A MODEL FOR ALLOCATING RECREATIONAL TRAVEL DEMAND TO NATIONAL FORESTS

Peter Gyamfi, International Bank for Reconstruction and Development, Washington, D. C.*

This paper documents the development of a model for allocating travel demand and the subsequent application of this model to allocate recreational demand from the centers of population in California to the main entrances of the national forests in California. The model, which is based on the principles of systems analysis, first decomposes the recreational system into a set of origin components, destination components, and travel link components. Each of these classes of components is then modeled separately in terms of its characteristics. The final model is the aggregation of the mathematical description of each component and the mode of interconnection of the components. The model has the capability of allocating travel demand in one step. The results of its application to California proved its ability to simulate the recreational travel system.

•THIS PAPER describes the development and application of an analytical model for allocating recreational demand from population centers in California to the national forests in the state. The work described is part of a package of analytical techniques developed at the University of California, Berkeley, to aid the U. S. Forest Service in its resource management planning process.

In planning for resource management in a national forest it is necessary to estimate the future recreational travel demand and the spatial distribution that it will follow. This estimation process is accomplished by a set of analytical models based on (a) the locations and characteristics of the forest resources and developed recreation areas; (b) the characteristics of the forest transportation system; (c) the locations and characteristics of population centers within a reasonable journey time to the forest; (d) the characteristics of the regional transportation system that links the population centers to the study forest; (e) the locations and characteristics of "competing" recreational complexes in the area; and (f) knowledge concerning the travel behavior of recreationists.

These analytical models deal with two levels of problem. The first problem is one of estimating the number of visitors that will be drawn to the study forest from the surrounding population centers. The second problem is to predict how these visitors, once there, will disperse to the many possible locations within the study forest. In order to deal with the bi-level nature of the problems without overemphasizing one level at the expense of another, two distinct allocation levels were modeled. They are the "macro-allocation" stage, which estimates the number of visits from the population centers to the study forest as a whole, and the "micro-allocation" level, which estimates the traffic on the forest roads and to the forest recreational areas.

The development of a macro-allocation model, based on systems analysis techniques, and the application of this model to allocate recreational flows to the national forests in California are described in the following sections.

---

*At the time this research was performed Dr. Gyamfi was with the Institute of Transportation and Traffic Engineering, University of California, Berkeley.

THEORETICAL FRAMEWORK OF MODEL

Choice of Approach

The systems model described next was selected for analyzing the macro-allocation of recreational trips. This choice was based on a review of literature concerning available models as well as an investigation of possible new approaches to modeling macro-allocation. It was concluded from earlier applications (1, 2, 3) that the systems model could be suitable for this problem if it were modified to improve its behavioral content and its predictive power.

Description of the Model

The systems model is based on a body of analytical techniques developed to simulate the behavior of certain physical systems. These techniques have the ability to characterize completely the interactive properties of a system by formulating a set of simultaneous equations that mathematically describe all components of the system and their mode of interconnection. Certain general steps are followed in the analysis of any system by this method. These steps, which are described in detail below, are shown in Figure 1.

The first step in the analysis of a system is the choice of units of the system as components. This choice generally depends on the type of system being analyzed as well as the purpose of the analysis. Specifically applied to the allocation of recreational travel demand to recreation areas, three classes of components are identified: (a) generating areas, or origins; (b) impedance components, or transportation links; and destination components, or national forests.

The second step in the analysis is the mathematical description of the components selected in step 1. This description is associated with two fundamental measurements of the components. In the purely physical systems (electrical, mechanical, heat transfer, etc.) these measurements are such that one is a "through" or "series" measurement, denoted Y, and the other an "across" or "parallel" measurement, denoted X. In the recreational system the through variable is the flow of recreationists in the system while the across variable is the propensity causing this flow.

Once the components have been selected and the basic measurements chosen, it is possible to formulate equations describing the system characteristics. These equations, called component terminal equations, have the general formula

$$Y = k \cdot f(\Delta X) \tag{1}$$

where k is a constant that depends on component parameters and X and Y are the fundamental measurements. The terminal equations of the three classes of components in the recreational system are derived in the following sections.

The Origin or Demand Components

The origin components were considered as sources of flow of recreationists. These are counties or groups of counties and some out-of-state areas. The general equation for the origins was

$$Y_i = \text{known}$$

The known flows are the output of a macro-generation model (4) developed for the purpose. No attempt will be made here to describe this model in detail. As specifically applied to recreational trip generation in California, the model had the formulation

$$Y_i = 138.6\ P_i^{0.385}\ D_i^{0.025} \tag{2}$$

for day trips and

$$Y_i = 88.3\ P_i^{0.382}\ D_i^{0.137} \tag{3}$$

for overnight trips, where

Y_i = the total recreational demand at origin i;
P_i = the population of origin zone i; and
D_i = accessibility of origin zone i to all national forests in California; i. e.,

$$D_i = \sum_j A_j d_{ij}^{\gamma 1} \tag{4}$$

where

γ_1 = -1.90 for day trips,
γ_1 = -1.50 for overnight trips,
A_j = attraction index of the forest j, and
d_{ij} = travel time from zone i to the forest j.

The Transportation Links

The class of system components comprising the transportation links is analogous to electrical resistance. At the macro-level, travel corridors are used as the travel links. The performance of each link is related to its travel impedance by the equation

$$Y_{1i} = K_1 \frac{1}{(R_{1i})} K_2 \, \Delta X_{1i} \tag{5}$$

where

Y_{1i} = the link flow through link i;
X_{1i} = the propensity to travel across link i;
R_{1i} = the link resistance of link i; and
K_1, K_2 = calibration constants.

The link resistance was assumed to be the total cost to the recreationists in traversing the link. This includes out-of-pocket costs, costs associated with travel time, costs associated with aesthetics, etc. It is interesting to point out that some of these costs might be negative. This is true for scenic routes where a longer distance on travel time might be desirable. As other modes of transportation become available for forest recreational travel, costs associated with arrival time variability and waiting time en route will have to be considered.

The resistance factor can be represented by the product of a link performance vector and an associated cost vector as follows:

$$R_1 = LPV \times ACV = \begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \end{bmatrix} \quad \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{bmatrix} \tag{6}$$

where

$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \end{bmatrix} = \begin{bmatrix} \text{travel time en route} \\ \text{waiting time en route} \\ \text{arrival time variability} \\ \text{aesthetic coefficient} \\ \text{travel distance} \\ \text{tolls} \end{bmatrix}$$

and C_1, C_2, . . . , C_6 are costs associated with the L's.

In this study it was possible to take into consideration only the total travel times and the tolls paid in traversing a link.

The Destination Components

The destination areas, the national forests, are modeled by equations that relate their attraction potential to their physical attractiveness. The latter is based on the physical and natural resources of the forest and the facilities and services provided to support these activities.

The equation for the destination areas is

$$Y_{di} = K_3 \, A_{di} \, f(\Delta X_{di}) \tag{7}$$

where

Y_{di} = attracted trips to destination i;
ΔX_{di} = the potential for recreational trip attraction;
K_3 = the attraction calibration constant; and
A_{di} = the attraction index of forest i.

Both the attracted trips, Y_{di}, and the potential for trip attraction, ΔX_{di}, are unknown in this equation. The attraction index, A_{di}, can, however, be obtained as the output of a macro-attraction model. A detailed description of this model, including its theoretical development, methodology, and analysis of results, is given elsewhere (4). An attraction index is a quantity that describes the relative attractiveness of a forest with respect to competing recreation complexes for a particular type of recreational trip. Three factors govern the value of this index: (a) the outdoor recreational activity preference of recreationists; (b) the on-site natural resources that enhance the recreational experience; and (c) the on-site facilities and services that complement the recreational resource. The natural resources in a forest determine the nature of the activities possible, while the facilities and services condition the activity opportunities. The interconnection among these three elements is shown in Figure 2.

It is possible to quantify or index the attractiveness of a forest if the three elements are identified and quantified. Table 1 gives the participation rates of recreational activities in the United States, and Table 2 gives the characteristic variables of a forest with the corresponding rating scores. Finally, Table 3 gives the attraction indices for the 18 national forests in California.

Formulation and Solution of the System Equations

Once the classes of recreational system components have been selected and modeled, it is possible to formulate mathematical equations to describe quantitatively the interaction of the components of the systems. The technique used to accomplish this depends on the nature of the system. For the analysis of the recreational system the linear graph technique was used.

The construction of the linear graph for the forest recreational system follows the same steps as those used for the physical systems. The first step is the representation of each of the components by its terminal graph. The second step is to join together, by their vertices, the component terminal graphs so that the resultant is in one-to-one correspondence with the union of the physical system. Figure 3 shows a simple transportation system with its corresponding linear graph.

Like other systems, the recreational system obeys the "cutset" and "circuit" postulates. The "cutset" postulate, which is a generalization of Kirchoff's current law, states that the algebraic sum of the flows at any node equals zero. The justification of this postulate in traffic flow is that, if there is no storage within the system, then there is a continuity of flow in the system and what goes in must come out.

The circuit postulate, on the other hand, equates the potential to travel around a closed circuit to zero. The basis of this postulate in traffic flow is that as a recreational trip from a node progresses the original desire for the trip dissipates and reduces to zero by the time a closed circuit is completed.

Figure 1. Steps in the solution of a system by linear graph methods.

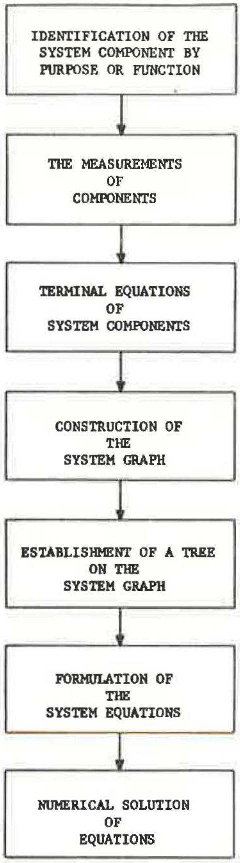


Figure 2. Interrelationship of natural resources, activity preferences, and facilities and services.

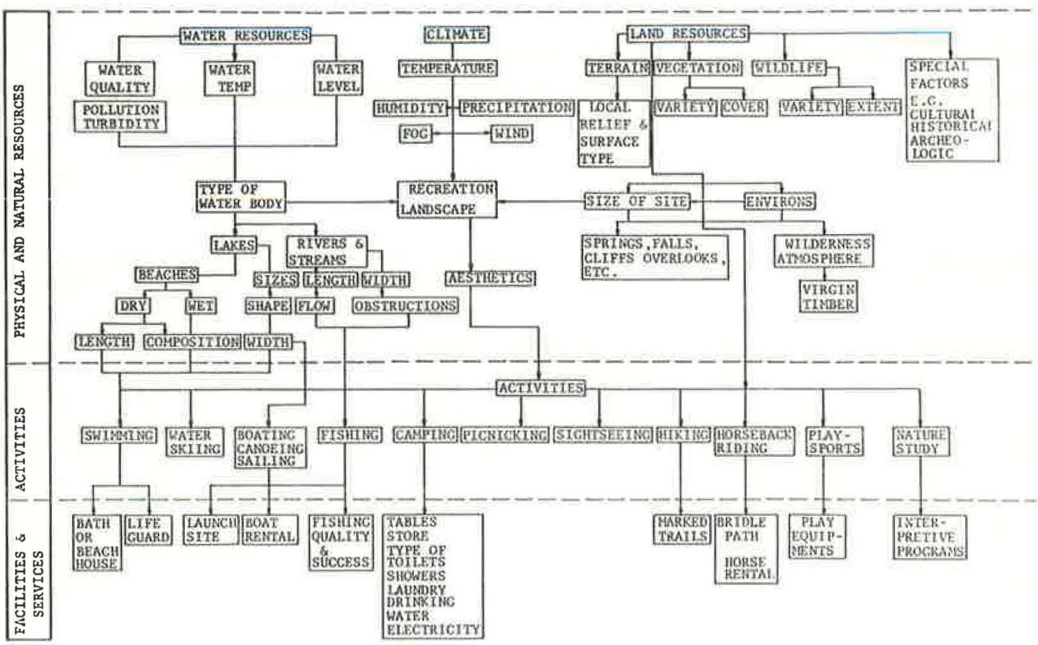


Table 1. Participation rates for outdoor recreational activities in the United States.

Activity	Percent Participation	Activity	Percent Participation
Picnics	53	Attending outdoor concerts, etc.	9
Driving for pleasure	52	Camping	8
Swimming	45	Hiking	6
Sightseeing	42	Horseback riding	6
Walking for pleasure	33	Water skiing	6
Playing outdoor games	30	Miscellaneous	5
Fishing	29	Hunting	3
Attending outdoor sports	24	Canoeing	2
Other boating	21	Sailing	2
Nature walks	14	Mountain climbing	1
Bicycling	9		

Source: National Recreation Survey, Study Report No. 19 (U.S. Govt. Printing Office, 1962).

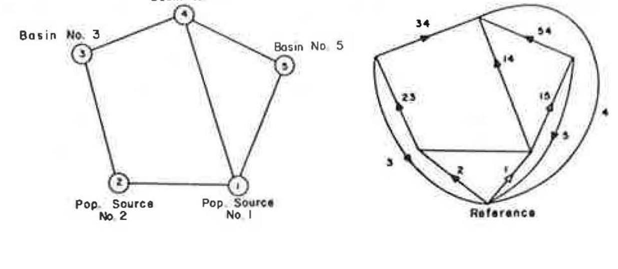
Table 2. Forest characteristics.

Variable	Score
1. Lake acreage	10,000 acres
2. Swimming quality	Sand—5, gravel—4, timbered—3, soil mud—2, rock—1, none—0
3. Presence of designated and protected swimming areas	Present—1, absent—0
4. Boat launching facilities	Present—1, absent—0
5. Lake fishing quality	Excellent—4, good—3, fair—2, poor—1, none—0
6. Stream and river fishing quality	Excellent—4, good—3, fair—2, poor—1, none—0
7. Presence of lifeguard	Present—1, absent—0
8. Boating quality	Excellent—4, good—3, fair—2, poor—1, none—0
9. Boating restrictions	Normal—3, speed-limit—2, no-motor—1, no-boating—0
10. Bath house	Yes—1, no—0
11. Local relief	Mountainous—4, hilly—3, rocky—2, flat—1
12. Land reform	Resources present—1, resources absent—0
13. Vegetation type	Evergreen—4, mixed evergreen and deciduous—2, deciduous—2, barren—1
14. Presence of virgin timber	Virgin—2, mixed—1.5, cut-over—1
15. Presence of unusual vegetation	Present—1, absent—0
16. Extent of cover shade	Over 75 percent shaded—4, 50-75 percent shaded—3, 25-50 percent shaded—2, 10-25 percent shaded—1, under 10 percent shaded—0
17. Special factors	Number of special features
18. Quality of backwoods areas	No detractions—5, minor detractions—4, substantial detractions—3, serious detractions—2, unacceptable detractions—1
19. Quality of wildlife habitat	Excellent—3, normal—2, poor—1
20. Store at camp	Out of site—2, on site—1
21. Showers	Yes—1, no—0
22. Toilet type	Combination—3, flush—2, pit—1
23. Laundry	Yes—1, no—0
24. Electricity	Yes—1, no—0
25. Marked bridle trails	Yes—1, no—0
26. Boat rental	Yes—1, no—0
27. Horse rental	Yes—1, no—0
28. Children's play equipment	Play sports—1, equipment—2

Table 3. Attraction indices of national forests.

Forest Name	Attraction Index	Forest Name	Attraction Index
"A"	0.76	"J"	0.21
"B"	0.53	"K"	0.31
"C"	0.69	"L"	0.98
"D"	0.68	"M"	0.47
"E"	0.25	"N"	0.45
"F"	0.25	"O"	0.93
"G"	0.62	"P"	0.71
"H"	0.18	"Q"	0.73
"I"	0.16	"R"	0.53

Figure 3. Transportation system (left) and linear graph of transportation system (right).



These postulates yield two sets of systems equations. One set of equations can be written for the through variables, Y, at each vertex of the system linear graph. Symbolically, this set of equations can be written as

$$\sum_{j=1}^{e} a_j Y_i = 0$$

where

$$a_j = \begin{cases} 0 \text{ if the } j\text{th element is not incident at the } k\text{th vertex;} \\ 1 \text{ if the } j\text{th element is oriented away from the } k\text{th vertex;} \\ -1 \text{ if the } j\text{th element is oriented toward the } k\text{th vertex; and} \end{cases}$$

e = the number of elements in the system.

The second set of equations, which involve the across variable (X), can be written for each circuit in the linear graph as

$$\sum_{j=1}^{e} b_j X_j = 0$$

where

$$b_j = \begin{cases} 0 \text{ if the } j\text{th element is not included in the } k\text{th circuit;} \\ 1 \text{ if the orientation of the } j\text{th element is the same as the orientation chosen for} \\ \quad \text{the } k\text{th circuit; and} \\ -1 \text{ if the orientation of the } j\text{th element is opposite to that of the } k\text{th circuit.} \end{cases}$$

This set of equations, together with the component terminal equations, constitutes the set of system equations. Theoretically it should be possible to solve the system equations to obtain the X and Y values for each component. In practice, the number of equations is so large that a number of shortcuts are required to reduce computer memory requirements. These shortcuts and a listing of the computer programs used to formulate and solve the system equations are given elsewhere (4).

APPLICATION OF THE MODEL TO NATIONAL FORESTS IN CALIFORNIA

This section describes the calibration and application of the systems model to simulate recreational travel to the national forests in California. Figure 4 shows the California national forests. The schematized regional transportation network is shown in Figure 5.

The components used in this test of the systems model are origin areas that represent counties, or groups of counties, and some out-of-state areas; 18 national forests in California; and the transportation network linking the origin areas with the national forests. The linear graph representation of the regional system is shown in Figure 6.

Input data to the model consisted of the origin flows computed by the macro-generation model (Table 4), the attraction indices of the national forests computed by the macro-attraction model (Table 3), and the travel time and flows associated with the 148 travel links representing the regional transportation system.

Calibration of the Systems Model

Calibration of the systems model involves estimation of the values of three parameters, K_1, K_2, and K_3 from Eqs. 5 and 7, that enable the model to duplicate best the observed travel pattern in the transportation network. Two levels of calibration were performed: coarse calibration runs followed by a set of fine calibration runs. The first calibration run involved the attraction constant, K_3. Four calibration runs were performed using values for K_3 of 0.001, 0.005, 0.01 and 0.05. From the patterns of the standard deviation of predictions obtained, K_3 was chosen at 0.005 with a coresponding standard error of prediction of 49.8 percent.

Figure 4. National forests and regional transportation system in California.

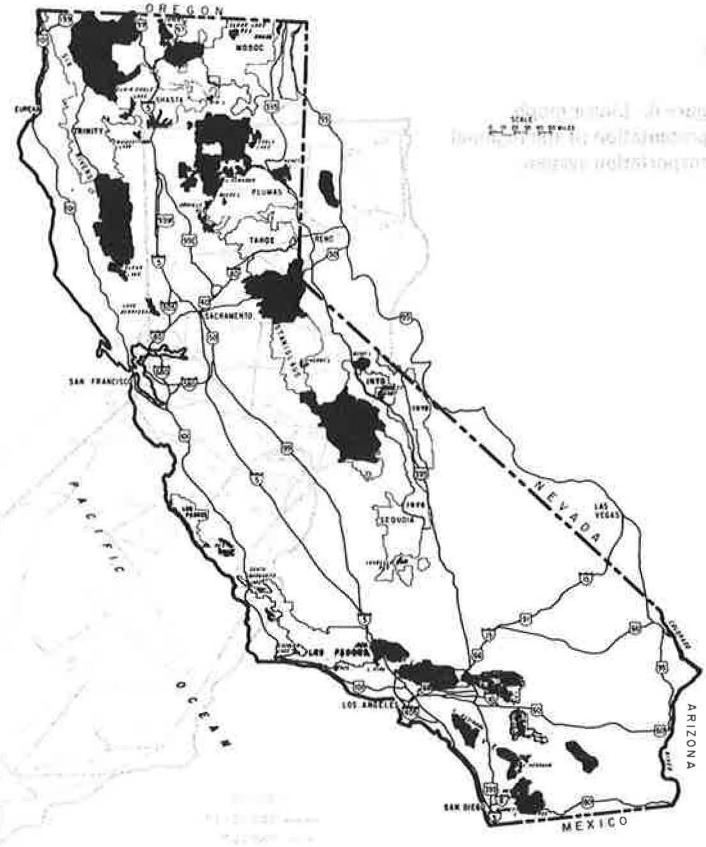


Figure 5. Schematized regional transportation network in California.

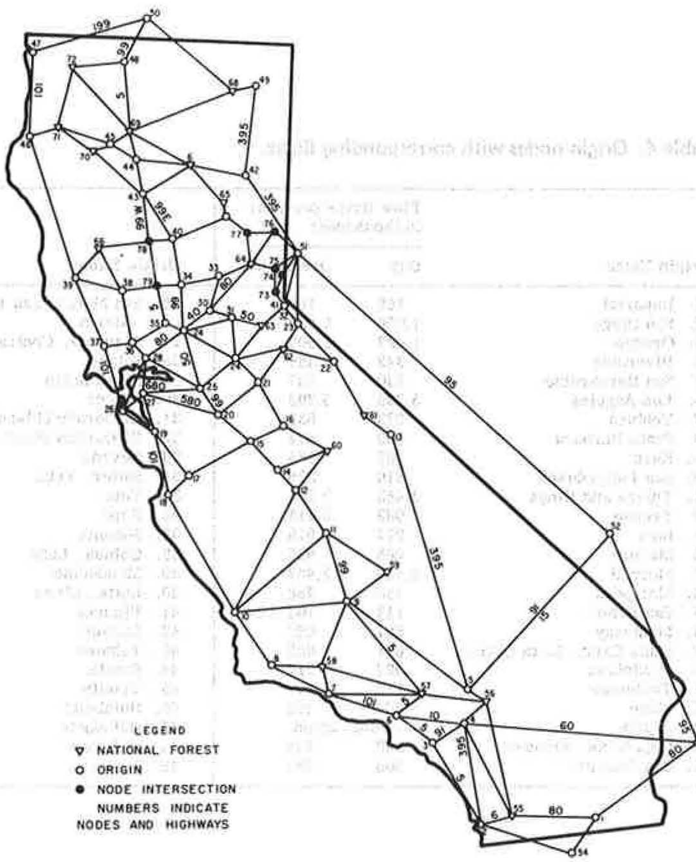


Figure 6. Linear graph representation of the regional transportation system.

Table 4. Origin nodes with corresponding flows.

Origin Name	Flow (trips per year in thousands) Day	Overnight	Origin Name	Flow (trips per year in thousands) Day	Overnight
1. Imperial	168	160	26. San Mateo, San Francisco, Marin	912	1,000
2. San Diego	1,056	1,030	27. Alameda, Contra Costa	989	945
3. Orange	1,022	1,007	28. Solano	90	85
4. Riverside	342	368	29. Sacramento	903	915
5. San Bernardino	630	627	30. Placer	473	491
6. Los Angeles	5,725	5,705	31. El Dorado (Placerville)	163	182
7. Ventura	623	638	32. El Dorado (South Lake Tahoe)	142	168
8. Santa Barbara	650	672	33. Nevada	115	103
9. Kern	585	585	34. Sutter, Yuba	203	213
10. San Luis Obispo	310	325	35. Yolo	350	377
11. Tulare and Kings	2,463	2,603	36. Napa	159	144
12. Fresno	5,082	5,113	37. Sonoma	356	330
13. Inyo	877	919	38. Colusa, Lake	93	70
14. Madera	965	935	39. Mendocino	132	127
15. Merced	2,589	2,487	40. Butte, Glenn	256	261
16. Mariposa	430	488	41. Plumas	93	107
17. San Benito	113	103	42. Lassen	467	447
18. Monterey	567	656	43. Tehama	177	163
19. Santa Cruz, Santa Clara	611	605	44. Shasta	542	579
20. Stanislaus	927	917	45. Trinity	378	402
21. Tuolumne	113	103	46. Humboldt	582	560
22. Mono	464	488	47. Del Norte	164	186
23. Alpine	No information		48. Siskiyou	415	446
24. Calaveras, Amador	368	384	49. Modoc	158	182
25. San Joaquin	505	482			

Figure 7. Actual attendance versus predicted attendance.

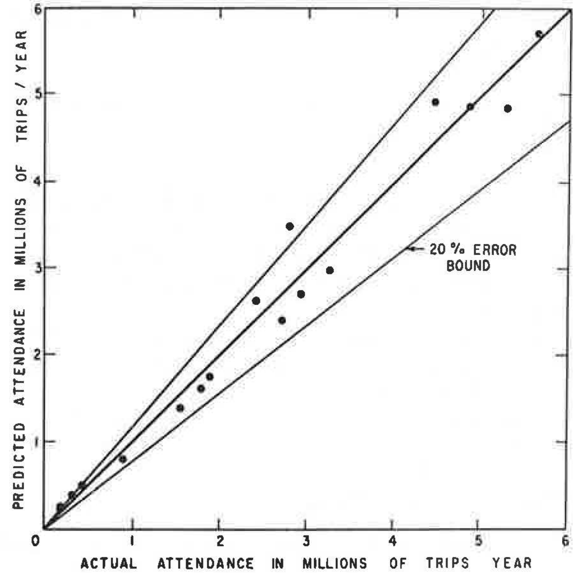


Table 5. Comparison between actual and predicted attendance (trips per year).

Forest Name	Actual Attendance (in thousands)	Predicted Attendance (in thousands)	Percent Difference
"A"	5,633	6,253	+11.0
"B"	1,783	1,694	-5.0
"C"	2,693	2,570	-4.6
"D"	4,875	5,133	+5.3
"E"	424	461	+8.8
"F"	1,831	1,769	-3.4
"G"	2,945	2,833	-3.8
"H"	315	338	+7.3
"I"	236	246	+4.2
"J"	893	826	-7.5
"K"	5,289	4,802	-9.2
"L"	1,523	1,459	-4.2
"M" and "N"	3,273	3,178	-2.9
"O"	4,458	4,759	+6.7
"P"	236	251	+6.4
"Q"	2,411	2,554	+5.9
"R"	2,798	2,690	-3.9

The fine calibration involved trying different values of K_1 and K_2, the link resistance constant and exponent respectively. With the destination attraction constant set at 0.005 and K_1 at 0.1, the link resistance exponent, K_2, was varied between 1 and 3 in steps of 0.5. A value of K_2 of 3.0 gave the lowest standard error of prediction, 33.2 percent. Next K_2 was set at 3 and K_3 at 0.005, and K_1 was varied between 0 and 1 in steps of 0.5. At $K_1 = 0.5$, the smallest standard error of prediction, 26.8 percent, was obtained.

Discussion of Model Results

The criterion used to evaluate the quality of the model calibration is the closeness between model results and observed data. Figure 7 shows this graphically. It is evident that the errors in model prediction were generally contained within a band of ±20 percent. The largest errors were associated with the low-attraction forests. Table 5 gives the observed and predicted attendance at the 18 forests.

More adjustment of model parameters may have produced lower errors of prediction. Fine-tuning of the attraction indices of forests also could have led to a better fit between model results and observed data. However, utility rather than extreme accuracy was the goal here and, considering the coarseness of the data input to the models, 26.8 percent error of prediction was considered reasonable.

EVALUATION OF THE SYSTEMS MODEL

The following general evaluation of the systems model is based on the experience of performing these tests:

1. By far the biggest drawback of the systems model is the lack of sufficient quantities of the right type of data. This applies particularly to the inventory of the natural resources, activities, facilities, and services in the forest.
2. The systems model is both simple and realistic in its treatment of component formulations and interactions. The results clearly demonstrate its realism. A look at the mathematics (4) will leave no impression of simplicity. However, once the model has been constructed and programmed, its use requires only the input of origin, travel link, and destination data cards.
3. The systems model performed adequately on very coarse and scant data. This situation cannot be generalized, however. The success achieved might be due to the relatively simple relationships that exist under low-density traffic conditions. For more complex traffic patterns, much more detailed data would be required than were used in this study. This is true of any allocation model.
4. The amount of personal judgment is identified and controlled. A certain amount of personal judgment was employed in quantifying the link resistance factors and the attraction indices. Judgment and intuition are absent once the input data are fed into the model and the consequences of an alternative plan are being estimated.
5. The systems model makes good use of specialist's time. Once the systems model is programmed it can be applied by anybody who can code a transportation network. The mathematics in the model need not be understood by the operator. However, the interpretation and further application of the model's output requires a specialist.
6. The model permits easy upgrading of its formulation and updating of its predictions. By modeling each component separately in terms of its physical characteristics, the systems model makes allowances for easy remodeling of the components as more knowledge is gained. Because of its running speed, the systems model facilitates sensitivity analyses.

CONCLUSION

As a result of the work described in this paper it can be concluded that the systems model is effective in simulating the California forest recreation system and in describing the flow of recreational traffic to the various national forests. The macro-generation and macro-attraction models, which provide inputs to the systems model, also perform their function satisfactorily.

REFERENCES

1. Ellis, J. B. A Systems Model for Recreation Travel in Ontario: A Progress Report. Ontario Dept. of Highways Rept. RR 126, Downsview, 1967.
2. Gyamfi, P. Allocation of Travel Demand to Low Density Areas. Institute of Transportation and Traffic Engineering Dissertation Series Rept., Univ. of California, Berkeley, Dec. 1970.
3. Ellis, J. B., Koenig, H. E., and Milstein, D. N. Physical Systems Analysis of Socio-Economic Situations. ORSA-TIMS Joint National Meeting, Oct. 1964.
4. Transportation Analysis Procedures for National Forest Planning: Project Report. Institute of Transportation and Traffic Engineering Spec. Rept., Univ. of California, Berkeley, July 1971, 100 pp.