A Simulation Study of the Cades Cove Visitor Vehicle Flow

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A Simulation Study of the

CADES COVE

Visitor Vehicle Flow

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As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources." The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

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INTRODUCTION

Only within the last 10 years has there been any active effort to develop and apply quantitative techniques to the management of natural resources for outdoor recreation. Some of the more fruitful applications have been in recreational traffic-flow analysis. These applications have been directed toward the study of regional recreation traffic, with little attention given to the flows within specific recreational developments. This study investigates the use of a computer simulation model applied to a specific traffic-flow problem within a major national park.

The Cades Cove loop drive is an 11-mile, one-way, hard-surface road which circles a mountain-enclosed valley in the Great Smoky Mountains National Park. The National Park Service has established a self-guiding auto tour, including a number of open-air exhibits, around this route. The visitor use of the loop has been steadily increasing since 1967, with as many as 1500 vehicles in the loop on peak days. The results of this heavy use have been severe traffic-crowding problems.

To remedy the crowding, National Park Service planners have proposed the establishment of a mass transit system. However, questions concerning the necessity of mass transit required the initiation of an evaluation project. This study is a result of that project.

The Great Smoky Mountains National Park

The Great Smoky Mountains, straddling the border between Tennessee and North Carolina, constitute the only large, mountainous, wild area left in the eastern United States. The area was designated as a national park in the mid-1930s to preserve the unique natural phenomena indigenous to the Southern Appalachian Mountains. The stated purpose of the Great Smoky Mountains National Park is to provide existing and future generations with the opportunity to experience the benefits associated with exposure to this impressive mountainous environment (USDI 1964).

The park is approximately 1262 km^2 (789 mile^2) of relatively undeveloped high mountains. There are 16 peaks within the park that are over 1800 m (6000 ft) high. There are over 1300 different plant species and six major forest types represented within the park. Eight tree species reach a world-record height in this favorable growth environment. The range of ecosystems spans the spruce-fir system, representative of Canada, to the yellow pine-hardwood, indicative of the southern Piedmont regions. The park provides a habitat for hundreds of bird species, numerous reptilian and amphibian species, and well over 50 species of mammals—the most famous is the black bear, and approximately 300 are said to reside within the park boundaries (Murlless and Stallings 1973).

To display the vast variety of natural beauty and also to preserve some remnants of the social mountain culture that existed in the Smokies when the park was founded, the National Park Service has developed a system of interrelated displays and visitor-access areas. The elements of this system can be divided into two subsets: those that are accessible directly by motor vehicle, and those that require some other type of visitor locomotion. While there is some overlap, the subsets generally may be distinguished as those elements that provide intensive recreation (that is, relatively high numbers of visitors per unit area), and those elements that provide extensive recreation (that is, low numbers of visitors per unit area).

The intensive elements include: 10 developed campgrounds; a relatively small road system; two major, mountain-culture, open-air museums; a number of self-guiding nature trails, several of which are vehicular trails; numerous picnic areas and scenic parking areas; and two visitor information centers. The major vehicular access points to the park are the centers of most of the intensive visitor use. These access areas are the Townsend Area in the northwestern section of the park, the Sugarlands Developed Area in the north-central section, and the Oconaluftee Developed Area in the south-central section. The Transmountain Highway (US 141) connects the Sugarlands and Oconaluftee areas and is the most heavily traveled park road (USDI 1972). The other intensively used areas are the Cades Cove Developed Area and the Fontana Laka Area. Cades Cove is connected with the Sugarlands and Townsend access areas via the Little River Road (Tenn. 73) and its extension, the Laurel Creek Road. These roads are also heavily traveled by park visitors (USDI 1972). Figure 1 displays the major road network within the park.

The extensive recreation development consists of a highly complex system of trails and back-country campsites. There are over 960 km (600 miles) of trails within the park and about 100 trail shelters, as well as specially equipped horse campsites and standard, designated, open areas with varying levels of facilities (pit toilets, fireplaces, garbage containers, etc.). There are numerous access points to the trail system since it intersects with almost all of the park's roads and intensively developed areas.

Visitation to the Great Smoky Mountains National Park has been rising steadily. Over 8 million persons visited the park in 1972 and that number is expected to increase to 20 million by 1990 (USDI 1973). The guidebooks describing the park already warn visitors to expect traffic jams on the park's roads during peak periods and, with the anticipated increased visitation, these occurrences can be expected to increase (Murlless and Stallings 1973).

Cades Cove

Cades Cove is a broad, flat-bottomed valley developed from 400-million-year-old Tennessee Valley limestone rock, completely surrounded by mountains developed from older sandstone and shale of the Smoky Mountain formations. The valley is located in the northwestern corner of the park and is accessible only by the Laurel Creek Road originating at the Townsend, Tennessee, park entrance.

The Cove was originally settled in 1819 when it constituted part of the western frontier. However, as the frontier was pushed westward, the mountainous environment caused the area to become a backwater of the pioneering culture, isolated from the developing civilization outside the mountains. The frontier culture was preserved in the Cove area until about 1900 when automobiles and telephones provided some practical means of communication with the outside world. At that time, there were about 100 families living in the Cove and its surrounding area. When the area was included in the park in the 1930s, many artifacts of the mountain culture were still present, and an effort to preserve and to display these remnants was included in the development objectives of the park (USDI 1964).

The Cove development presently consists of a campground, a picnic area, and an 11-mile, one-way, hard-surface loop drive. The loop drive runs around the entire perimeter of the Cove and is the focus of the Cove area development. Along the route are 38 exhibits displaying cabins, churches, farm buildings, scenic views, and a highly developed open-air museum. Figure 2 shows the Cove loop and the major exhibit locations. There are also two one-way exits from the loop: one over Rich Mountain Road to the north and one via the Parson's Branch Road to the southwest. These exits are recommended only for four-wheel-drive vehicles. Also, there are two unpaved, two-way crossovers within the loop: one at the east end via Sparks Lane and one at the west end via Hyatt Lane.

The present operation of the drive is to provide the visitor or vehicle with a leaflet at the loop entrance. The leaflet describes each of the exhibits and each is marked by a numbered sign along the road correspondingly documented in the leaflet. Visitor parking areas are adjacent to most of the exhibits.

The Problem

Corresponding with the increased park visitation, the visitor use of the Cades Cove loop drive has been increasing. During the last 4 years (1971–74), use of the loop drive has been extremely high—up to 1500 vehicles per day on peak days. Heavy traffic congestion occurs in the loop during these peak periods. Weekends during July, August, and October are the times when the greatest congestion occurs. During these periods, traffic is bumper-to-bumber over parts of the 11-mile trip and many of the parking areas are full, resulting in severe traffic congestion and a major detraction from the

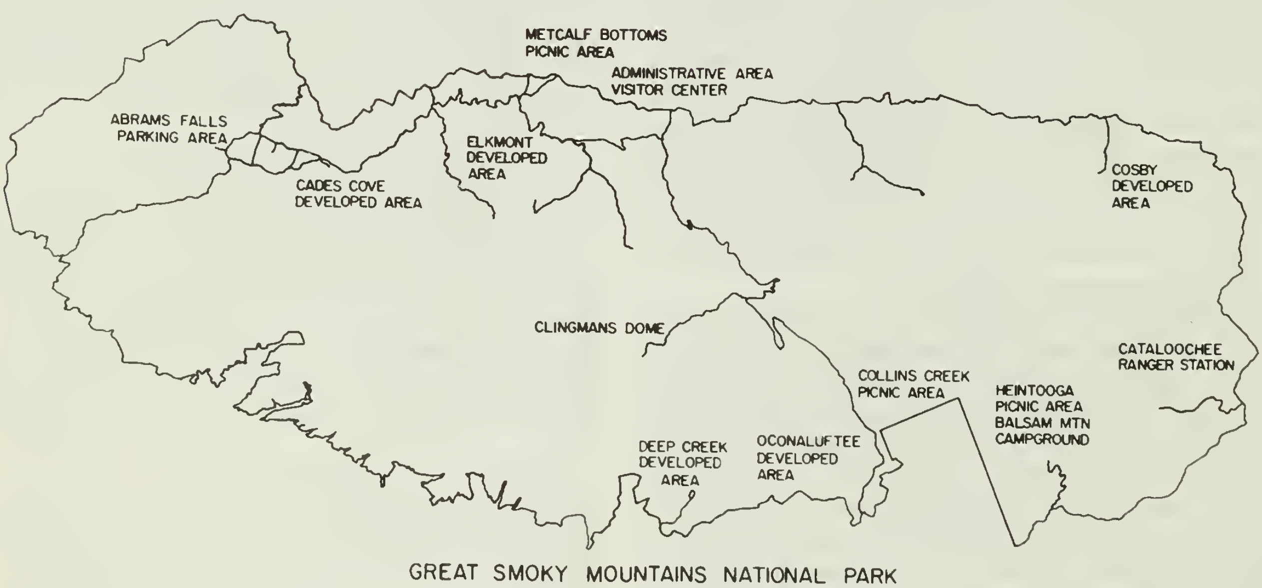

Fig. 1. Sketch map of the road system in the Great Smoky Mountains National Park.

"country lane" type of environment that the drive was designed to provide (USDI 1972). Table 1 shows vehicle use of the loop drive from 1967 to 1971. Since 1971, use during the peak periods has continued to increase.

TABLE 1. Vehicles on Cades Cove loop drive.[a]

Month	1971	1970	1969	1968	1967
January	4,750	1,619	1,865	831	2,095
February	3,650	2,516	2,157	1,672	2,353
March	6,700	4,320	3,418	2,875	4,513
April	15,300	6,467	7,429	5,127	6,398
May	14,550	4,735	6,385	4,826	6,970
June	20,800	21,279	21,368	14,477	22,650
July	23,200	24,849	26,132	18,885	30,250
August	32,500	30,100	31,321	25,929	26,257
September	19,250	18,500	19,621	16,914	17,056
October	27,250	32,350	29,326	24,129	27,617
November	13,250	9,750	7,629	4,140	5,324
December	3,250	3,250	4,671	2,217	1,706
Totals	184,450	161,375	161,322	122,022	153,189

[a]USDI 1972: 17.

To alleviate the crowded traffic conditions, National Park Service planners proposed to install a mass transportation system around the loop. The system would provide continuous bus transportation and eliminate private vehicles from the drive. It would require the construction of a large parking facility at the entrance to the loop and maintenance of a fleet of buses. A decision to implement this system was delayed indefinitely in 1972 due to the questions raised by the ranger staff concerning the need for and cost of such a system. Any action on the proposal would require that a detailed study of the current operation of the loop be developed. Further, with the passage of the National Environmental Policy Act of 1969, it had to be proved that other less environmentally drastic development or management procedures could not be invoked to achieve the same results as the mass transit plan (Anderson 1973).

OBJECTIVES AND APPROACH

The purpose of this study was to develop a tool that could be used in the evaluation of the mass transit system proposed for the Cades Cove loop road. To accomplish this, a modeling process was initiated with the establishment of a series of specific objectives: (1) to develop a computerized model of the current visitor vehicle flow through the Cades Cove loop; (2) to construct the model so that various alternative management strategies for loop operation could be implemented and evaluated; and (3) to design the model so that the effects on visitor vehicle flow of different development plans could be evaluated.

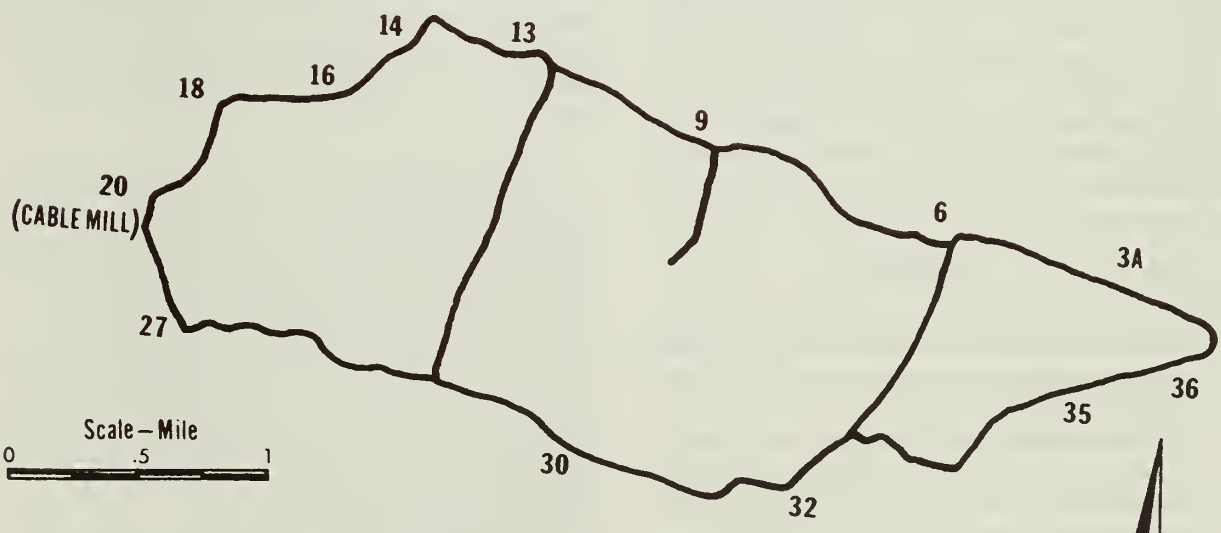

Fig. 2. Sketch map of the Cades Cove loop drive indicating the major exhibits.

LEGEND

3A "Cades Cove Today" Sign
6 John Oliver Cabin
9 Methodist Church
13 Scenic View Parking Area
14 Wildlife Parking Area
16 Skyline View
18 Abrams Falls Parking Area
20 John P. Cable Open Air Museum
27 Peter Cable Place (Honey)
30 Tipton Oliver Place
32 View of Cades Mountain
35 Carter Shields Cabin
36 Panoramic View

The management strategies included such measures as mass transit and controlled visitor entries into the loop. The development plans included such changes as the construction or deletion of exhibits and the expansion of parking facilities.

The approach to the development of the model began with the search for an analytical procedure that would describe the system accurately. Since no such procedure was found, the development of a computerized simulator was undertaken. Several guidelines for the development of the simulator were established prior to program design and were enforced throughout the program construction. First, the computer program would be modular, that is, each model segment would be developed as a separate subprogram so any change in a segment would not drastically affect the overall program. Second, the model would be stochastic in nature, that is, each value generated by the model would have a random component determined probabilistically. Finally, a simple input and output format would be developed and maintained. The motivation behind this final guideline was the anticipated eventual use of the model by National Park Service personnel not rigorously trained in operations research or computer science.

These guidelines and objectives were then combined into a series of five basic tasks: (1) the construction of an initial hypothetical model; (2) the design and implementation of a sampling procedure to estimate the model parameters; (3) the development and application of a verification procedure to test the model validity; (4) the refinement of the model in light of the verification results; and (5) the demonstration of the use of the model as a management tool in the analysis of the Cades Cove loop drive problem.

REVIEW OF LITERATURE

> Operations research is a scientific approach to problem solving for executive management. An application of operations research involves
>
> Constructing mathematical, economic, and statistical descriptions or models of decision and control problems to treat situations of complexity and uncertainty.
>
> Analyzing the relationships that determine the probable future consequences of decision choices and devising appropriate measures of effectiveness in order to evaluate the relative merit of alternative choices (Wagner 1969:4).

The major efforts in the application of operations research techniques to recreation management problems have been in the areas of predicting recreation travel flow from population centers to recreation sites and evaluating primary recreation benefits (Cessario 1969). The modeling work in travel flow primarily has dealt with regional demand determination, and little has been done with the analysis of specific recreation developments (Ladd 1972). The models are of three major types: regression models, gravity models, and linear system models. The regression and gravity models predict the total visits to a recreation site generated by a given population center. In these models, total visitation within a given time period is expressed as a function of such variables as population size, site attractiveness, and distance of the site from the population center. These models are not concerned with the actual routes taken by the visitors. Linear system models predict the total visits for a given time period to a recreation area by actually defining the network routes and treating recreation travel flow as analogous to the flow of electric current through a circuit. Total visits are developed on the basis of a series of "terminal" equations which predict the total number of visitors that will be "grounded" at the various recreation sites. It is a general requirement of these types of models that systems be somewhat simplified in order to keep the number and form of the "terminal" equations manageable.

Gravity models seem to be most successfully applied to the problem of predicting recreational visitation for areas with a limited number of sites. Linear system models seem to be appropriate for predicting recreational traffic flows in statewide and large, regional systems (Ellis and Van Doren 1966). Each of these techniques requires that site attractiveness be quantified (Cessario 1969).

A comprehensive application of the gravity and regression analysis was the work of Milstein and Reid (1966) in developing forest recreation demand projection for the state of Michigan. This work was used as the basis for the Michigan statewide recreational plan. An extensive application of linear system models was completed by The Institute of Transportation and Traffic Engineering (1971) at the University of California in the development of a procedure for transportation planning analysis in national forests. This technique was incorporated into the management plans of several national forests in California.

As stated previously, the initial direction of this thesis project was to find a suitable analytical method which could be employed to model the loop-drive system. The most appropriate of the reviewed procedures was the waiting line models. There has been widespread use of these models in traffic management and planning problems (Bhat and Rao 1972). This family of models initially appeared to hold great promise for the loop-drive system. The methodology for implementation supporting this type of model has been extensively developed (Bhat 1969), making it even more attractive.

The basic waiting line model consists of two major components: the input process and the service mechanism (Hillier and Lieberman 1974). Each of the processes is defined in terms of a probability distribution. Once the distributions are determined, a series of "balance equations" can be constructed describing the probabilities that there are exactly some number, say n, of visitors in the system. Assuming that there is some maximum number, N, of visitors that can be in the system at one point in time, these equations can be solved and the following relation developed (Stidham 1974):

$$L_q = \sum_{n=0}^{N} (n - s)P_n$$

where

L_q = expected number of visitors in queue for an activity,
s = maximum number of people in an activity at one point in time, and
P_n = long-run probability that there are exactly n people in and waiting for the activity.

Two major difficulties forced rejection of this technique. First, the Cades Cove loop system represents a series of service mechanisms, that is, each exhibit is a separate service facility. Therefore, the system would have to be treated as a waiting-line network model. To model such a system it is necessary to assume both a Poisson arrival process and negative exponential service times for each service facility. If these assumptions cannot be made, no theory exists for the solution of the system (Hillier and Lieberman 1974). The use of a negative exponential distribution of service times is not appropriate in that the service times appear to be symmetrically distributed around a mean value. This will be shown in subsequent chapters. Second, all waiting-line models must assume that the system reaches a steady state over time, i.e., that eventually the system will reach an equilibrium in which long-run probabilities of discrete numbers of individuals in the system can be established (Feller 1968). This assumption also fails in the case of Cades Cove as it would be difficult or implausible to assert that the system reaches a steady state even within the time frame of a single day.

Simulation is often the technique chosen for waiting-line networks when the existing theory cannot be applied (Wagner 1969), and it is a tool which long has been used in the application of operations research to real-life systems. Basically, simulation is a technique for performing sampling experiments on a model of a system (Hillier and Lieberman 1974). The term "model" refers to the imitation of a real system, while "simulation" is the method used to implement and later experiment with the model (Stiteler 1965).

One problem with simulation is the difficulty of including sufficient detail to describe the system accurately (Fishman 1974). In the loop-drive situation, the detail is manageable and the data for the model parameters were obtainable, making simulation a viable method. There has been some use of simulation in the traffic analysis work of The Institute of Transportation and Traffic Engineering (1971). A simulation model was applied to determine the location of one-lane roads in national forests. The technique also was endorsed as a useful transportation modeling scheme by Nolan and Sovereign (1972) in their review of transportation modeling procedures.

Simulation also has been applied to general recreation planning. Salmen et al. (1972) successfully applied a simulation process in the evaluation of design proposals for ski areas in Colorado. Devine (1972) demonstrated the use of a simulation technique in the analysis of visitor activity choices for state parks in Pennsylvania.

MODELING PROCEDURE

Model Logic and Assumptions

The Cades Cove Visitor Vehicle Flow Model is a computer simulation describing the distribution of visitor vehicles within the Cades Cove loop drive. The model simulates an inspection of the loop drive on a user-controlled regular time interval. This inspection consists of a count of the number of vehicles that arrive at the loop, the number of vehicles on each section of road within the loop, the number of vehicles in each of the exhibits, and the number of vehicles that leave the loop—all during the current time interval. These inspections are made for every time interval within each simulated day.

The simulation consists of four basic modeling processes. The first is the generation of weather conditions for each simulated day. It was assumed that only two weather conditions—rain and no rain—affected the loop-drive operation and that the weather on any given day was independent of the previous day's weather. The weather conditions were then simulated with a Bernoulii model. This model requires that there be only two possible outcomes for any event and that the probability of a given outcome for each event is a constant and is independent of all outcomes of previous events (Feller 1968). The probability of one outcome is given by p and the probability of the second outcome is q, where $q = 1 - p$. For the weather model, p is the probability of rain and q is the probability of no rain. The estimate of p, $\hat{p}$, was determined by

$$\hat{p} = \frac{\text{number of rainy days}}{\text{total number of days}}.$$

The value of $\hat{p}$ can be obtained from past weather records. The current value used in the model is based on a sample of the 1974 summer season. The determination of each day's weather is accomplished by generating a random number between zero and one and comparing this number to $\hat{p}$. If the random number is less than or equal to $\hat{p}$, the weather assignment is rain, otherwise the assignment is clear. The choice of this model was based on two criteria: (1) preponderance of cloudy, damp days (Murlless and Stallings 1973) would indicate that it is necessary only to distinguish between days when it physically does or does not rain; and (2) the relative simplicity of this type of model.

The arrival process was simulated with a Poisson model. The rate at which vehicles arrived at the loop was assumed to vary with the day of the week, the time of day, and the weather conditions. This resulted in 42 separate Poisson distributions. Further, it was assumed that the number of arrivals for a given inspection period was independent of the previous number of arrivals. Arrivals were noted in terms of inspection periods, that is, the variable of concern was the number of arrivals in one inspection time interval. The probability density function for the Poisson model is given by

$$p(k; \lambda) = \frac{e^{-\lambda} \lambda^{k}}{k!}$$

where

$p(k; \lambda)$ = the probability of k occurrences in one time unit, and

λ = mean occurrences in one time unit, $\lambda \geq 0$.

In this simulation, λ was estimated by

$$\hat{\lambda}_{wdt}$$

where

$\hat{\lambda}_{wdt}$ = arithmetic mean arrivals for conditions wdt,

w = {0, 1} with the value of w corresponding to the weather condition (i.e., 0 = no rain, 1 = rain),

d = {1, 2, ..., 7} with the value of d corresponding to the day of the week (i.e., 1 = Friday, 2 = Saturday, . . ., 7 = Thursday), and

t = {1, 2, 3} with the value of t corresponding to the time of day (i.e., three daily time divisions with 1 = first division, 2 = second division, 3 = third division).

There are 42 values for $\hat{\lambda}_{wdt}$, one for each combination of weather, day, and daily time division. The determination of arrivals for each time period was accomplished by generating a random number from a Poisson distribution with parameter $\hat{\lambda}_{wdt}$. The choice of the Poisson model was based on the classical application of this model to simulate independent arrivals over time (Dixon and Massey 1969).

The determination of the fraction of vehicles that enter a given loop-stop for each inspection is the next model, that is, it is necessary to determine for each inspection period the fraction of vehicles which are approaching a given loop that stop and enter it. It was assumed that the mean fractions for each stop would not be influenced by day of the week, time of day, or weather conditions. A normal distribution model was chosen to simulate these fractions. The normal distribution probability density function (*pdf*) is given by

$$p(y) = \frac{e^{-(y - \mu)^2/2\sigma^2}}{\sigma\sqrt{2\pi}}$$

where

$p(y)$ = value of the *pdf* at point y,

μ = population mean ($0 \leq \mu \leq 1$), and

σ = population standard deviation.

In this case, μ and σ are estimated by $\bar{Y}$ and s where

$$\bar{Y} = \frac{\text{vehicles that entered the stop in sample period}}{\text{total vehicles that entered loop during the sample period}}$$

and

s = an arbitrarily small number relative to the numbers of vehicles entering the stops.

$\bar{Y}$ is greater than or equal to zero and less than or equal to one and s^2 has been set to one.

This procedure for estimating s^2 was chosen to eliminate the effects of extreme observations. Generally, s^2 is estimated from a random sample of observations of the system, that is,

$$s^2 = \frac{\sum (X_i - \bar{X})^2}{n - 1}$$

where

s^2 = sample variance,

X_i = value of the ith observation,

$\bar{X}$ = mean of the observations, and

n = number of observations.

The general procedure reflects strongly the occurrence of observations that deviate widely from the mean. Therefore, the above procedure was incorporated.

The implementation of the model is similar to that of the arrival model, that is, a random number is generated from a normal distribution with mean $\overline{Y}$ and variance s^2 but truncated at zero and one. The random number is then used as the fraction of vehicles that enter the stop for the current inspection period.

No information was available in the literature concerning the application of specific mathematical models to the entry process. Therefore, due to the apparent symmetric distribution of the fractional entries around a mean, the small variance relative to the mean, and the simplicity of the application of the normal model, this distribution model was chosen.

The final process for which a statistical model was developed was the simulation of fractional turnovers within stops. Again, a normal distribution model was employed and μ and σ were estimated by $\overline{Y}$ and s, respectively, where for each stop

$\overline{Y}$ = mean over each sample of vehicles whose turnaround time is less than or equal to one inspection period /(total vehicles that entered the stop)

and

s = an arbitrarily small number relative to the numbers of vehicles in the stop.

This model was implemented in the same manner as the fractional stop entry process.

It was assumed that, although the mean fractional turnaround times varied with each stop, they were constant with respect to days, times, and weather conditions. The normal model was chosen for the process for the same reasons as were stated for the stop-entry process model selection

Output Considerations

The simulator maintains a set of variables containing the values of the current use of each of the stops and the current numbers of vehicles on each of the loop-road segments, crossovers, and exit roads. In addition, the simulator maintains summary information concerning each of these variables on a daily and weekly basis.

The organization of the output information is in three formats: tabular, statistical, and graphic. As with most simulations, the output must be aggregated and summarized to be useful. Therefore, the simulator was constructed so that the user has options to establish the level of detail and frequency of output data required for his particular interests.

General Model Operation

The simulation procedure reduces to a series of six steps: (1) the inputs are read, interpreted, and stored within the program; (2) the weather for the simulated day is determined; (3) the arrivals are generated and input as entries into the system; (4) each of the stops is inspected for entering and leaving vehicles; (5) the current status and summary descriptions are calculated and updated, and any required output is generated; and (6) steps two through five are repeated for each of the desired inspection periods and days. The simulation is designed to progress either through a week of variable daily simulations or to repeat the same conditions for any desired number of repetitions up to seven. This limit can be increased simply if desired.

Model Divisions

Five major subprograms make up the simulation program.[1] Each of these subprograms performs a separate function within the overall operation. The control program reads and stores the input data, sets the parameters for the program run, and initiates the simulator. The weather subprogram simulates the weather conditions for each modeled day. The arrival subprograms generate the arrivals at the Cove area. The loop-road routine simulates the traffic distribution within the loop-drive area. The output routines control the printing of the requested output data. The interrelationship of the modules is displayed in Fig. 3.

The operational sequence of the model is shown in Fig. 4. The input data and program parameters are processed and stored in the control program. Next, the control program starts the simulation by calling the weather subprogram, which returns the weather conditions for the first day. Then the control program establishes the simulated time interval for inspecting the loop-drive activity area and calls the arrival subprograms for the first time interval. The arrival routines determine the number of arrivals for this period and return this value to the control program. The loop-drive subprogram determines the number of vehicles currently in the various stops and road sections and accumulates running totals of vehicles on a daily and weekly basis. These data are then returned to the control program, which calls the output routines if output is to be printed, or begins the simulation of the next inspection period by calling the arrival

[1]A source listing of the program, as well as a users' and programmers' guide, are available from the author at the School of Forest Resources, The Pennsylvania State University, University Park, Pennsylvania.

routines if no output is to be printed for the current time period. This process is repeated until all the inspections for each day have been completed.

Control Program

The first section in the control program (Fig. 5) sets simulation parameters at their default values. Next, it checks for title and date input cards and prints a diagnostic if one or the other or both are not found. It then checks for input data that will replace the default values. This is done by identifying a keyword for each parameter, reading the keyword on the data card, and then branching to the proper input format code. If an unidentifiable keyword is found, the data card is listed with a diagnostic message and an error key is set "on." The program then resumes. The program will terminate before beginning the simulation if the error key has been set "on." All data cards are read in this manner until an end-of-data card is found. The user has the option of printing the default values of all the variables. If not specified by the proper input card, the defaults will not be printed.

The simulation may be started on any day of the week and may proceed for any period thereafter. Alternately, a given day with specific weather conditions may be repeated for experimental runs. This facility was included in the program to allow the investigation of the random variation that has been included within the simulator. To accommodate these experiments, the program branches to a separate section of code in the control program set up for this purpose and then operates in the same manner as before.

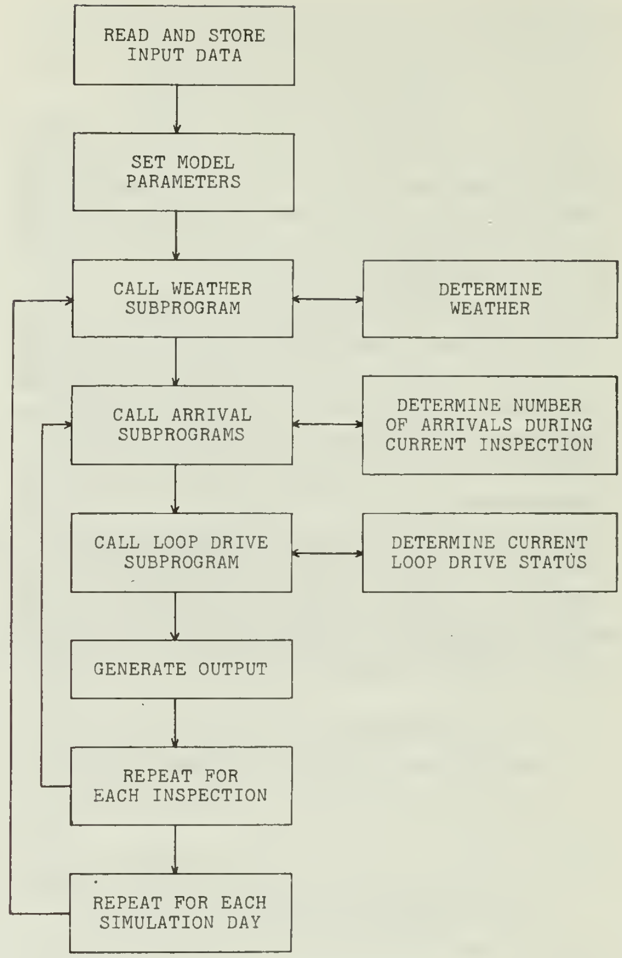

Fig. 4. General operation sequence of the model.

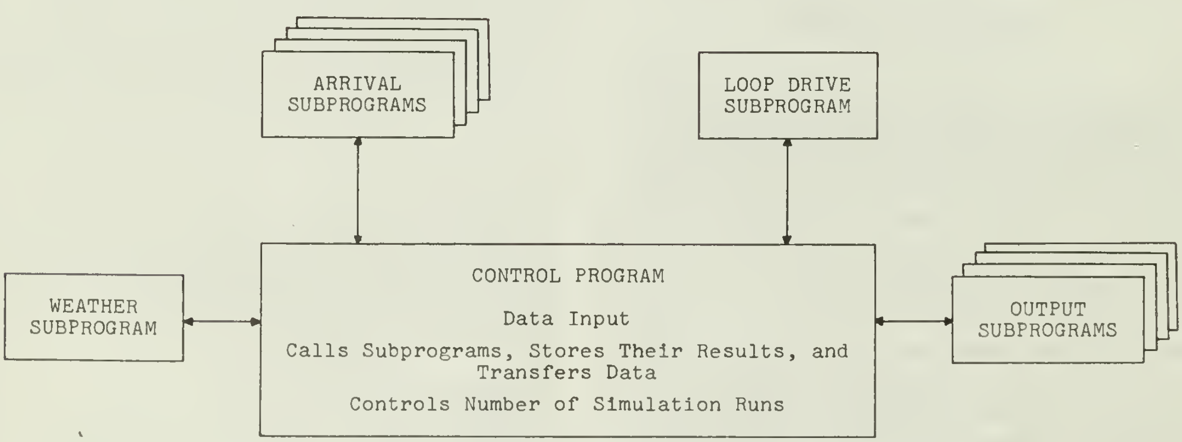

Fig. 3. Interrelationship programs.

Weather Subprogram

After the control program has completed the above step, the weather subprogram (Fig. 6) is called. Based on a rain probability as the argument, the weather determination is made by first generating a uniformly distributed random number between zero and one and comparing this number to the rain probability. If the number is less than the probability, the weather is rainy; otherwise, the weather is clear. The random number generator is the RAND subprogram described by Naylor et al. (1968). This subprogram prints the day of the week and the weather condition and then returns to the control program.

The number of inspection periods for the day then is set within the control program, using the number supplied as input. The program calls the arrival subprograms, which determine the arrivals at the Cades Cove loop road for the period. The number of arrivals is then returned to the control program.

Arrival Subprograms

The number of arrivals is determined by selecting the appropriate mean number of arrivals from a matrix of means and generating a Poisson distributed number of arrivals. The matrix has been given by input and its elements are the previously described values of $\hat{\lambda}_{wdt}$. The arrival subprograms (Fig. 7) determine and retrieve the proper mean and then call a Poisson subroutine with the appropriate value of $\hat{\lambda}_{wdt}$ as an argument. The Poisson subroutine returns the number of arrivals at Cades Cove to the arrival module. The algorithm for generating Poisson distributed values with a given mean was taken from Naylor et al. (1968).

Loop-Drive Subprogram

The control program next calls the loop-drive subprogram (Fig. 8) with the current arrivals as its main argument. This subprogram interrogates every loop stop during the inspection process. For each loop stop, it

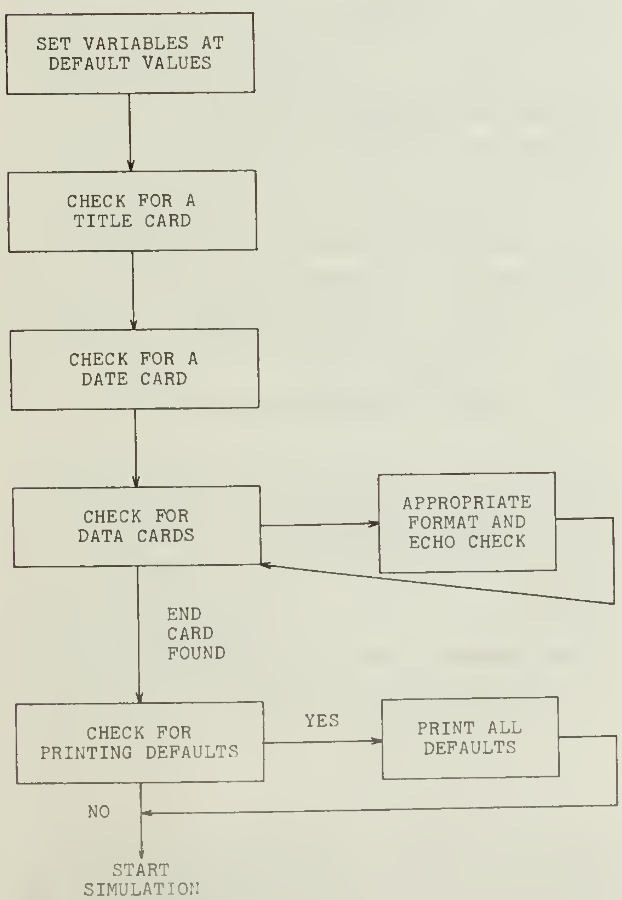

Fig. 5. General flow chart of the input section of the control program.

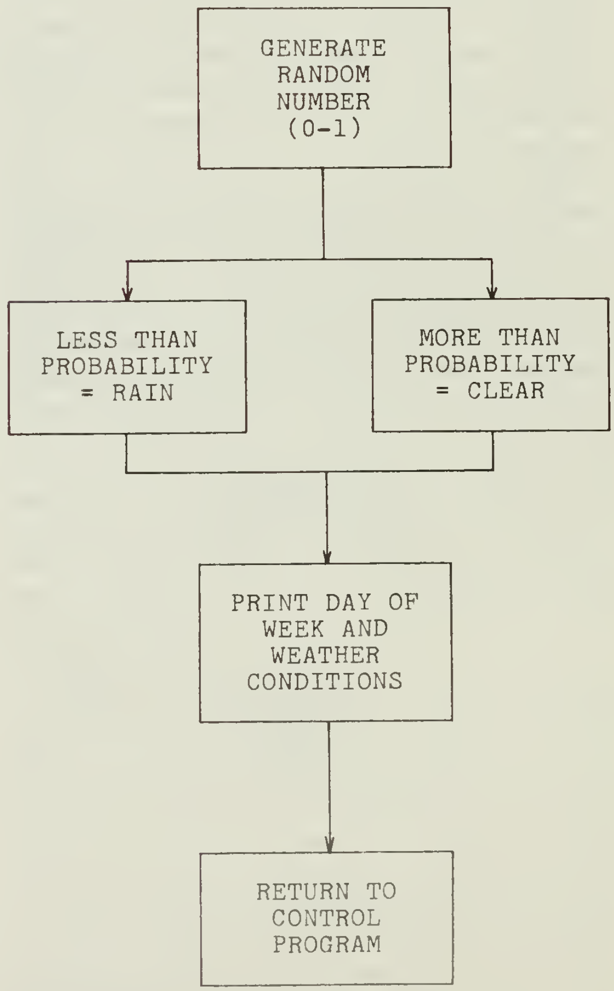

Fig. 6. General flow chart of the weather subprogram.

checks to see if the current stop is a loop crossover or exit. If this is the case, it branches to a separate section of the subprogram code, described later. Following this check, a determination of vehicles leaving the current stop in the inspection period is made. This is accomplished by retrieving, from an input list, the mean fraction of vehicle turnovers in one inspection period for the stop. Then, a normally distributed random number between zero and one is generated using this fraction as the mean and an arbitrarily small variance. This number, which is the percentage of vehicles that will leave the stop for the current period, is multiplied by the number of vehicles currently in the stop with the resultant product being the number of vehicles leaving the stop for the period. The departing vehicles are added to the vehicles approaching the next stop. The normally distributed random number is generated according to Naylor et al. (1968). A count is kept of the number of unoccupied parking spaces available at the stop by subtracting the leaving vehicles from those currently in the stop.

Next, the number of vehicles entering the stop is determined. This, again, is accomplished by generating a normally distributed random number between zero and one with an input-supplied average fraction of vehicles that enter the stop as the mean parameter with a small variance. By multiplying this random number by the vehicles approaching the stop, the number of current entering vehicles is determined. These vehicles are subtracted from those approaching the stop and the remainder is added to the vehicles approaching the next stop. Finally, the number of available parking spaces is subtracted from the number of entering vehicles. Any positive remainder from this subtraction determines the number of vehicles turned away from this stop due to a full parking lot and these are added to the number approaching the next stop. Running totals of the vehicles using and turned away from each stop are maintained as well as the current values of the number of vehicles in and approaching each stop.

The number of crossover and exiting vehicles is determined in a similar manner. A fraction of vehicles taking a crossover or exit is determined using the above normal distribution procedure with input-supplied mean fractional values. The vehicles completing a crossover must be added in at the appropriate road section, and those entering a crossover must be deleted from the count of vehicles approaching the next stop. Also, the vehicles taking one of the exit roads must be deleted from the corresponding road sections. The number of vehicles completing a crossover in the current inspection period is determined, again, by applying the normal distribution technique with the mean given by the average fraction of vehicles completing the crossover in one inspection period.

Output can be generated from this subprogram at the end of each inspection period if requested. The current

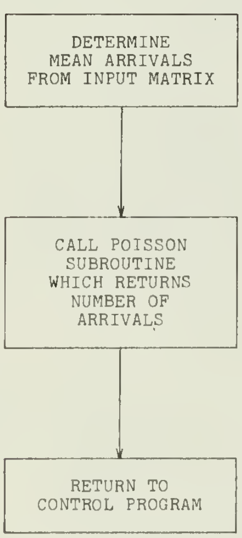

Fig. 7. General flow chart of the arrival subprograms module.

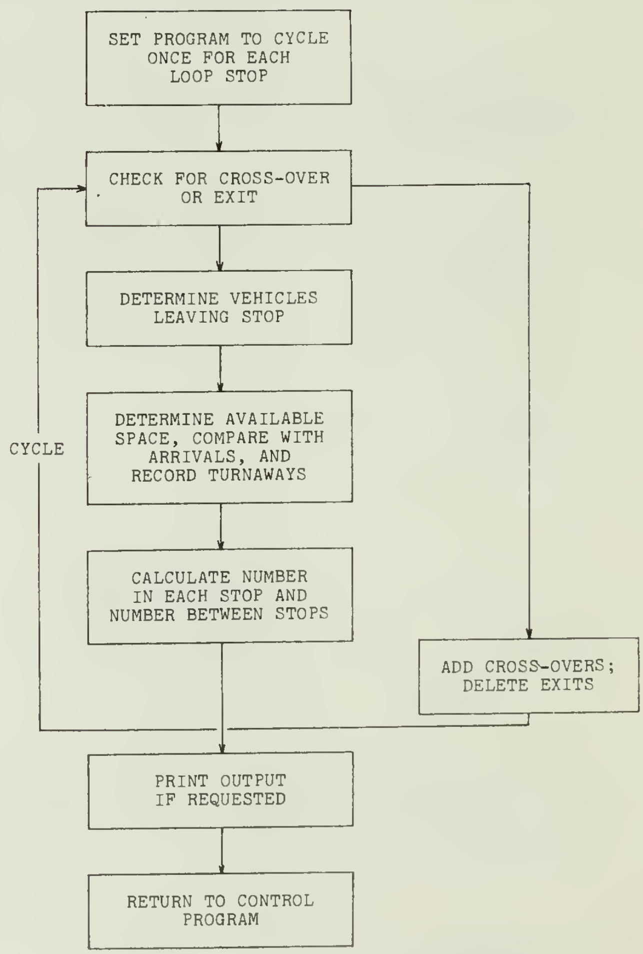

Fig. 8. General flow chart of the loop-drive subprogram.

status of each of the loop stops and road sections can be printed as well as the current numbers of vehicles turned away from each stop and using the crossover roads and exits.

Output Subprograms

The final subprogram is the output subprogram (Fig. 9). It controls the level and frequency of program output as indicated by the program input parameters. The general output is a tabular list of the daily and weekly numbers of vehicles that entered or were turned away from each of the stops, as well as the numbers of total loop users and users of the crossover and exit roads. Also, descriptive statistics (mean and variance) and graphs of daily hourly arrivals and stop turnaways can be generated via two subroutines linked with this subprogram. The graphs are developed by creating a disc file which can be processed through the graphic routines available at The Pennsylvania State University Computation Center. Output examples can be found in the simulation results section of this paper.

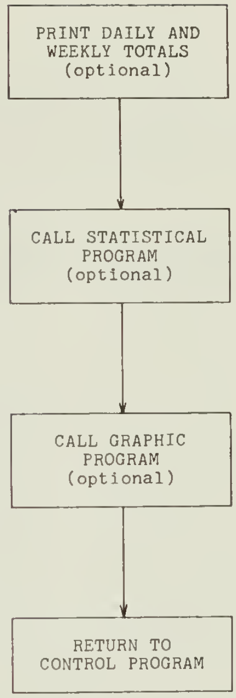

Fig. 9. General flow chart of the output subprograms.

Input

There are six basic input categories: (1) the model time frame, days, and conditions to be simulated; (2) the arrival rates for entries into the loop; (3) the parking capacities of the loop stops; (4) the mean fraction of vehicles that stop at each of the stops; (5) the mean fraction of vehicles leaving each stop in one inspection period; and (6) the output controls.

The simulation is equipped with a set of default values so that the input can be limited to only those elements that are to be changed for experimentation. A list of these default values is given in the users' manual.[2]

Program Language and Timing

The simulator is written in Fortran IV according to the ANSI conventions. It is currently operational on an IBM 370/168 computer at The Pennsylvania State University Computation Center. The program consists of about 2000 statements and simulates a 1-week period in about 22 seconds. The graphics display program is the Quick Draw Graphics System (QDGS) available at the above computation center and the display device is a Tektronix 4010 cathode ray tube.

[2]Available from the author at the School of Forest Resources, The Pennsylvania State University, University Park, Pennsylvania.

SAMPLING PROCEDURE

The objective of the sampling procedure was to construct a data base that would allow the estimation of the model parameters for the various specific submodels in the overall model. The parameters are: the average numbers of vehicles entering the loop drive, varied according to the time of day, day of the week, and weather conditions; the average fraction of vehicles stopping at the various loop stops; and the average fraction of turnovers for one inspection period within these stops. These estimates are then used as the values of $\hat{\lambda}_{wdt}$ in the arrival-generation process, $\overline{Y}$ in the stop-entry process, and $\overline{Y}$ in the stop-turnaround process.

The procedure was based on the use of data collection cards (Fig. 10). The cards were handed to the driver upon entering the Cove and were collected upon departure. The cards consisted of a printed list of selected Cove stops. The stops were numbered as they appear in the "Cades Cove Self-Guiding Auto Tour" leaflet (USDI 1971). Next to each stop number were two blanks, one for the time the vehicle entered the corresponding stop and the other for the time it left. The blanks were filled in by the sampling personnel stationed at the stops to be monitored.

DATA CARD

To provide more information to the National Park Service on the use of the Cades Cove loop drive, we are measuring the traffic flow. If you would give this card to the sampling personnel, when they request it, we would be very grateful. Thank you very much for your cooperation.

Date ________ Day of the Week ________ Weather ________

Stop	Time In	Time Out	Stop	Time In	Time Out
Ent.	____		20&21	____	____
1	____	____	22	____	____
3A	____	____	27&28	____	____
6	____	____	30	____	____
9	____	____	32	____	____
13	____	____	35	____	____
14	____	____	36	____	____
16	____	____	Exit		____
18	____	____			

Fig. 10. Sample data card.

Not all stops were monitored in every sampling period. When the traffic was light, the visitor was asked to voluntarily fill in the corresponding times for nonmonitored stops. This visitor-supplied information was not used in the data analysis but was collected for other purposes.

The sampling took place from 28 June through 1 September 1974. Data were collected during selected days and during selected periods in each day (Table 2). The selection of sampling days and periods was predetermined to yield accurate data for the variety of traffic situations according to nonholiday week days, weekends, and holidays, as well as hours during the day. The selection guideline was to maximize the amount of information captured within budgetary constraints.

The entrance and exit of the loop and the Cable Mill area (Stop 20) were continuously sampled in every sampling session. To maximize the efficiency of the sampling procedure, the remaining stops were sampled using a stratified sample procedure. The stratification was based on coarse estimates of relative stop popularity solicited from the ranger staff. The estimates were collected in terms of the overall daily percentage of vehicles that enter each stop (Table 3). Only stops with greater than a 5% estimated visitation rate were included in the sample. All sampling periods were 1 hour in duration, and the number of sampling periods per stop was determined in relative proportion to the estimated visitation rate. The sampling periods were then randomly assigned to the various sample days. The resulting stratification is

TABLE 2. Selected days and periods of sampling.

	Number of sampling sessions		
	8 a.m. to 11 a.m.	11 a.m. to 4 p.m.	4 p.m. to 7 p.m.
Monday	0	2	0
Tuesday	1	5	0
Wednesday	0	2	0
Thursday	0	2	0
Friday	0	4	1
Saturday	1	10	1
Sunday	1	9	1

TABLE 3. Estimated relative use of the most heavily used stops.

Stop number and name		Estimated percentage of vehicles stopping
3A	"Cades Cove Today" Sign	20
6	John Oliver Cabin	66
9	Methodist Church	10
13	Scenic View Parking Area	25
14	Wildlife Parking Area	10
16	Skyline View	8
18	Abrams Falls Parking Area	12
20 & 21	John P. Cable Open Air Museum	60
27 & 28	Peter Cable Place (Honey)	8
30	Tipton Oliver Place	10
32	View of Cades Mountain	12
35	Carter Shields Cabin	7
36	Panoramic View	12

given in Tables 4 and 5, by stop and by date, respectively.

Data were keypunched from the field forms and key-verified. The data were checked for invalid or out-of-range data values, including missing data. In addition, entry times were checked against exit times for each stop and for adjacent stops. For miscoded day or date, corrections were made. For all other errors, the cards were removed from the data set. Of approximately 14,000 observations, less than 400 were removed for an approximate error rate of 2.8%. All error checking was accomplished via a computer program specifically written for that purpose.

TABLE 4. Detailed organization of total sampling scheduled by stop

Stop number	Total hours sampled: Monday Wednesday Thursday	Tuesday	Friday	Saturday	Sunday	Total hrs/stop
3	1	2	2	13	12	30
6	5	5	3	26	23.5	62.5
9	1	1	1	6	4	13
13	5	1	–	11.5	17	34.5
14	1	1	1	6	4	13
16	3	1	1	5	3	13
18	1	5	–	6	5	17
27	–	1	1	7	5	14
30	2	1	1	8	6	18
32	1	1	1	5	4	12
35	1	1	1	4.5	3	10.5
36	1	1	1	5	4	12
Total hrs per day	22	21	13	103	90.5	

The sampling procedure was completed at a cost of approximately $6200 and involved approximately 1400 man-hours. The support for the sample was supplied as part of the visitor-use survey developed by the Denver Service Center of the National Park Service (USDI 1973).

TABLE 5. Detailed organization of total sampling scheduled by date.

Date	Hours/day/stop — Stops: 3A	6	9	13	14	16	18	27	30	32	35	36	Total hrs/day
June 28	–	1	–	–	–	–	–	1	1	–	1	–	4
29	2	2	1	1	1	–	–	–	2	1	–	1	11
30	1	4	–	2	1	–	1	–	–	–	–	–	9
July 2	1	2	–	–	–	–	–	–	–	–	–	–	3
4	–	1	–	1	–	–	1	–	1	–	–	–	4
5	1	1	–	–	–	–	–	–	–	–	–	–	2
6	1	2	–	1	–	–	–	–	–	–	–	–	4
13	1	4	–	2	–	–	1	–	–	–	–	–	8
14	2	1.5	1	1	1	–	–	1	–	–	–	–	7.5
15	1	2	–	1	–	–	–	–	–	–	–	–	4
16	1	1	–	–	–	–	–	–	1	–	–	1	4
20	1	4	1	1	1	–	2	1	–	1	–	–	12
21	–	4	–	4	–	–	–	–	–	–	–	–	8
26	1	1	1	–	–	–	–	–	–	–	–	–	3
27	4	2	–	1	–	–	–	–	1	–	–	1	9
28	1	2	1	1	–	–	2	1	1	–	–	2	11
31	–	–	1	1	1	–	–	–	–	1	–	–	4
Aug. 3	1	2	–	0.5	–	–	–	–	1	1	1	–	6.5
4	4	2	–	2	–	1	–	1	1	–	–	–	12
6	–	2	–	–	1	1	4	–	–	1	1	–	10
10	2	2	1	2	1	1	–	2	1	–	1.5	–	13.5
11	2	2	–	1	1	–	1	1	1	1	1	1	12
12	–	1	–	1	–	2	–	–	–	–	–	–	4
17	1	2	1	1	1	1	1	1	1	1	–	1	12
18	1	3	–	2	–	–	–	–	–	–	1	1	8
24	–	2	–	1	1	2	1	2	1	–	–	–	10
25	1	3	1	2	–	–	1	1	–	2	1	–	12
27	–	–	1	1	–	–	1	1	–	–	–	–	4
28	–	1	–	1	–	–	–	–	1	–	–	1	4
29	–	–	–	–	–	1	–	–	–	–	1	–	2
30	–	–	–	–	1	1	–	–	–	1	–	1	4
31	–	4	2	1	1	1	1	1	1	1	1	2	16
Sept. 1	–	2	1	2	1	2	–	–	2	1	1	–	12
Total hrs/stop	30	62.5	13	34.5	13	13	17	14	18	12	10.5	12	

SAMPLE DATA ANALYSIS

Arrivals

The initial step in analyzing the arrival data was to develop a series of computer-generated graphs to display the timed arrivals over various days, times, and weather conditions. These graphs were developed using the QDGS programs previously described. The first set of graphs displayed the number of 5-minute arrivals for each day that a sample was taken. An example of the graphs is given in Fig. 11.

In an effort to identify trends in the data, the arrivals were grouped in hourly intervals and a set of graphs displaying the hourly arrivals for each sample day was developed. An example of these graphs is given in Fig. 12. To further analyze the hourly arrival trends, a series of graphs displaying the moving averages of hourly arrivals on a 5-minute interval was constructed. The moving average is defined as the number of arrivals from a given starting time to a time exactly 1 hour later. The starting times were set at every 5 minutes. Therefore, the first interval was from 11 a.m. until 12 a.m., the second interval was from 11:05 a.m. until 12:05 p.m., etc. An example of these graphs is given in Fig. 13. There did seem to be a consistent data hump in the arrivals in the time interval from 12 a.m. until 2 p.m., with a skewness to the left. An arrival-frequency histogram was developed for each sample day. These graphs consistently displayed the left-skewed bell shape that is characteristic of the Poisson distribution. An example of the arrival-frequency histogram is given in Fig. 14.

The actual determination of arrival rates was a two-step process. The mean number of arrivals in a 5-minute interval was determined for each day of the week and each of two weather conditions, clear and rainy. Only the hours from 11 a.m. to 3 p.m. were used in the determination since the majority of the data collected were in this range, and this is the time period of most of the visitor activity within the Cove. This mean is the previously described variable $\hat{\lambda}_{wdt}$. It is calculated for each weather condition w and for each day of the week d as follows:

$$\overline{X}_{wd} = \frac{\sum_{j=1}^{k} \sum_{i=1}^{n} X_{ij}}{n*k}$$

where

w = {0, 1} the weather condition (i.e., 0 = clear, 1 = rainy),
d = {1, 2, ..., 7} the day of the week,
$\overline{X}_{wd}$ = the average number of arrivals (arrival rates) for a 5-minute interval for weather condition w and day d,
j = {1, 2, ..., k} the sample days for weather condition w and day d,
i = {1, 2, ..., n} the 5-minute intervals between 11 a.m. and 3 p.m. (i.e., 60),
X_{ij} = the number of arrivals for 5-minute interval i and sample day j for weather condition w and day of the week d.

The values of $\overline{X}_{wd}$ then were adjusted to reflect the skewness of the sample data. This was accomplished for each day and weather condition by:

$$\hat{\lambda}_{wdt} = \overline{X}_{wd} + \delta_t$$

with

$$\frac{\sum_{t=1}^{3} \hat{\lambda}_{wdt}}{3} = \overline{X}_{wd}$$

where

$\hat{\lambda}_{wdt}$ = the 5-minute arrival rate for weather condition w, day of the week d, and time interval t;
δ_t = the adjustment to $\overline{X}_{wd}$ that reflects the skewness of the arrival patterns; and
t = {1, 2, 3} the time intervals into which each simulated day has been divided (i.e., t = 1 corresponds to the period from 11 a.m. to 12:30 p.m., t = 2 corresponds to the period 12:31 p.m. to 2 p.m., etc.)

In the cases where there was no sample value for a weather condition for a given day, the values were extrapolated from the average effects of weather of the other days. The complete listing of the values of $\hat{\lambda}_{wdt}$ is given in Table 6.

Stop Turnovers

Again, the initial step in the analysis of the sample data for the fractional stop turnovers was the construction of representative graphs for each stop. The first of the graphs was a set of histograms displaying the frequency of each specific turnaround time in minutes. An example of this type of graph is given in Fig. 15. A second set of graphs was developed to display the percentage turnover within each stop on a 5-minute interval for each sample day. An example of these graphs is shown in Fig. 16.

The determination of the mean percentage turnover in each stop was made by taking the arithmetic average of the mean percentage turnover for all days on which the stop was sampled. The results of these determinations are listed in Table 7.

Stop Entries

Since it would have required an additional man-hour of sampling for each stop, it was not feasible to count the number of vehicles that passed by the sampled stops during the periods that they were being sampled. This complicated the determination of the mean fraction for stop entries. The calculation of these fractions was therefore estimated on the basis of loop-entry times. This was accomplished by taking the total number of vehicles that entered the sampled stop and dividing it by the total number of entries into the loop between the entry time of the first sampled vehicle and this time plus the sampling interval, that is, if the first sampled vehicle for a given stop entered the loop at 11 a.m. and the stop was sampled from 12 a.m. to 1 p.m., then the total number of sampled vehicles would be divided by the number of vehicles that entered the loop from 11 a.m. to 12 a.m. The list of these stop entries is given in Table 8.

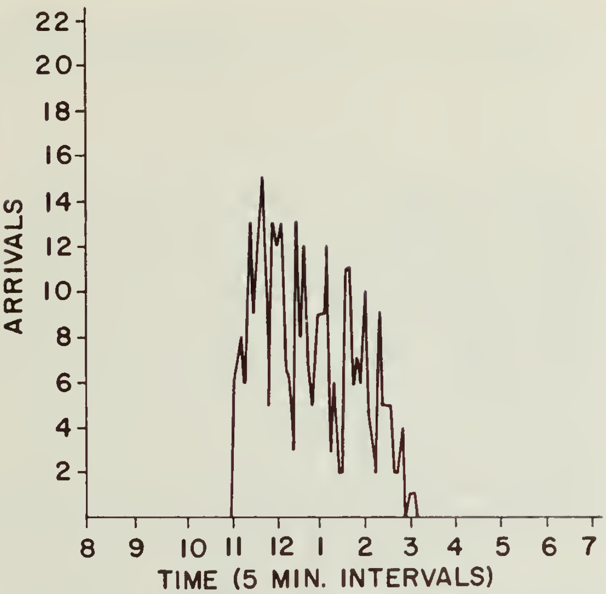

Fig. 11. Number of arrivals in hourly intervals on Tuesday, 23 July 1974.

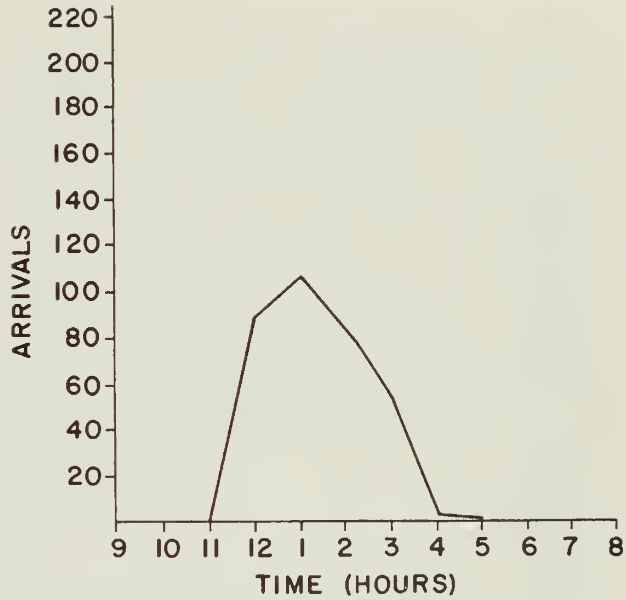

Fig. 12. Number of arrivals in hourly intervals on Tuesday, 23 July 1974.

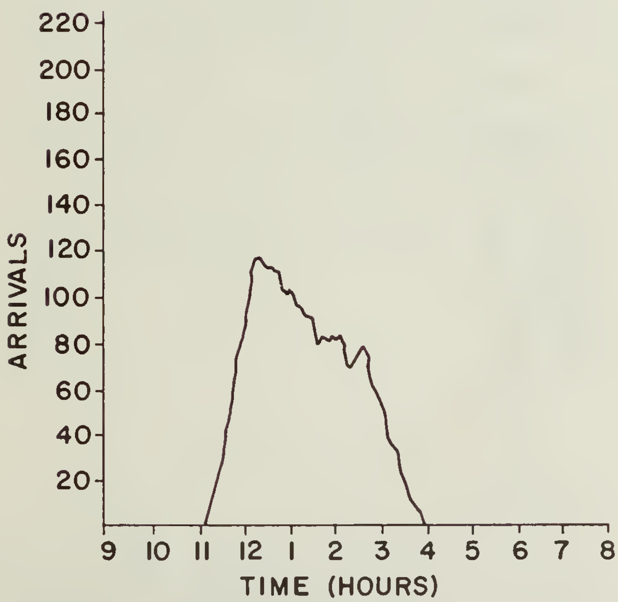

Fig. 13. Moving, hourly average of arrivals on a 5-minute interval on Tuesday, 23 July 1974.

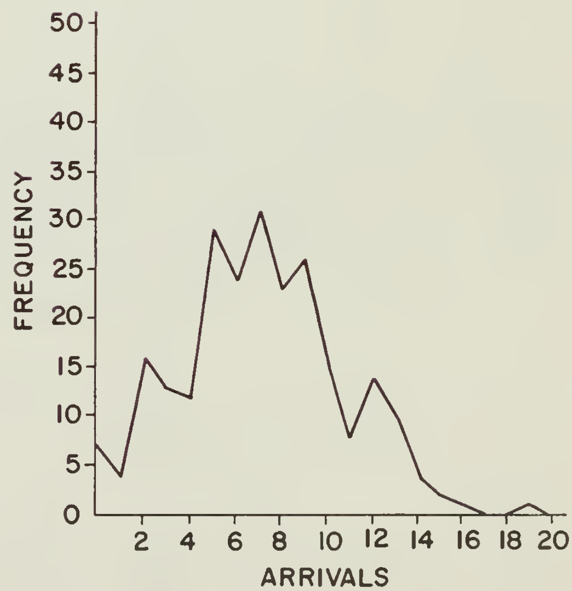

Fig. 14. Frequencies of numbers of arrivals on a 5-minute interval on clear Tuesdays.

TABLE 6. The 5-minute arrival rates for each day and weather condition.

Day	Time 1	Time 2	Time 3
Clear Weather Arrival Rates			
Monday	4	8	4
Tuesday	8	9	6
Wednesday	7	9	7
Thursday	6	11	6
Friday	5	7	4
Saturday	6	7	6
Sunday	9	11	8
Rainy Weather Arrival Rates			
Monday	7	10	7
Tuesday	8	8	6
Wednesday	5	5	5
Thursday	4	7	3
Friday	4	5	3
Saturday	5	8	4
Sunday	8	10	8

TABLE 7. Mean fractional turnover rates for a 5-minute interval at each stop.

Stop number	Fraction
3A	1.00
6	0.07
9	0.44
13	0.92
14	1.00
16	0.82
18	0.33
20	0.07
27	0.54
30	0.60
32	1.00
35	0.62
36	1.00

TABLE 8. Fraction of vehicles entering each stop.

Stop number	Fractional entries
3A	0.21
6	0.24
9	0.11
13	0.21
14	0.12
16	0.07
18	0.18
20	0.67
27	0.12
30	0.08
32	0.10
35	0.06
36	0.05

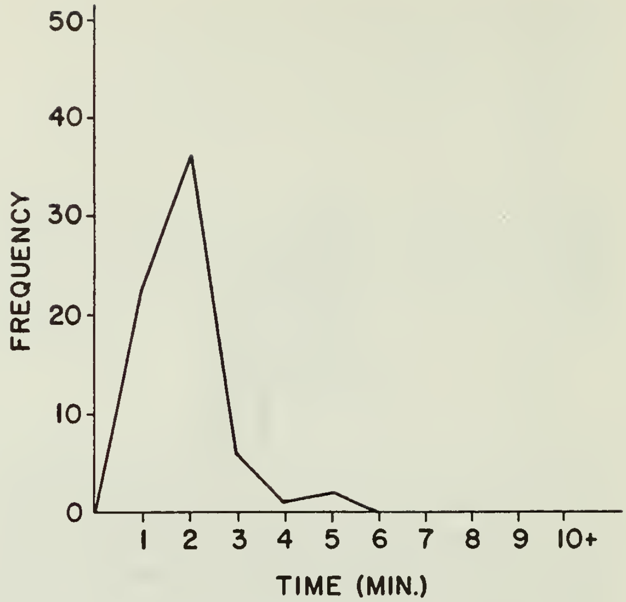

Fig. 15. Frequencies of stop-turnaround times for stop 32.

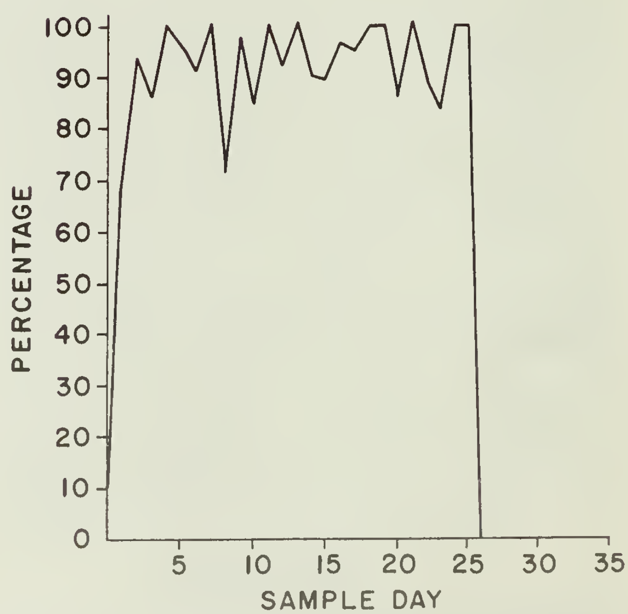

Fig. 16. Percentage of turnaround times for stop 18 that were 5 or less minutes.

MODEL VERIFICATION PROCEDURES AND RESULTS

Arrival Process

A test of the assumption of a Poisson distribution of arrivals was the initial step in the model-verification procedure. The anticipated test was the chi-square goodness-of-fit test (Mendenhall and Scheaffer 1973) for the Poisson distribution. However, the test requires that there be relatively high numbers of observations for each data cell. In terms of the model, this meant there had to be a relatively high number (generally greater than five) of occurrences of the same number of arrivals in a 5-minute interval for each day. This was not the case. For most days, less than 5% of the arrival values had more than five occurrences. Therefore a goodness-of-fit test could not be applied.

The next choice was to simulate daily arrivals and compare the simulated values with those of sampled days. Five simulations of each combination of day and weather (i.e., 14 combinations) were run, and the daily arrivals for each combination were subtracted from the sample mean of daily arrivals for the corresponding day and weather condition. An analysis of variance test for significant differences (Dixon and Massey 1969) between the sample means and the simulated values was conducted. The results of that analysis are given in Table 9. The grand mean of the differences was −0.31, and none of the differences was significant at the 0.2 level of significance. Therefore, it was assumed that the Poisson distribution was adequately modeling the arrival process.

TABLE 9. Results of analysis of variance test for significant differences between sample means and simulated values.

Source	Required value significance ($\alpha = 0.05$)	Degrees of freedom	Mean square	F ratio
Days	2.25	6	21.57	0.067
Weather	4.00	1	14.57	0.045
Interaction	2.25	6	41.90	0.130
Error	–	56	321.52	–

Stop Turnover Process

As previously stated, the fraction of vehicles leaving a given stop in a 5-minute interval was assumed to be a normally distributed random variable. To test this assumption, a Kolmogorov-Smirnov test for normality (Lilliefors 1967) was applied. Of the 13 sampled stops, all but 4 of the fractional turnovers could not be rejected as normally distributed at the 0.01 level of significance (Table 10). Each of the four rejected stops had frequent occurrences of 100% turnover, which would indicate that the turnover percentages should be deterministic at the 100% level. Table 11 shows the frequency of the 100% turnover level for these stops. In addition, at stops 3A, 32, and 36, samples of two or less vehicles were taken on some sample days. For these stops, these small sample sizes deviated quite drastically from the mean. It was concluded that for these few data entries the stop number was erroneously recorded and the data should have been deleted. In view of this conclusion, it was assumed that the turnover fractions for these stops could be simulated with the normal model and a mean of 100% and the small variance of 1.

TABLE 10. Results of goodness-of-fit test for normality.

Stop number	Kolmogorov-Smirnov test statistic[a]	Kolmogorov-Smirnov critical value ($\alpha = 0.01$)
3A	0.363	0.231
6	0.170	0.187
9	0.156	0.203
13	0.190	0.203
14	0.426	0.245
16	0.259	0.261
18	0.183	0.239
20	0.068	0.177
27	0.153	0.235
30	0.182	0.239
32b	–	–
35	0.219	0.275
36	0.368	0.275

[a]Test statistic = MAX $F^*(x) - S_n(x)$, where $F^*(x)$ = cumulative probability function for the normal distribution with mean $\bar{X}$ (sample mean) and variance s^2 (sample variance) and $S_n(x)$ = cumulative frequency distribution of the sample data.
[b]All observations for stop 32 were 100%.

TABLE 11. Frequency of 100% turnovers for stops failing the goodness-of-fit test for normality.

Stop number	Number of observations	Frequency of 100% turnovers
3A	21	15
14	17	13
32	11	11
36	11	7

Stop Entry Process

The fraction of entering vehicles, as the fractional turnover process, was assumed to be a normally distributed random variable. However, due to the lack of data for the number of vehicles passing a given stop, no test of this assumption could be formulated.

Hourly Exits from Loop

An overall test of model validity using data collected in the sampling procedure but not directly incorporated into the model was devised based on the hourly number of vehicles leaving the loop. It was assumed that, given the exact number of arrivals for a given sampled day, simulation would generate the same number of vehicles exiting from the loop as were measured in the sample data. Therefore, a program was developed that calculated the mean number of vehicle exits for each sampled hour for each sampled day. Then, five repetitions of the simulation were run for each day. The simulation used the sample entry values. The actual hourly exits were compared with the means of the simulated exits. This procedure was carried out only for clear days due to the lack of sample data for rainy Tuesdays and Sundays. Further, Fridays were not included in this comparison since no data for clear Fridays were available. The results of the comparison are given in Table 12. The overall mean of the deviations is approximately nine vehicles per hour, which is roughly an average of 2% error in the estimate. However, there were only seven values that had a deviation of over 30 vehicles.

There does appear to be a tendency to underestimate the exits, particularly in the latter hours of the day. The reason for this bias could be twofold: (1) some of the observations are based on only one observation day; and (2) in shifting the arrival rates to approximate more closely the hourly samples, an overshift in the earlier times may have occurred, causing the exits to be skewed toward the earlier hours. It is assumed that by refining the arrival rates, the accuracy of the exit prediction could be improved, but given the current magnitude of the mean deviation, it was not deemed necessary to perform this refinement at this time. There appears to be no reason for rejecting the validity of the overall simulation process.

SIMULATION RESULTS

Model Output

The model output is of three types: tabular, statistical, and graphic. As a demonstration of these output forms, a simulation of 1 week of loop-drive operation under current conditions and using the sampling information was developed.

Only the sampled stops were used in the simulation run to increase the clarity of the output records. The weather conditions were modeled as a random variable using the technique described earlier. The simulation was run for 4 hours for each day of the week starting with Friday. The input used to generate this run is given in the appendix. For conciseness, only Friday's daily generated data will be displayed. Table 13 is a reproduction of the statistical data produced for this day, and Table 14 is a reproduction of the tabular data. Figures 17 and 18 are reproductions of the graphical representations generated by the model of daily and hourly arrivals and daily turnaways of vehicles (due to full parking facilities at the given stops). The weekly tabular and statistical data generated by this run are given in Table 15, and the graphical displays of weekly arrivals and turnaways are reproduced in Figs. 19 and 20, respectively.

TABLE 12. Comparison of sample mean and simulated clear weather hourly loop exits.

Day	Number of observations	Hour	Sample mean	Simulated observations				
Monday	1	12–1	32.0	27	30	28	28	21
		1–2	83.0	62	66	77	52	72
		2–3	66.0	69	67	56	64	61
		3–4	59.0	67	61	45	64	67
Tuesday	4	12–1	30.4	31	33	33	31	25
		1–2	88.0	71	77	87	61	79
		2–3	98.0	84	85	68	78	82
		3–4	101.6	89	78	65	83	85
Wednesday	1	12–1	33.0	36	40	38	33	28
		1–2	79.0	80	85	98	72	90
		2–3	104.0	97	95	79	88	92
		3–4	92.0	99	89	74	96	99
Thursday	1	12–1	37.0	33	35	34	31	23
		1–2	84.0	75	83	95	65	86
		2–3	83.0	93	92	76	86	91
		3–4	118.0	97	86	71	94	94
Saturday	7	12–1	25.0	22	25	21	21	16
		1–2	59.1	52	55	66	45	59
		2–3	73.7	67	66	58	63	64
		3–4	85.0	71	65	51	66	71
Sunday	7	12–1	35.5	26	28	26	24	20
		1–2	87.5	71	78	89	62	78
		2–3	124.1	105	101	86	93	100
		3–4	139.6	125	116	98	120	126

TABLE 13. Statistical data generated for a rainy Friday.

	Hours			
	11–12	12–1	1–2	2–3
Arrivals	43	65	52	37
Hourly arrival mean = 49.250				
Standard deviation = 12.176				
	Hours			
	12–1	1–2	2–3	3–4
Exits	18	48	53	33
Hourly exit mean = 38.00				
Standard deviation = 15.811				
Mean turnaways = 0.846				
Standard deviation = 3.051				

TABLE 14. Tabular data generated for a rainy Friday.

Stop number	Number of vehicles at each stop	Number of vehicles turned away from each stop
3A	39	0
6	46	11
9	21	0
13	35	0
14	25	0
16	17	0
18	35	0
20	126	0
27	14	0
30	8	0
32	15	0
35	6	0
36	10	0
Daily total of arrivals at the loop road = 197		

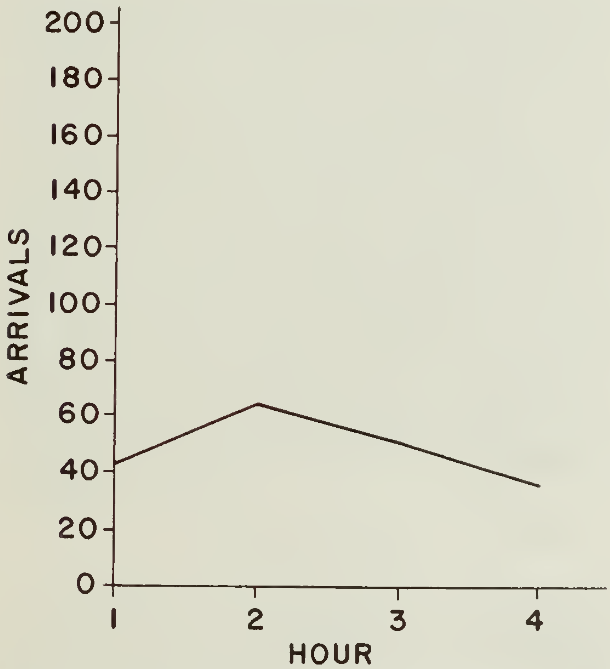

Fig. 17. Hourly arrivals for a simulated rainy Friday.

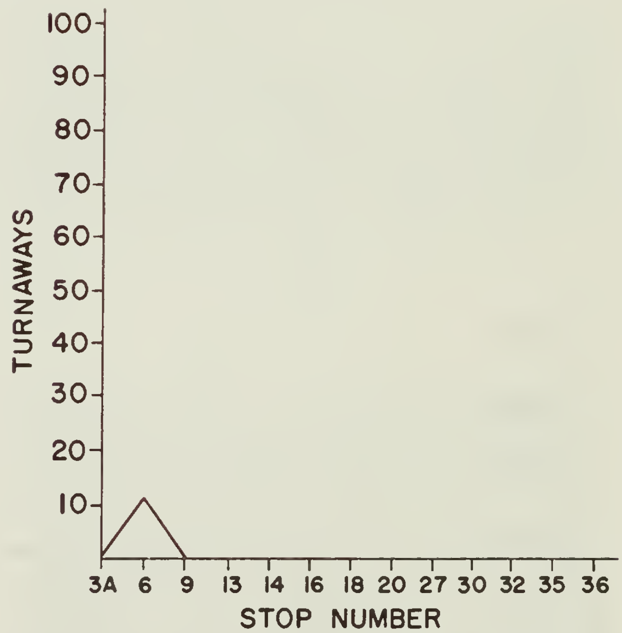

Fig. 18. Vehicle turnaways by stop for a simulated rainy Friday.

System Observations

The only observation of note is that stop 6 is the only stop at which there appears to be an underdevelopment in relation to demand. This might have been expected, given that stop 6—a cabin homestead display—is the first major exhibit in the loop. It has a relatively small parking capacity (10 vehicles) and a relatively high level of probable visitation (24%). The high levels of turnaways at the stop would lead to heavy traffic congestion in this part of the loop drive and therefore would indicate that some methods of alleviating this turnaway problem be investigated.

TABLE 15. Weekly tabular and statistical data.

	Stop number												
	3A	6	9	13	14	16	18	20	27	30	32	35	36
Number of vehicles using each stop	479	547	247	429	266	177	379	1422	210	161	168	110	119
Number of vehicles turned away from each stop	0	247	0	0	0	0	0	0	0	0	0	0	0

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Daily arrivals	197	326	464	250	343	328	350

Weekly total of arrivals at the loop road = 2258
Mean daily arrivals = 322.571
Standard deviation = 83.912
Mean weekly turnaways = 52.385
Standard deviation = 188.875

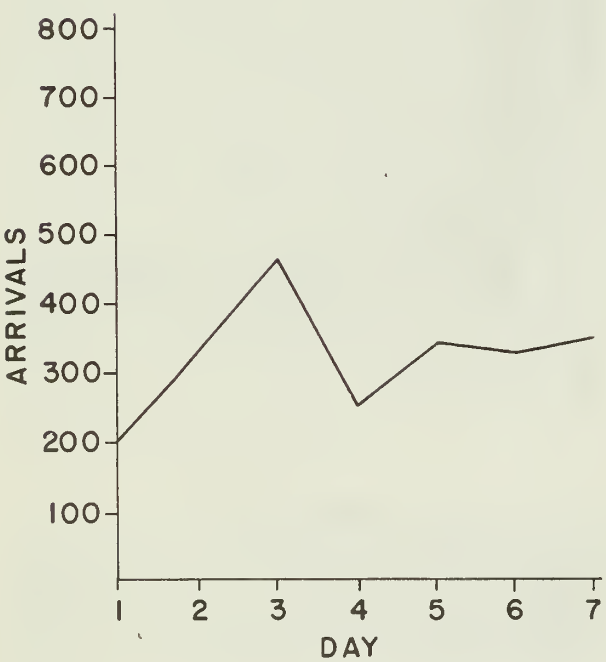

Fig. 19. Total daily use of the loop in vehicles for a simulated week.

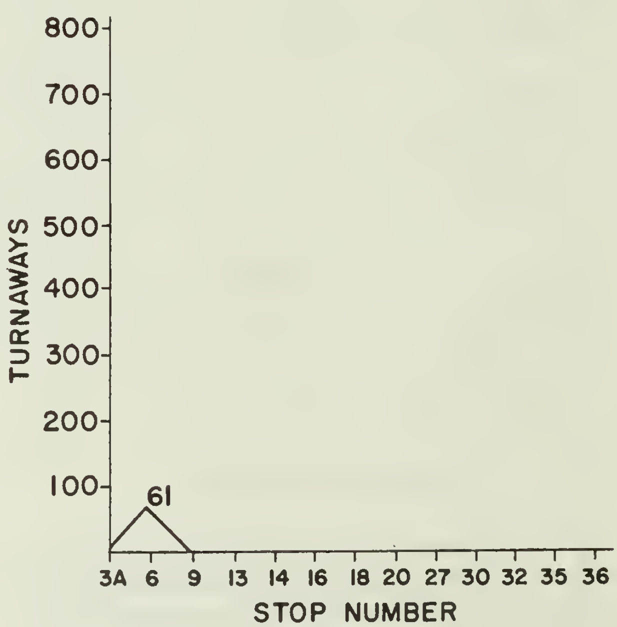

Fig. 20. Total weekly vehicle turnaways by stop for a simulated week.

DEMONSTRATIONS OF MODEL USE

Objectives

The model was developed to assist the National Park Service planner and manager in making major development and policy decisions in the management of the Cades Cove loop drive. Therefore, a series of three demonstrations highlighting the application of the model to some development and management alternatives have been constructed. These are simply demonstrations; they are not the extensive experimentation that should be conducted before making any final recommendations concerning an alternative. However, they do indicate the procedure by which such experimentation would be undertaken.

Demonstration One

Due to the current overcrowding at stop 6, which was indicated in the previous chapter, the effects of doubling the parking facility at this stop were investigated, that is, increasing the parking capacity from 10 to 20 vehicles. The change was accomplished by altering one card in the input list (appendix) and rerunning the simulation. The result of this change was the reduction of the number of weekly vehicle turnaways from the previous 247 to 61. The daily range of turnaways at stop 6 was 0-22 vehicles, with a 20-vehicle parking capacity compared with 11 to 65 with a parking capacity of 10 vehicles. By doubling the parking capacity at stop 6, a reduction in turnaways of better than 60% occurred, which should alleviate much of the traffic congestion in that portion of the loop. The results of the parking facility change indicate that this type of action should be thoroughly investigated as an alternative to mass transit.

Demonstration Two

The use of a mass transit system is an anticipated alternative in the management of the loop drive. The second application of the model relates to its potential in the evaluation of such a system.

The evaluation would necessarily be in two steps. It would require first a careful examination of such elements as the number of mass transit vehicles, the scheduling of arrivals and departures of the vehicles, and the size of the supporting developments that would be necessary for the operation of the system. The model provides a tool for estimating these values.

In each of the determinations, a series of assumptions would be required. First, the service objectives would have to be defined, that is, the level of use (e.g., peak period use, average use, etc.) the system must accommodate would have to be stated. Next, a decision would have to be made as to the maximum waiting time for the potential users. Also, the passenger capacity of the transit vehicles must be established. Finally, there must be a valuation of the visitor carrying capacity for each stop. At present, the parking lot size sets the limit on visitor use of the stops. However, with the implementation of mass transit, more concentrated use of the steps can be anticipated and the effects of this concentration must be analyzed and incorporated into the mass transit management plan.

The number of mass transit vehicles (N) is calculated from the required mass transit vehicle departures (D) from the loop entrance by:

$$D = \frac{\text{average number of arriving passengers per maximum waiting time interval}}{\text{number of passengers per mass transit vehicle}}$$

$$N = D \times \frac{\text{mass transit vehicle round trip time}}{\text{maximum waiting time interval}}$$

To illustrate the application of this current arrival rate on clear Sundays (20 vehicles per 10 minutes), a maximum waiting time of 10 minutes, a 70-passenger mass transit vehicle, and a 100-minute vehicle round trip (11 miles × 15 miles per hour + 2 minutes per stop for loading and unloading) could be assumed. Then,

$$D = \frac{70}{70} = 1$$

$$N = 1 \times 10 = 10$$

Therefore, this system would require 10 mass transit vehicles with one vehicle leaving every 10 minutes.

The model could then be used to evaluate the operation of such a system and to determine the size of the required supporting facilities (e.g., the passenger vehicle parking lot). Thus, there will be variation in the arrivals of passengers, and through the use of the model, estimates of the probabilities of partially used and overcrowded mass transit vehicles could be determined, and parameters for an analytical queueing procedure could be developed. Also, the model in its current form could be used to simulate the use of the required visitor parking facility by recording the difference between arriving and leaving vehicles. To illustrate this activity, a simulation was run for 1 week based on the current arrival rates and assuming the passenger vehicle exits to be at the same rate as under the current private vehicle-use system. The results of this run are given in Table 16. The minimum parking lot capacity to service each of these vehicles, based on this run, is 153 vehicles, shown in Table 16, for a clear Sunday between the hours of 1 and 2 p.m. However, the average use of the parking lot under this system is only 83 vehicles, which means the parking lot will be only about half full on the average.

TABLE 16. Results of run using mass transit system.

Day	Weather	Hourly parking facility use			
		11–12	12–1	1–2	2–3
Friday	rainy	30	54	58	67
Saturday	clear	52	81	101	95
Sunday	clear	76	110	153	132
Monday	clear	44	80	82	81
Tuesday	clear	64	99	106	107
Wednesday	clear	48	79	117	95
Thursday	clear	43	82	102	86

Demonstration Three

The National Park Service has predicted that the use of the Great Smoky Mountains National Park will reach 20,000,000 visitors by 1990 (USDI 1973). The final demonstration of model use is a determination of peak period use based on the 1990 predicted visitation figures. First, an estimate of the vehicles that will enter the loop must be evaluated. This is accomplished through a simple proportion calculation given by:

$$V_{1990} = \frac{V_{1974} \times PV_{1990}}{PV_{1974}} = 1365$$

where

V_i = maximum number of vehicles using Cades Cove on clear Sundays in year i, and
PV_i = yearly visits to Great Smoky Mountains National Park in year i.

The maximum daily use of Cades Cove for 1974 was garnered from the 1974 sample data used in the model construction. The 1974 park visitation was estimated to be 9 million, based on the projection given in the Great Smoky Mountains National Park "Visitor Road and Trail Usage Analysis" (NASA 1974).

Then by assuming the following 5-minute arrival rates—29 vehicles from 11 a.m. to 12:30 p.m., 29 vehicles from 12:30 p.m. to 2 p.m., and 28 vehicles from 2 p.m. to 3 p.m.—a simulation was run for clear Sundays with five repetitions. The results of this run are given in Table 17. These indicate that only two stops (6 and 20) have disproportionately large numbers of turnaways. Most of the stops are receiving relatively high visitations and the total visitation is about 2.5 times the current level.

TABLE 17. Results of increased arrival rates.

Stop number	Mean daily use	Mean daily turnaways
3A	261.4	0.2
6	307.2	257.6
9	152.6	19.0
13	265.0	11.0
14	165.0	1.0
16	105.6	0.8
18	227.8	0.0
20	872.8	192.8
27	144.6	12.8
30	106.2	23.0
32	125.0	2.8
35	77.8	0.8
36	78.6	6.2

Mean daily arrivals = 1336.8
Standard deviation = 20.67

Demonstration Conclusions

Even though the analysis of the mass transit system was a demonstration, the results indicate that it is not an appropriate management choice. Further investigation would be warranted, but the anticipated underuse of the system implies that another alternative should be developed. The results of demonstrations one and three indicate this other alternative should include the expansion of the current parking facilities at several given locations (i.e., stops 6 and 20). The effects of the expansion of stop 6 certainly warrant inclusion in a management plan.

A thorough analysis and development of a series of alternative evaluations can now be completed with the model; therefore, the primary objective of this study has been met. Thus, given the alternative, the model can be applied immediately and the alternative evaluation completed in less than 1 man-month.

POSSIBLE MODEL APPLICATIONS FOR EXTENDED MANAGEMENT USE

The model was specifically designed for use in long-range loop-drive plans. However, with some modifications and extensive experimental use, the model could become a day-to-day management tool. Given the current National Park Service concern with carrying capacity (Sudia 1973), limiting the visitor use of the loop drive becomes a viable management alternative. If, in its operation, the limitation is based on projections of use, the model could become the basis for the loop management. The visitor use at a later time on a given day could be calculated from a sample taken early in the day. The model could be used to generate a series of tables that would indicate appropriate actions based on these sample data.

As an example, the prediction tables could be developed on the basis of a count of vehicles in one of the major stops. If a count at 10 a.m. predicted overcrowding conditions in the Cove by 2 p.m., a sign could be set up at the visitor center warning visitors of the overcrowded conditions at the loop during specific time periods and recommending alternate, less-crowded periods for their visit. Such a system could be implemented with some analyses of the sample data already collected and numerous simulation runs.

A second management possibility would be to control the number of vehicles entering the loop over a given period of time. This would require a monitoring system for loop entries that could be used to slow the entry of vehicles to a rate that would not overcrowd the system. The model would be employed to determine what the maximum rate of entries over the given time period would be to maintain the maximum level of use.

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APPENDIX

Sample Data Input List

```
//DATA. INPUT DD *
TITLE        EXPT. # I       UP CAPACITY AT STOP #6
DATE         9-4-75
TIME FRAME        # OF DAYS 7,      IST DAY #1,      INCREMENT BY 1 DAY, 5 MIN. INSPECTIONS
REPEAT DAY        0  SUNDAY        WEATHER CONDITIONS 0       REPETITIONS 5
MASS TRANSIT      0
CLEAR WEATHER ARRIVAL RATES      NO. OF DAYS 7       DIVISIONS 3
FRIDAY                  5        7        4
SATURDAY                6        7        6
SUNDAY                  9       11        8
MONDAY                  4        8        4
TUESDAY                 8        9        6
WEDNESDAY               7        9        7
THURSDAY                6       11        6
POOR WEATHER ARRIVAL RATES      NO. OF DAYS 7       DIVISIONS 3
FRIDAY                  4        5        3
SATURDAY                5        8        4
SUNDAY                  8       10        8
MONDAY                  7       10        7
TUESDAY                 8        8        6
WEDNESDAY               5        5        5
THURSDAY                4        7        3


STATIONS IN LOOP THIS RUN       3A, 6, 9, 13, 14, 16, 18, 20, 27, 30, 32, 35, 36
NO. OF COVE STOPS CONSIDERED IN THIS RUN       13
COVE STOP CAPACITIES
CAPACITY FOR STOP # 1        15
CAPACITY FOR STOP # 2        10
CAPACITY FOR STOP # 3        10
CAPACITY FOR STOP # 4        10
CAPACITY FOR STOP # 5        10
CAPACITY FOR STOP # 6        10
CAPACITY FOR STOP # 7        50
CAPACITY FOR STOP # 8       150
CAPACITY FOR STOP # 9        10
CAPACITY FOR STOP #10         5
CAPACITY FOR STOP #11         8
CAPACITY FOR STOP #12         8
CAPACITY FOR STOP #13         5
MATRIX OF VEHICLES STOPPING AND TURNOVER RATES, AS FRACTIONS, FOR EACH STOP
AVERAGE STOPPING AT STOP # 1        .21            AVERAGE TURNOVER       1.00
AVERAGE STOPPING AT STOP # 2        .24                                    .07
AVERAGE STOPPING AT STOP # 3        .11                                    .44
AVERAGE STOPPING AT STOP # 4        .21                                    .92
AVERAGE STOPPING AT STOP # 5        .12                                   1.00
AVERAGE STOPPING AT STOP # 6        .07                                    .82
AVERAGE STOPPING AT STOP # 7        .18                                    .33
AVERAGE STOPPING AT STOP # 8        .67                                    .07
AVERAGE STOPPING AT STOP # 9        .12                                    .54
AVERAGE STOPPING AT STOP #10        .08                                    .60
AVERAGE STOPPING AT STOP #11        .10                                   1.00
AVERAGE STOPPING AT STOP #12        .06                                    .62
AVERAGE STOPPING AT STOP #13        .05                                   1.00
OUTPUT:  LOOP ROAD DAILY
DAILY TOTAL  1, WEEKLY TOTAL  1, FULL LIST  1, DEFAULT  0
STATS:  DAILY ARRIVALS  1, DAILY TURNAWAYS  1, DAILY EXITS  1,
        WEEKLY ARRIVALS  1, WEEKLY TURNAWAYS  1
```

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