F-factor of the gravity model corresponding to the distance between i and j.

Separate models were developed for out-of-state origin zones and in-state (Kentucky) origin zones to reflect distinctively different patterns in trip production. Several production equations evaluated are given in Table 1. The accuracy of these equations, as measured by the squared correlation coefficient R^2, is somewhat marginal. At the same time, a generalized, second-degree polynomial in the three independent variables yielded little increase in accuracy. Similarly, a cross-classification model showed no improvement.

Therefore, the following models were judged to be the most suitable among those investigated:

For out-of-state zones,

$$P_i = 803.1\ POP_i^{1.05}\ I_i^{4.19}\ AR_i^{1.03} \tag{3}$$

For in-state zones,

$$P_i = 4{,}050.3\ POP_i^{0.93}\ AR_i^{0.54} \tag{4}$$

where

P_i = productions of origin zone destined to Kentucky recreational areas,
POP_i = total population of the zone in millions,
I_i = average effective buying income per household of the zone in tens of thousands of dollars, and
AR_i = accessibility of zone to Kentucky recreational areas in millions of accessibility units.

Population and accessibility were important for both in-state and out-of-state zones, whereas family income significantly improved the accuracy only for out-of-state productions. Equations 3 and 4, combined with projections of future per capita recreational travel (2), allow predictions to be made of future productions of trips destined to Kentucky outdoor recreational areas.

Attractions

Development of a model to accurately simulate attractions was particularly difficult because of the wide variety among the 42 recreational areas. These areas included small fishing lakes such as Beaver Lake, large water-based resort complexes such as Kentucky Lake-Lake Barkley, and national scenic attractions such as Mammoth Cave. Kaltenbach (9) has also summarized many of the independent variables used by others to estimate trip attractions. Based on this summary, it was concluded that independent variables affecting attractions should include measures of the extent of water-oriented facilities, measures of the availability of overnight accommodations, measures of the development of day-use facilities, measures of the accessibility to population centers, and measures of the quality of the physical environment including historic, cultural, and scenic attractions.

The extent of water-oriented facilities was measured in terms of lake acreage (LAKE), linear feet of swimming beach (BEA), and square feet of swimming pools (POOL). Overnight accommodations were expressed as the sum of the numbers of campsites, cottages, and motel or lodge rooms (ON). Number of golf holes (GH), number of picnic tables (PIC), number of drama seats (DRAM), miles of hiking trails (HIK), and miles of horseback trails (HB) were used as appropriate measures of the development of day-use facilities. Accessibility to population centers was defined as

$$AP_j = \sum_i POP_i F_{ij} \tag{5}$$

where AP_j = accessibility of recreational area j to population. Unfortunately, it was impossible to devise suitable measures of the quality of the physical environment, and this factor had to be omitted from the analysis.

Linear regression analysis yielded the following simple equation for estimating attractions:

$$A_j = \underset{(0.17)}{10.2\ GH} + \underset{(2.08)}{3.28\ PIC} + \underset{(0.14)}{0.324\ ON} + \underset{(0.10)}{0.0643\ DRAM} + \underset{(0.15)}{2.24\ HIK} + \underset{(0.45)}{8.17\ HB}$$

$$+ \underset{(0.83)}{0.293\ BEA} + \underset{(1.92)}{0.227\ POOL} + \underset{(4.46)}{0.0986\ LAKE} \qquad (6)$$

The t-ratio for each regression coefficient, defined as the ratio of the value of the coefficient to its standard error, is shown in parentheses. Regression coefficients significantly different from zero at the 95 percent confidence level have t-ratios in excess of about 2.0. Unfortunately, Eq. 6 contains several independent variables not significantly different from zero at the 95 percent confidence level. Development of a similar equation in which all the independent variables are statistically significant yields the following:

$$A_j = \underset{(4.09)}{4.09\ PIC} + \underset{(2.16)}{0.211\ POOL} + \underset{(7.26)}{0.1111\ LAKE} \qquad (7)$$

Accuracy obtained with both Eqs. 6 and 7 was reasonably good as evidenced by R^2's of approximately 0.88. The R^2 was increased to 0.92 when the accessibility term, defined by Eq. 5, was included in either an additive or multiplicative form. However, use of this accessibility term was considered unacceptable because of the unreasonable negative coefficient in the additive equation and the similarly unreasonable negative exponent in the multiplicative equation.

Equation 6 or 7, combined with projections of future per capita recreational travel (2), can be used to make suitable predictions of future attractions for most recreational areas. However, attractions will generally be underestimated for recreational areas of high scenic appeal or areas that are very close to large population centers.

DISTRIBUTED FLOW MODELS

Single-Equation Models

Many of the factors in Figure 1 that influence outdoor recreational travel could have been considered as possible candidates for the independent variables of single-equation models. However, it was obvious that, to be manageable, the number of independent variables had to be much less than the number of factors shown in Figure 1. Furthermore, Matthias and Grecco (11) and Tussey (21) have concluded that simpler equations often produce better predictions than more complex ones.

Based on the literature review and the ease of acquiring data, we decided to represent the recreational demand at each origin (D_i of Eq. 1) by the single variable of population. This is certainly the most important of the demand-generating factors and one that is easy to acquire and easy to predict for future time periods.

The supply of recreational facilities (S_j of Eq. 1) was represented by attractions as estimated by Eq. 6. Selection of the estimated attractions to represent supply was based on the desirability for achieving consistency within the data base; a desire to include measures of day-use activity, overnight accommodations, and water-based activity; the necessity for including facilities present at all recreational areas; and an analysis of the importance of the variables based on the literature review.

The final factor to be considered was the price of the recreational experience (PR_{ij} of Eq. 1), represented here by the distance separating the origin zone from the recreational area. To determine the required 7,980 distances, we established a system of nodes including the 190 origin-zone nodes and the 42 recreational-area centroids. Links were then constructed connecting all adjacent nodes. Airline distances were used for the links interconnecting the 120 Kentucky origin zones, the 42 recreational areas, and the zones of Ohio, Indiana, Tennessee, and Michigan. Over-the-road distances were used outside these five designated states. The minimum path distances from each origin zone to each recreational area were determined using ICES TRANSET I (17).

Having selected the independent variables, the form of the expression to be evaluated was

$$V_{ij} = f(DIS_{ij}, POP_i, A_j) \tag{8}$$

where

V_{ij} = 10-hour departing vehicular flow between recreational area j and origin zone i,
f = some function,
DIS_{ij} = distance in miles between the recreational area and the origin zone,
POP_i = population of the origin zone in thousands, and
A_j = estimated attractions of the recreational area as defined by Eq. 6.

The first phase of the analysis was an attempt to simulate flows at individual recreational areas, disregarding effects of varying attractions by treating each area separately. Results of this analysis for three of the recreational areas are given in Table 2. In all cases, the attempt to use linear regression analysis on a transformed nonlinear equation proved futile. Hence, results from only nonlinear regression analyses are reported here. A similar difficulty has been noted previously by Matthias and Grecco (11).

First, the basic linear equation

$$V_{ij} = k_1 + k_2 DIS_{ij} + k_3 POP_i \tag{9}$$

was tested to verify the suspected nonlinearity. Small R^2's for each of the three recreational areas given in Table 2 were evidence of this nonlinearity.

Next, a relation of the type reported and used successfully by Tussey (21) was investigated:

$$V_{ij} = k_1 DIS_{ij}^{k_2} POP_i \tag{10}$$

Table 2 gives the notable improvement in R^2 that Eq. 10 offered as compared with Eq. 9. It was suspected, however, that the simple expression for the effect of distance in Eq. 10 would not be valid for such a wide range in distances as encountered in this study. A simple means for treating such a situation is to use dummy variables as indicated in the following equation:

$$V_{ij} = k_1 DIS_{ij}^{x_1 k_2 + x_2 x_3 + x_3 k_4} POP_i \tag{11}$$

where

x_1 = 1 for $0 < DIS_{ij} \le 100$ and 0 otherwise,
x_2 = 1 for $100 < DIS_{ij} \le 300$ and 0 otherwise, and
x_3 = 1 for $DIS_{ij} > 300$ and 0 otherwise.

Little or no improvement in R^2 resulted from the use of Eq. 11. Accordingly, use of dummy variables was dismissed from further consideration.

Concern for the effects of distance persisted, however, and it was decided to separate the data set into three parts based on short-, medium-, and long-range distance intervals and to evaluate Eq. 10 separately for each of these data subsets. Results of this evaluation, also given in Table 2, yielded no significant improvement over Eq. 11 or the first use of Eq. 10. It was concluded, therefore, that the effect of distance on distributed travel flows was adequately expressed by Eq. 10.

Preliminary examination of the O-D data had revealed that the per capita flows seemed to depend on the population of the origin zone, increasing population causing a decreasing per capita flow. This suggested that an equation of the following form might prove beneficial:

$$V_{ij} = k_1 DIS_{ij}^{k_2} POP_i^{k_3} \tag{12}$$

A nonlinear regression analysis was performed using Eq. 12 and data from Columbus-Belmont State Park. A substantial improvement was noted in R^2. However, the exponent on the population term was negative. Such an exponent fails to meet the test of reasonableness and suggests a high collinearity between the population and distance variables. Because of this unreasonableness and operational difficulties encountered in the regression analysis for the other two recreational areas given in Table 2, further attempts to examine Eq. 12 were abandoned.

A final equation of significant interest was reported by Matthias and Grecco (11) and is of the following form:

$$V_{ij} = k_1 e^{k_2 DIS_{ij}} POP_i \tag{13}$$

where e = base of natural logarithms. Equation 13, although producing satisfactory results as noted in Table 2, proved slighty inferior to Eq. 10.

It was next necessary to modify the form of the model to accept attractions (Eq. 6) as an independent variable measuring the supply of recreational opportunities. For these analyses, the data were separated into two subsets—one for distances less than or equal to 100 miles and the other for distances greater than 100 miles—in an attempt to reduce the population-distance collinearity and to recognize the large number of very small distributed flows for the longer distances. Because there were so many zero flows associated with the long-distance subset, cross-classification techniques were selected as the most acceptable means of analysis. The cross-classification matrix consisted of 180 cells representing all possible combinations of six distance groups, five population groups, and six attractiveness groups. Each distributed flow was entered into the appropriate cell as a departing flow per thousand people, and the weighted mean of all flows within each cell was recorded as the representative value.

The first model to be evaluated for the short-distance subset by nonlinear regression represented the following modification of Eq. 10:

For $DIS_{ij} \leq 100$,

$$V_{ij} = k_1 DIS_{ij}^{k_2} POP_i A_j^{k_3} \tag{14}$$

The total R^2 resulting from the use of this model was 0.28, and only 17 percent of the individual R^2's for the 42 recreational areas exceeded 0.50. These results were considered to be unsatisfactory, and the following model was suggested as a possible improvement:

For $DIS_{ij} \leq 100$,

$$V_{ij} = k_1 DIS_{ij}^{k_2} POP_i^{k_3} A_j^{k_4} \tag{15}$$

Unlike prior efforts to raise the population term to a power, this effort succeeded in producing the following acceptable least squares equation:

For $DIS_{ij} \leq 100$,

$$V_{ij} = 1.107\ DIS_{ij}^{-1.083}\ POP_i^{0.441}\ A_j^{0.868} \tag{16}$$

A total R^2 of 0.40 resulted from the use of this model. Detailed comparison of simulated versus actual flows indicated that the model consistently underestimated the larger flows and overestimated the smaller ones. However, all attempts to develop more accurate nonlinear regression models were unsuccessful.

Cross-Classification Model

Development and application of a cross-classification model is almost a trivial matter once the independent variables have been identified. For the analysis reported here, the same independent variables were used as for the single-equation models. The dependent variable was the 10-hour departing flow per 1,000 population of the origin zone. Figure 2 shows the complete model and identifies the categories into which the independent variables were classified. An R^2 of 0.68 was obtained using this model.

Portions of the model have been plotted (Fig. 3 through 5) to indicate visually the

Figure 2. Distributed vehicle flows per 1,000 people from cross-classification analysis.

ATTRACTIVENESS INDEX FACTOR GROUP	DISTANCES (MILES)	POPULATION (THOUSANDS) 0-10	10-100	100-1000	1000-10000	10000-100000
	0- 20	0.95898163	0.37657559	0.16223729	0.0	0.0
	20- 40	0.07621366	0.04382936	0.09810883	0.0	0.0
	40- 60	0.03046736	0.00665962	0.01014474	0.02425961	0.0
	60- 80	0.00447205	0.00213163	0.00075684	0.00793951	0.0
	80- 100	0.00501749	0.00134144	0.00087748	0.00135821	0.0
0- 100	100- 150	0.0	0.00209034	0.00086263	0.00042550	0.0
	150- 250	0.00236395	0.00113672	0.0	0.00008044	0.0
	250- 400	0.0	0.00194506	0.0	0.0	0.0
	400- 700	0.0	0.0	0.0	0.00001943	0.0
	700-1300	0.0	0.0	0.0	0.00002829	0.00000457
	1300-3000	0.0	0.0	0.0	0.00001465	0.00000711
	0- 20	1.13544655	5.72978306	0.0	0.0	0.0
	20- 40	0.50813001	0.64762914	0.16062135	0.0	0.0
	40- 60	0.09077013	0.07542700	0.19504023	0.0	0.0
	60- 80	0.00946701	0.04417120	0.03474323	0.0	0.0
	80- 100	0.00978377	0.02821740	0.01148133	0.0	0.0
100- 250	100- 150	0.01283454	0.01465168	0.00521773	0.01120973	0.0
	150- 250	0.0	0.01779335	0.00267404	0.00496950	0.0
	250- 400	0.00974108	0.01038040	0.00106779	0.00049610	0.00026823
	400- 700	0.0	0.0	0.0	0.00023177	0.00013441
	700-1300	0.0	0.0	0.0	0.00014438	0.00004732
	1300-3000	0.0	0.0	0.0	0.00001783	0.00003980
	0- 20	13.60512066	2.15327835	1.69190311	0.0	0.0
	20- 40	0.45618343	0.84385180	0.0	0.05734091	0.0
	40- 60	0.07118195	0.20437711	0.05361288	0.0	0.0
	60- 80	0.08550048	0.09662765	0.02636402	0.0	0.0
	80- 100	0.08958763	0.07254964	0.11188710	0.00930038	0.0
250- 500	100- 150	0.12461966	0.03304999	0.04490374	0.00147254	0.0
	150- 250	0.06225098	0.03363845	0.01334620	0.01168360	0.00223527
	250- 400	0.00599639	0.00172808	0.00508884	0.00435554	0.00706346
	400- 700	0.0	0.0	0.00032421	0.00202752	0.00088352
	700-1300	0.0	0.0	0.00074924	0.00085544	0.00085450
	1300-3000	0.0	0.0	0.00032310	0.00038885	0.00028194
	0- 20	17.07408142	14.42647648	4.35972214	0.0	0.0
	20- 40	1.23048592	0.98168427	0.06762052	0.0	0.0
	40- 60	0.34941846	0.26402664	0.11306220	0.0	0.0
	60- 80	0.08732462	0.07660019	0.69479340	0.0	0.0
	80- 100	0.04565455	0.04019441	0.06184201	0.04536866	0.0
500- 1000	100- 150	0.07295336	0.03790832	0.01202674	0.01365991	0.0
	150- 250	0.02795955	0.02301007	0.00477299	0.00526530	0.0
	250- 400	0.01548490	0.00816158	0.00185738	0.00121748	0.00260782
	400- 700	0.0	0.0	0.0	0.00050416	0.00029665
	700-1300	0.0	0.0	0.00008404	0.00026949	0.00026645
	1300-3000	0.0	0.0	0.0	0.00010759	0.00011941
	0- 20	19.38731934	5.39795589	0.0	0.0	0.0
	20- 40	1.09620857	1.13166714	0.49376857	0.0	0.0
	40- 60	0.22912484	0.44439262	0.34142214	0.0	0.0
	60- 80	0.05523006	0.12133151	0.40397137	0.08435732	0.0
	80- 100	0.06004418	0.04569305	0.04844257	0.09810972	0.0
1000- 2000	100- 150	0.02523594	0.04007056	0.01873372	0.01772470	0.0
	150- 250	0.03705391	0.01600631	0.00513345	0.00448848	0.0
	250- 400	0.01967793	0.00619185	0.00224304	0.00144763	0.00132626
	400- 700	0.0	0.0	0.00062903	0.00060745	0.00077247
	700-1300	0.0	0.0	0.00013438	0.00035780	0.00025655
	1300-3000	0.0	0.0	0.00027983	0.00028034	0.00013434
	0- 20	9.30527592	16.86503601	0.0	0.0	0.0
	20- 40	1.61003971	2.61544514	1.88730049	0.0	0.0
	40- 60	0.24922538	0.68204987	0.00874927	0.0	0.0
	60- 80	0.23705786	0.32020891	0.04441848	0.0	0.0
	80- 100	0.10578489	0.10133439	0.09276676	0.0	0.0
2000- 4000	100- 150	0.18476230	0.10318834	0.05605559	0.05523141	0.0
	150- 250	0.07273781	0.08328956	0.02152548	0.03683314	0.0
	250- 400	0.15019166	0.04602881	0.01176453	0.00443741	0.00067058
	400- 700	0.0	0.0	0.00090592	0.00138012	0.00214037
	700-1300	0.0	0.0	0.00047370	0.00087972	0.00033799
	1300-3000	0.0	0.0	0.00041116	0.00012996	0.00023882
	0- 20	4.85889149	21.91233826	0.0	0.0	0.0
	20- 40	0.24458832	27.33007813	0.0	0.0	0.0
	40- 60	0.0	2.28969002	0.0	0.0	0.0
	60- 80	0.93365526	1.73152637	0.00729106	0.0	0.0
	80- 100	0.55362606	0.55689758	1.63489532	0.0	0.0
4000-10000	100- 150	0.29150647	0.23062080	0.19563627	0.0	0.0
	150- 250	0.31635976	0.20414138	0.07663280	0.16524690	0.0
	250- 400	0.0	0.0	0.04418130	0.00874706	0.00447054
	400- 700	0.0	0.0	0.00181183	0.00144137	0.00092559
	700-1300	0.0	0.0	0.0	0.00086951	0.00094638
	1300-3000	0.0	0.0	0.00088904	0.00042389	0.00044779
	0- 20	107.38320923	111.47634888	0.0	0.0	0.0
	20- 40	41.39472961	21.06471252	0.0	0.0	0.0
	40- 60	6.48586330	20.13973999	0.66606885	0.0	0.0
	60- 80	5.39302994	6.34304714	0.0	0.0	0.0
	80- 100	1.95128021	2.99995136	0.0	0.0	0.0
10000-20000	100- 150	0.19966675	0.72808444	0.64073777	0.08552021	0.0
	150- 250	0.49463910	0.54417735	0.32898664	0.06843203	0.0
	250- 400	0.25180978	0.30700815	0.06867200	0.05273020	0.19035572
	400- 700	0.0	0.0	0.02297622	0.01006312	0.0
	700-1300	0.0	0.0	0.00549426	0.00490166	0.00383404
	1300-3000	0.0	0.0	0.00165747	0.00344839	0.00119410

Table 1. Production equations.

Equation	Squared Correlation Coefficient	
	Kentucky	Out-of-State
$P = a_1 + a_2POP + a_3AR$	0.67	0.10
$P = a_1 + a_2POP^{a_3} + a_4I^{a_5} + a_6AR^{a_7}$	0.71	—
$P = a_1POP^{a_2}I^{a_3}AR^{a_4}$	0.71	0.84
$P = (a_1 + a_2AR)^{a_3} (1 - e^{-a_4POP}) I^{a_5}$	0.74	0.83
$P = a_1POP^{a_2}AR^{a_3}$	0.70	0.71

Note: P = productions of an origin zone, POP = total population of zone, I = average effective buying income per household in zone, AR = accessibility of zone to Kentucky recreational opportunities, a_i = constants, and e = base of natural logarithms.

Table 2. Regression analysis for three recreational areas.

Equation Number (see text)	Squared Correlation Coefficient		
	Columbus-Belmont State Park	Kentucky Lake-Lake Barkley Complex	Lake Beshear-Pennyrile State Park
9	0.01	0.09	0.02
10	0.76	0.66	0.59
11	0.76	0.66	0.60
10[a]	0.76	0.71	0.61
12	0.95	—	—
13	0.71	0.57	0.60

[a]Separate calibrations were made for three data subsets based on distance intervals of 0 to 100 miles, 100 to 300 miles, and greater than 300 miles.

Figure 3. Effect of population on flow rate.

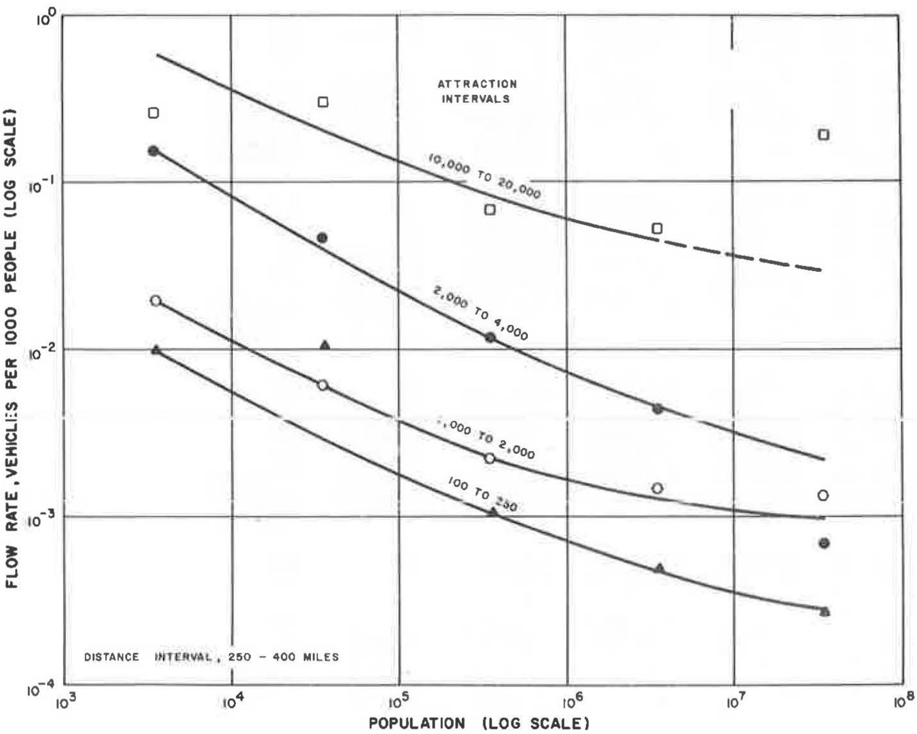


Figure 4. Effect of attractiveness of recreation area on flow rate.

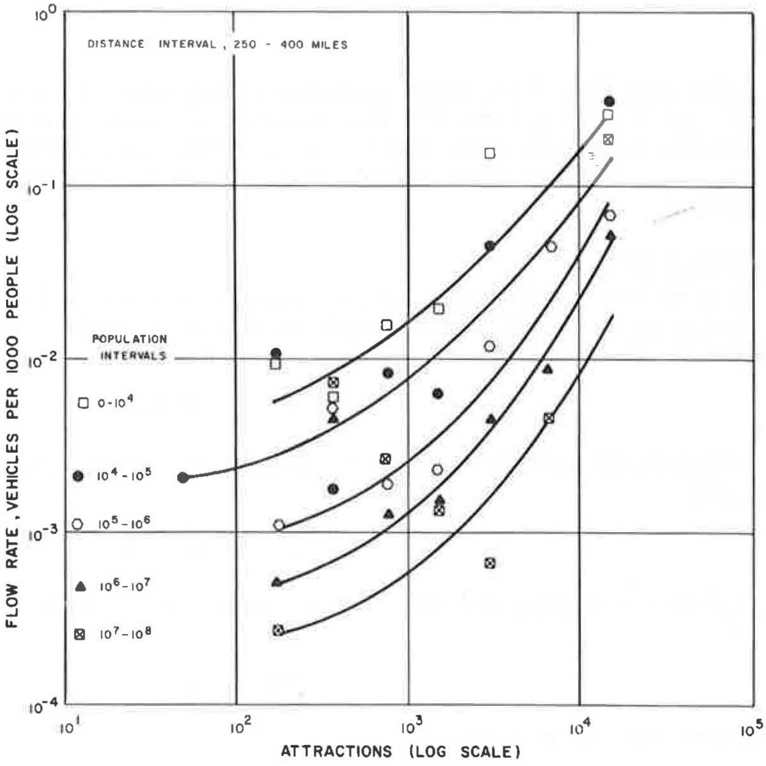
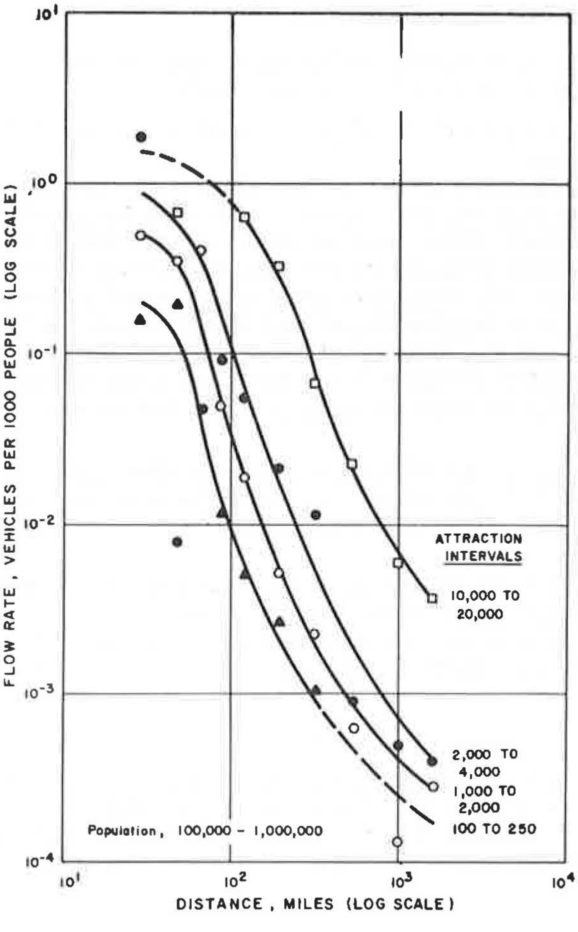


Figure 5. Effect of distance on flow rate.



effects of the three independent variables on flow rate. From the cross-classification model, per capita distrubuted flows were found to decrease at a decreasing rate with increasing population of the origin zone, increase at a variable rate with increasing attractions of the recreational area, and decrease at a decreasing rate with increasing distances.

Gravity Model

The gravity model in all of its varied forms is certainly the most widely used trip distribution model. The model employed here is of a form described by the Federal Highway Administration (3):

$$V_{ij} = P_i A_j F_{ij} / \sum_k A_k F_{ik} \tag{17}$$

In practice, the attractions (A_j) of Eq. 17 are replaced by "adjusted" attractions (AA) to yield

$$V_{ij} = P_i AA_j F_{ij} / \sum_k AA_k F_{ik} \tag{18}$$

Equation 18 was applied iteratively until the following constraining equality was satisfied:

$$\sum_i V_{ij} = A_j \tag{19}$$

Adjusted attractions were calculated as

$$AA_j = AA_j' A_j / \sum V_{ij}' \tag{20}$$

where

AA_j' = adjusted attractions from the prior iteration, and
V_{ij}' = distributed flows from the prior iteration.

A maximum of 10 iterations was required in this study to satisfy Eq. 19 and thereby balance the trip ends.

The gravity model must be calibrated before it can be applied; that is, the F-factors are determined as a function of distance. This was also an iterative, numerical procedure. A set of F-factors was first assumed, and the distributed flows (V_{ij}) were estimated using the actual productions and attractions from the O-D survey. During calibration, 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. In addition, the percentage of trips occurring within each of 19 distance intervals, as estimated by the model, was required to be within 5 percent of the corresponding value obtained by survey. If these conditions were not satisfied, new factors were estimated as follows:

$$\text{New F} = \text{old F} \; \frac{\text{percentage of trips in distance interval by O-D survey}}{\text{percentage of trips in distance interval by latest gravity model distribution}} \tag{21}$$

The process was then repeated until the convergence criteria based on average trip length and trip-length distribution were satisfied.

F-factors obtained from the calibration phase are given in Table 3. They are approximately related to distance as follows:

$$F_{ij} = k/DIS_{ij}^{2.1} \tag{22}$$

For purposes of comparison, F-factors developed by Smith and Landman (19) and Ungar (22) are also given in Table 3. With the exception of the shorter distances, F-factors developed here compared quite favorably with those of Ungar. However, they showed little similarity to the irregular F-factors developed by Smith and Landman.

The gravity model, using the F-factors of Table 3 and actual O-D survey productions and attractions, simulated trip interchanges quite accurately as evidenced by an R^2 of 0.89. Average trip length and trip-length distribution were also acceptable. However, when using simulated productions (Eqs. 3 and 4) and attractions (Eq. 6), the R^2 decreased to 0.52, indicating that the greater problem in using the gravity model for recreational travel is not the distribution model itself but rather the trip generation phase in which productions and attractions are estimated.

Intervening Opportunities Model

Like the gravity model, the intervening opportunities model is a distribution model requiring trip-end data as input. The model can be stated mathematically (4) as

$$V_{ij} = P_i\left[e^{-LA} - e^{-L(A+A_j)}\right] \qquad (23)$$

where

L = probability that a random destination will satisfy the needs of a particular trip, and
A = sum of attractions of all recreational areas closer to origin i than recreational area j.

The opportunities model of Eq. 23 does not automatically distribute all of the productions. This potential difficulty can be readily overcome by adding a constant K as follows (16):

$$V_{ij} = KP_i\left[e^{-LA} - e^{-L(A+A_j)}\right] \qquad (24)$$

in which

$$K = 1/\left(1 - e^{-L\sum_k A_k}\right) \qquad (25)$$

Trip-end balancing is also required with the opportunities model to ensure that

$$\sum_i V_{ij} = A_j \qquad (26)$$

This can be done by rewriting Eq. 24 in terms of "adjusted" attractions (AA and AA_j) as

$$V_{ij} = KP_i\left[e^{-LAA} - e^{-L(AA+AA_j)}\right] \qquad (27)$$

Equation 27 was applied iteratively until the trip ends were balanced; that is, Eq. 26 was satisfied. Adjusted attractions were computed following each iteration using Eq. 20.

Calibration of the opportunities model entails selection of the value of the probability parameter L that yields the best simulation of the actual O-D trip interchanges. Smith and Landman (19) suggested an iterative process whereby an initially assumed value of L is adjusted so that the simulated average trip length is nearly equal to the actual average trip length. For each iteration, a new L is calculated as follows:

$$\text{New L} = \text{old L}\ \frac{\text{calculated average grip length from prior iteration}}{\text{actual average trip length}} \qquad (28)$$

This method of determining L was originally attempted here, but convergence was extremely slow. Therefore, a new method was used whereby the initially assumed estimate was modified by a given increment in successive iterations and the optimum L selected as that that maximized R^2. This incremental method proved much more effective than the method suggested by Smith and Landman.

The best value of L was found to be 0.00033. This compared with a value of 0.00069 as reported by Smith and Landman (19). The large difference between these two L-values was due in part to the large difference in the total number of attractions between the two studies.

Using actual attractions and productions, the calibrated model simulated trip interchanges with an R^2 of 0.70. This was considerably less than that achieved with the gravity model. A second evaluation was made using the opportunities model in which trip ends were not forced to balance. This yielded an improved R^2 of 0.79 but, of course, violated the constraint of Eq. 26. It was concluded that the low accuracy achieved with this model was probably due to the fact that the 42 recreational areas demonstrated such a wide range in attractions (from a low of 45 to a high of 18,220). Pyers (16) has reported a similar problem and suggested that it might be overcome by using two different values of L—one for small generators and one for large generators. This possibility was not investigated here.

When simulated productions and attractions were used with the opportunities model, the accuracy with which trip interchanges were simulated, as measured by R^2, was 0.40. The large reduction in R^2 from 0.70 when actual productions and attractions were used further indicated that trip generation was a greater problem in recreational travel modeling than trip distribution.

COMPARISON OF MODELS

Adequacy of the four distributed flow models can be evaluated in many ways. Perhaps the best way is to compare the accuracy with which the 7,980 trip interchanges of the O-D survey can be simulated by each of the models. The R^2, a measure of this accuracy, is summarized for each of the types of models given in Table 4. The cross-classification model, which explained approximately 68 percent of the observed variance, was definitely the most accurate of the four models. A similar measure of accuracy is the percentage of the 42 recreational areas for which the models can simulate trips with an R^2 of at least 0.50. Based on this measure, the superiority of the cross-classification model is again given in Table 4.

Good distributed flow models will likewise accurately simulate average trip length and trip-length distribution. Table 4 indicates that, with the exception of the opportunities model, all models were satisfactory in simulating average trip length. A comparison of the actual and simulated trip-length distributions is shown in Figure 6. The cross-classification model was superior for simulating trip-length distribution, and the gravity model was adequate. However, the single-equation and opportunities models produced distributions that significantly departed from the actual both in position and in shape.

All models were calibrated essentially on the basis of average conditions. The degree to which the flows at any particular recreational area could be accurately simulated depended to a significant degree on how much the area deviated from average. Thus, for recreational areas that had significant day-use activity commonly associated with shorter trips, such as Lake Cumberland and Lake Barkley, the models predicted a longer than actual average trip length. On the other hand, for areas of primarily national interest, such as Mammoth Cave, the models predicted a shorter than actual average trip length. The manner in which this difficulty can be overcome is not readily apparent unless a stratification based on trip purpose can be used. This is obviously impossible with data obtained from a license-plate, O-D survey such as reported here.

Other factors useful in comparing model types are simplicity and ease of application. However, the single-equation and cross-classification models offered certain advantages over the gravity and opportunities models. These included more limited input data requirements and the possibility for making predictions without the use of a computer. In addition, they allowed less restrained use of independent judgment and permitted a single recreational area to be examined by itself.

In comparing only the two distribution models, the gravity model was considerably more accurate than the opprotunities model and simulated the actual trip-length distribution much better. It was also considerably less costly to calibrate and apply. In general, computer cost for the opportunities model was found to be three or four times more than that for the gravity model. The gravity model was able to handle the wide variety of sizes of the recreational areas, whereas the opportunities model was not able to do so.

Table 3. F-factors for gravity model.

Distance Interval (miles)	F-Factor[a] Developed Here	Smith and Landman (19)	Ungar (22)
0 to 10	10,735.62		1,545
11 to 20	3,400.18	4,290	1,267
21 to 30	917.27	4,090	750
31 to 40	483.68	2,540	376
41 to 60	162.22	2,790	180
61 to 80	90.21	90.2	90.2
81 to 100	36.09	22.9	54.4
101 to 125	21.01	11.5	34.6
126 to 150	11.60	4.69	22.9
151 to 200	8.86	0.70	13.6
201 to 250	5.07	0.00	6.2
251 to 325	3.11		
326 to 400	1.40		
401 to 550	0.65		
551 to 700	0.29		
701 to 1,000	0.20		
1,001 to 1,300	0.12		
1,301 to 1,700	0.08		
1,701 to 3,000	0.05		

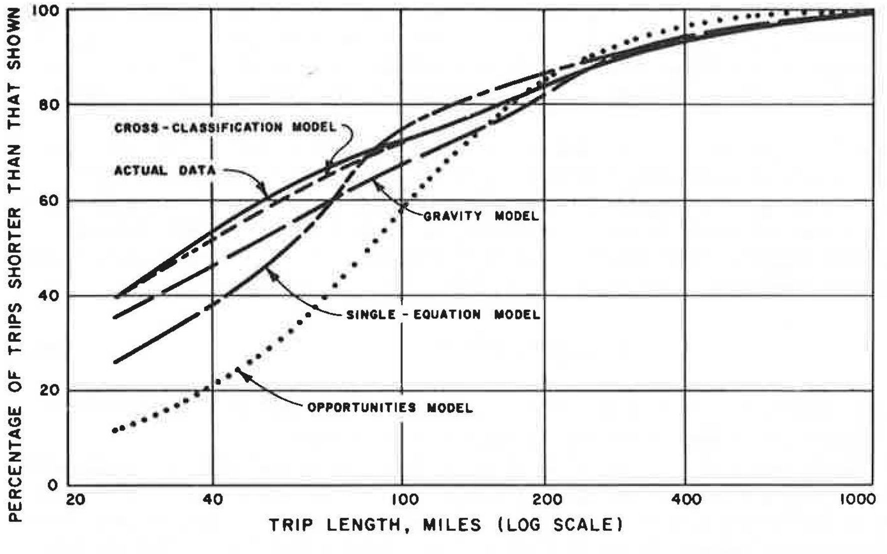
[a]F-factors of Smith and Landman and Ungar were modified by factoring to achieve conformity at a distance of about 70 miles.

Table 4. Model evaluation.

Model	Total R^2 [a]	Percentage of Recreational Areas With $R^2 \geq 0.50$ [b]	Average Trip Length[c] (miles)
Cross classification	0.679	45	113.7
Gravity	0.519	31	115.9
Single equation[d]	0.403	19	110.3
Opportunities	0.396	10	126.1

[a]Determined on basis of 7,980 distributed flows.
[b]Percentage of the 42 recreational areas having individual $R^2 \geqslant 0.50$.
[c]Actual average trip length was 109.0 miles.
[d]Equation 16 for distances less than or equal to 100 miles and a cross-classification model for greater distances.

Figure 6. Trip-length distributions.



Based on the preceding evaluations, the cross-classification model was certainly the best of the four models investigated here. Development of this model makes available for the first time an acceptable technique for simulating travel flows to outdoor recreational facilities in Kentucky. When coupled with projections of trends in per capita recreational activity (2), the cross-classification model should prove most effective in predicting future flows to either existing or proposed recreational facilities. Any type of outdoor recreational area can be considered so long as it is possible to estimate its attractions either by comparison with existing facilities or by the use of Eq. 6 or 7. The specific Kentucky model may have limited potential for use outside the state because recreational demand, the mix of available recreational facilities and activities, and consumer preferences vary regionally.

SUMMARY AND CONCLUSIONS

The purpose of this study was to evaluate different models for simulating average summer Sunday flows to outdoor recreational areas in Kentucky from population centers throughout the United States. The primary findings and conclusions of the study are as follows:

1. The impact of recreational travel can be evaluated in a way that is beneficial to highway planners by estimating distributed vehicular flows among all origin zones and all recreational areas during a short time period such as a day. The average summer Sunday is the day of most intense interest because outdoor recreational travel typically peaks on summer Sunday afternoons.

2. Overall results indicate the license-plate, O-D survey is a most satisfactory way to gather O-D data of the type required here, particularly because it enables maximum utilization of personnel without requiring voluntary participation of the traveler and because it allows a very large sampling rate. The time selected for the O-D survey, 10 a.m. to 8 p.m. on summer Sundays, proved to be completely acceptable. However, to be most useful, the O-D survey must be supplemented by a continuous traffic-counting program.

3. The pattern of trip production to outdoor recreational areas in Kentucky differed between in-state and out-of-state origin zones. For in-state zones, population (POP) and accessibility to recreational opportunities (AR) were the most significant indicators of productions. For out-of-state zones, population, average income (I), and accessibility to recreational opportunities were found to be significant. The best equation for simulating productions (P) was found to be of the following general form:

$$P = k_1 POP^{K_2}\, AR^{K_3}\, I^{K_4} \qquad (29)$$

However, such an equation explains only about 70 percent of the variance for in-state zones and about 84 percent of the variance for out-of-state zones.

4. Attractions (A) to recreational areas of varying types and sizes can be reasonably approximated by a linear equation involving the nature and extent of recreational facilities. The following facilities, listed in the order of highest to lowest significance, were identified as having important effects on attractions and were judged essential for encompassing the wide range of recreational areas studied: water area, picnic tables, swimming pools, horseback trails, beach, golf, hiking trails, overnight accommodations, and outdoor drama. The linear equation utilizing these variables explained about 89 percent of the variance in attractions. However, this equation proved unsuitable for simulating attractions at areas deviating significantly from the average, such as those of high scenic interest and those highly accessible to large population centers.

5. Four types of travel models, including single-equation, cross-classification, gravity, and intervening opportunities models, were evaluated here. The cross-classification model was found to be the most acceptable means for simulating and predicting distributed outdoor recreational travel flows. In virtually any travel modeling effort, cross-classification analysis can be gainfully employed if only for the purpose of visually depicting the effects of various independent variables.

6. The cross-classification model demonstrated that per capita distributed flows decrease at a decreasing rate with increasing population of the origin zone, increase at a variable rate with increasing attractions of the recreational area, and decrease at a decreasing rate with increasing distance.

7. The best single-equation model for simulating distributed flows (V_{ij}) for short-range travel was of the form

$$V_{ij} = k_1 DIS_{ij}^{k_2} POP_i^{k_3} A_j^{k_4} \tag{30}$$

where DIS_{ij} = distance between origin zone i and recreational area j. This nonlinear flow equation, as others investigated here, had to be evaluated using nonlinear regression analysis. Linear regression using transformed (linearized) equations proved totally unsuitable.

8. The gravity model is a simple and effective model for distributing recreational trips. Accuracy of the trips so distributed depends in large part on the accuracy of estimating productions and attractions. F-factors developed in the gravity model calibration are a convenient and useful means for explaining the effects of distance on travel impedance.

9. The intervening opportunities model can be calibrated very effectively by incrementing the probability parameter L in such a way as to maximize the accuracy of the trip-interchange simulation. However, the opportunities model was found to be decidedly inferior to the gravity model. The intervening opportunities model cannot produce satisfactory results with only one value of L if recreational areas of widely differing attractiveness are present in the study area.

10. For flow models using distinct trip generation and distribution phases, trip generation was found to be the most critical problem in outdoor recreational travel modeling.

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