ESTIMATING SOCIAL CARRYING CAPACITY THROUGH COMPUTER SIMULATION MODELING: AN APPLICATION TO ARCHES NATIONAL PARK, UTAH

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Abstract: Recent research and management experience has led to several frameworks for defining and managing carrying capacity of national parks and related areas. These frameworks rely on monitoring indicator variables to ensure that standards of quality are maintained. The objective of this study was to develop a computer simulation model to estimate the relationships between total park use and the condition of indicator variables. In this way, the social carrying capacity of parks might be estimated more proactively.

Introduction

Carrying capacity is a perennial issue in parks and outdoor recreation. Recreation can cause impacts to park resources (e.g., compaction and erosion of soil, destruction of groundcover vegetation) and the quality of the visitor experience (e.g., crowding and conflicting uses). Carrying capacity addresses the amount of recreation-related impact and associated visitor use that can ultimately be accommodated in parks and outdoor recreation areas. Carrying capacity is becoming increasingly important in the national park system where annual visits will soon surpass 300 million.

This study addresses application of carrying capacity to Arches National Park, Utah. Previous research has led to establishment of selected indicators and standards of quality for major attractions within the park (National Park Service 1995; Manning et al. 1996a). For example, to avoid unacceptable levels of crowding, the number of people-at-one-time (PAOT) at Delicate Arch should not exceed 30 more than 10 percent of the time. But how many visitors can be allowed to hike to Delicate Arch before this standard of quality is violated? Moreover, how many visitors can be allowed in the park before standards of quality are violated at this and other attraction sites? Computer simulation models of visitor use were developed to help answer these and related questions.

Background for the Study

Overview of carrying capacity

In studying the effects of increasing recreation use, researchers and managers were initially concerned about environmental impacts as measured by such variables as soil compaction, vegetation decline, and change in wildlife behavior. Using a well-known concept in natural science, recreation researchers started to think of these impacts in terms of carrying capacity. The central idea of carrying capacity is that there is a limit to the amount of use a resource such as a park can accommodate. As researchers explored the issue further, it soon became obvious that there were impacts to the visitors' experience as well as environmental impacts (Wagar 1964). The intuitive idea is that the presence of increasing numbers of visitors affects the quality of the outdoor recreation experience, and this is often referred to in the literature as social carrying capacity.

Contemporary carrying capacity frameworks in outdoor recreation have taken a management by objectives approach to defining and managing this issue. Management objectives are formulated for the degree of resource protection and the type of recreation experience desired. These management objectives are made operational through a set of indicators and standards of quality (Manning 1999). Indicators of quality are defined as measurable, manageable variables that reflect the essence or meaning of management objectives. Standards of quality are defined as the minimum acceptable condition of indicator variables. Indicator variables are monitored over time, and management action is required to ensure that standards of quality are maintained. Frameworks that use this approach to defining and managing carrying capacity include Limits of Acceptable Change (LAC) (Stankey et al. 1985), Visitor Impact Management (VIM) (Graefe et al. 1990), and Visitor Experience and Resource Protection (VERP) (National Park Service 1997).

While these carrying capacity frameworks have been successfully applied in a number of park and recreation areas, a potential weakness of this approach to carrying capacity is its arguably <u>reactive</u> nature. That is, it relies on a monitoring program to determine when standards of quality are violated, or are in danger of being violated. A more <u>proactive</u> approach to mananging carrying capacity would be to estimate the level of visitor use that will cause standards of quality to be violated, and to ensure that such levels of visitor use are not allowed. Computer simulation modeling has the potential to facilitate a more proactive approach to defining and managing social carrying capacity.

Overview of simulation modeling and applications to outdoor recreation

Simulation modeling is the imitation of the operation of a real-world process or system over time. It involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system. Simulation modeling enables the study of, and experimentation with, the internal interactions of a complex system. The approach is especially suited to those tasks that are too complex for direct observation, manipulation, or even analytical mathematical analysis (Banks and Carson 1984, Law and Kelton 1991, Pidd 1992).

The most appropriate approach for simulating outdoor recreation is dynamic, stochastic, and discrete-event, since most recreation systems share these traits. Models that represent systems as they change over time are *dynamic* models, differing from static models that represent a system at a particular point in time. Complex and highly variable systems are often modeled using *stochastic* simulation. A stochastic simulation model contains probabilistic components and takes into account the random variation of systems over time. *Discrete-event* simulation models are dynamic models that imitate systems where the variables change instantaneously at separated points in time. This contrasts with continuous systems where variables change continuously over time. A mountain stream is usually modeled as a continuous system, where variables such as stream flow change continuously over time. An example of a discrete-event system is a campground: variables, such as the number of campers, change only when there are campers arriving or departing.

From the mid-1970's to the early-1980's, researchers explored computer simulation modeling as a tool to assist recreation managers and researchers (Manning and Potter 1984, McCool et al. 1977, Potter and Manning 1984, Schechter and Lucas 1978, Smith and Headly 1975, Smith and Krutilla 1976). The main goal of the Wilderness Travel Simulation Model, as it came to be known, was to estimate the number of encounters that occurred between recreation parties in a park or wilderness area. The model required input variables such as typical travel routes and times, arrival patterns, and total use levels. Outputs included the number of encounters between visitor parties of various types and the date and location of encounters. Initial tests established the validity of the model, but the model soon fell into disuse. Computers were relatively inaccessible at the time, and the evaluative component of carrying capacity research had not yet produced defensible numerical standards of quality.

Recent changes in computing power complemented advances in evaluative research to provide the context and impetus for the present study to revisit computer simulation for recreation research and management. Simulation-capable computers have become "smaller, cheaper, more powerful and easier to use by non-specialists" (Pidd 1992, p. 3). Exponential growth in the power of personal computers has facilitated the use of graphic user interface and visual interactive modeling technologies to make the simulation process accessible to non-specialists (Pidd 1992). These advances have led to the wide proliferation of simulation in the fields of business management and manufacturing.

In the 1990's there was renewed interest in applying simulation approaches to outdoor recreation management. Studies at Acadia National Park (Wang and Manning 1999), Yosemite National Park (Manning et al. 1998a, Manning et al. 1999), Yellowstone National Park (Borrie et al. 1999), and on Alcatraz Island (Manning et al. 1998b) used a simulation approach similar to the Wilderness Travel Simulation Model. These studies involved building models of specific sites or specific activities to determine social carrying capacities within these National Park areas.

The following section describes carrying capacity research at Arches National Park. This ongoing planning and research process provided the opportunity for this study.

Visitor Experience and Resource Protection (VERP) research at Arches National Park

The VERP framework described above was first applied to Arches National Park, Utah (National Park Service 1995). A program of social science research was conducted to help managers formulate indicators and standards of quality (Manning et al. 1995; Manning et al. 1996a; Manning et al. 1996b). The first phase of research addressed potential indicators of quality. Using open- and close-ended questions, visitors were asked to identify variables that contributed to or detracted from the quality of their experience in the park. Several indicators of quality were identified, including the number of visitors at prime attraction sites, including Delicate Arch, The Windows, and Devils Garden.

The second phase of research addressed standards of quality. As part of this study, visitors to Delicate Arch, The Windows, and Devils Garden were asked to rate the acceptability of a series of photographs showing a range of visitors at these sites. These photographs were developed using photo editing computer software (Manning et al. 1996a). Based on study findings, park managers established crowding-related standards of quality at these sites. For Delicate Arch, the standard of quality was no more than 30 PAOT more than 10 percent of the time. For The Windows, the standard of quality was no more than 20 PAOT more than 10 percent of the time. For Devils Garden, the standard of quality was no more than twelve PAOT along a 100 meter section of trail more than 10 percent of the time. Once these standards of quality were established, park staff began a program of monitoring these sites to determine if standards of quality were being maintained.

Given these indicators and standards of quality, information was needed on the relationships between PAOTs and total use levels of the Park. The literature described above suggests that computer simulation may have special applications to the dynamic and descriptive aspects of park use and carrying capacity. The overall purposes of this study were to 1) develop a computer simulation model of total park use that could estimate the relationships between total park use and PAOTs at attraction sites, and 2) test the validity of this computer simulation model.

Methods

Data collection
A variety of methods were employed to gather the baseline data necessary for building a model of visitor travel in Arches. These were vehicle counts with traffic counters, on-site visitor surveys, field visits, and map analysis. In addition, parking lot counts and PAOT counts were conducted to validate model outputs. These are described in more detail below.

Data on how many and what time visitors entered the Park were gathered using a traffic counter at the Park entrance. Data were gathered for a seven-day period in the summer of 1997, from August 19 through August 25. Total daily vehicle entries for these seven days averaged to 1346 per day.

Information on visitor characteristics and travel patterns were gathered with on-site survey instruments in the summers of 1997 and 1998. In 1997 426 vehicle travel questionnaires were administered to visitors exiting the Park on August 14, 16, 20, 25, 26 and 30. These were administered from 7:00 a.m. to dusk. Safety concerns preempted surveying after dark. In the same year 180 hiking questionnaires were administered to visitors returning from their hikes to Delicate Arch on August 15, 18, and 24. In 1998 160 questionnaires were administered to tour bus drivers on 42 days between July 9 and October 22. Also in 1998 245 hiking questionnaires were administered to hikers returning from their hikes around The Windows on July 18, 19, 27, and August 2 and 3. Likewise in 1998 320 questionnaires were administered to hikers returning from their hikes in the Devil's Garden section on July 5, 6, 8, and August 3 and 6. In all of these surveys one visitor from each group was asked about their group size, the total amount of time they had spent on the roads or trails (depending on the survey), and where and how long they paused during the visit. Finally, with the aid of the interviewer, they were asked to retrace the route of their trip on a map of the Park.

The lengths of road and trail sections between intersections were calculated from Park maps.

For model validation purposes the number of vehicles in the Wolf Ranch (Delicate Arch), The Windows, and Devil's Garden parking lots were counted 11 times a day between 6:00 a.m. and 10:00 p.m. on August 19, 21, 23, and 25 1997. In addition, PAOT counts were conducted at Delicate Arch every minute for several hours each day on twelve days between August 24 and September 26, 1999. The total numbers of vehicles entering the park was recorded with traffic counters on each of the parking lot count and PAOT count days.

Model algorithm and programming
The simulation model was built using the object-oriented dynamic simulation package, Extend (1996). The structure of the model was built with hierarchical *blocks* that represented specific parts of the Park's road and trail systems. The three main types of hierarchical blocks that comprised the model were entrance/exit blocks, intersection blocks, and road and trail section blocks.

The entrance/exit blocks were built to generate the simulated visitor parties. Visitor parties were generated using an exponential distribution varying around mean values from the entrance counts. The exponential distribution has been demonstrated to accurately simulate arrival rates at park areas with random arrival patterns (Wang and Manning 1999). The parties were then randomly assigned travel modes (automobile or bus) and group size, both according to probability distributions derived from the visitor surveys. Simulated visitor parties were then randomly assigned travel speeds according to a lognormal distribution, which has been demonstrated to accurately simulate different travel speeds in parks (Wang and Manning 1999). The means and standard deviations were calculated from the travel times reported by survey respondents and the lengths of their travel routes. Lastly, the visitor parties were randomly assigned a route identification number according to frequencies of actual routes reported by survey respondents.

The intersection blocks were built to direct simulated visitor parties in the right direction when they arrive at road and trail intersections. Lookup tables unique for each intersection direct each party toward the correct next intersection as indicated by their route identification numbers and how many times, if any, they have been through that intersection.

The road section blocks were built to simulate travel through the road section by delaying simulated visitor parties for the appropriate period of time, according to their assigned travel speeds. The parking lot and attraction blocks also held simulated visitor parties for periods of time. In addition, they were designed to output the numbers of visitors in those areas throughout the simulated day.

Model runs
The model was run with three total use levels: current average total use level, half of the current average, and double the current average. Twelve runs were made for each use level to capture stochastic variation. The average PAOT conditions at Delicate Arch were recorded from these runs.

Figure 1. Relationship Between PAOT at Delicate Arch and Park Total Use Levels

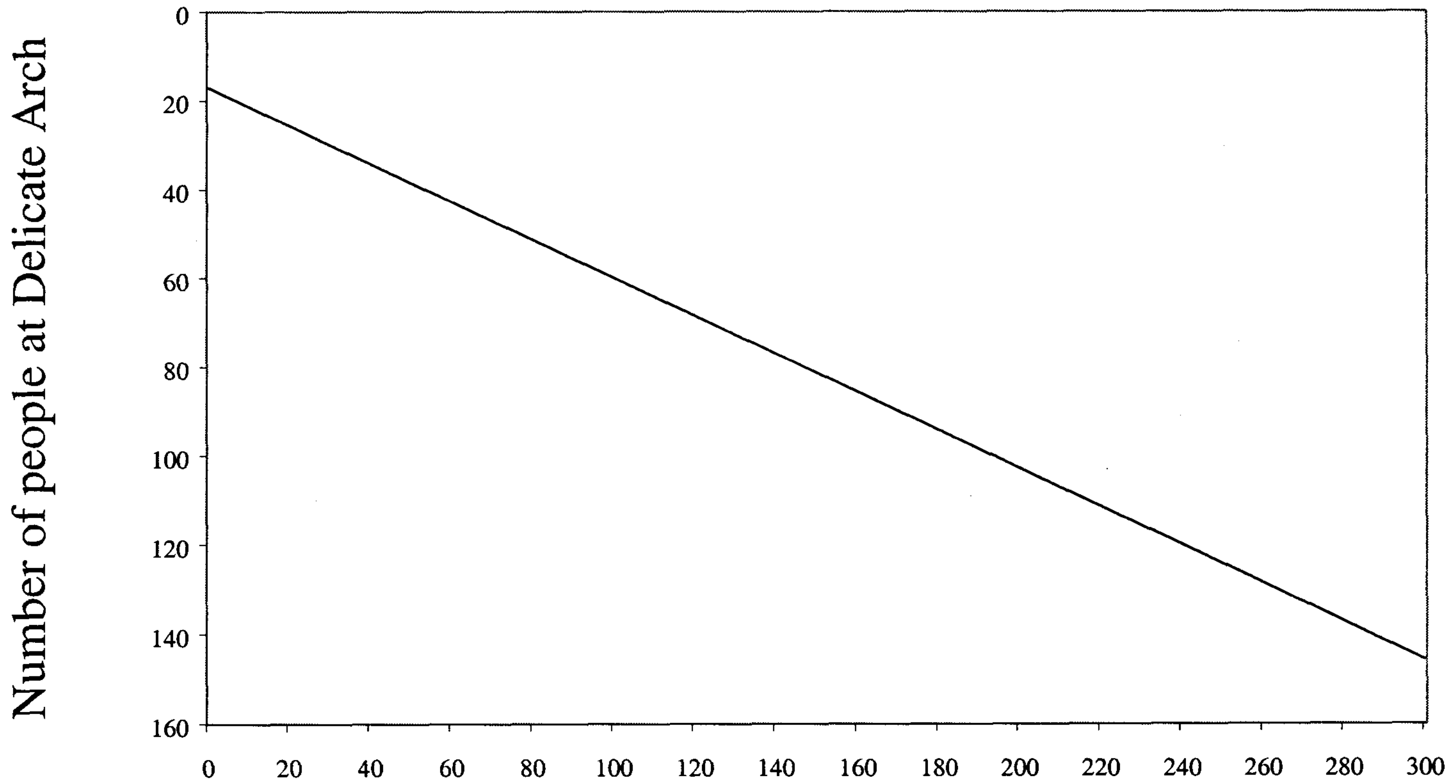


Figure 2. PAOT Comparisons at Delicate Arch

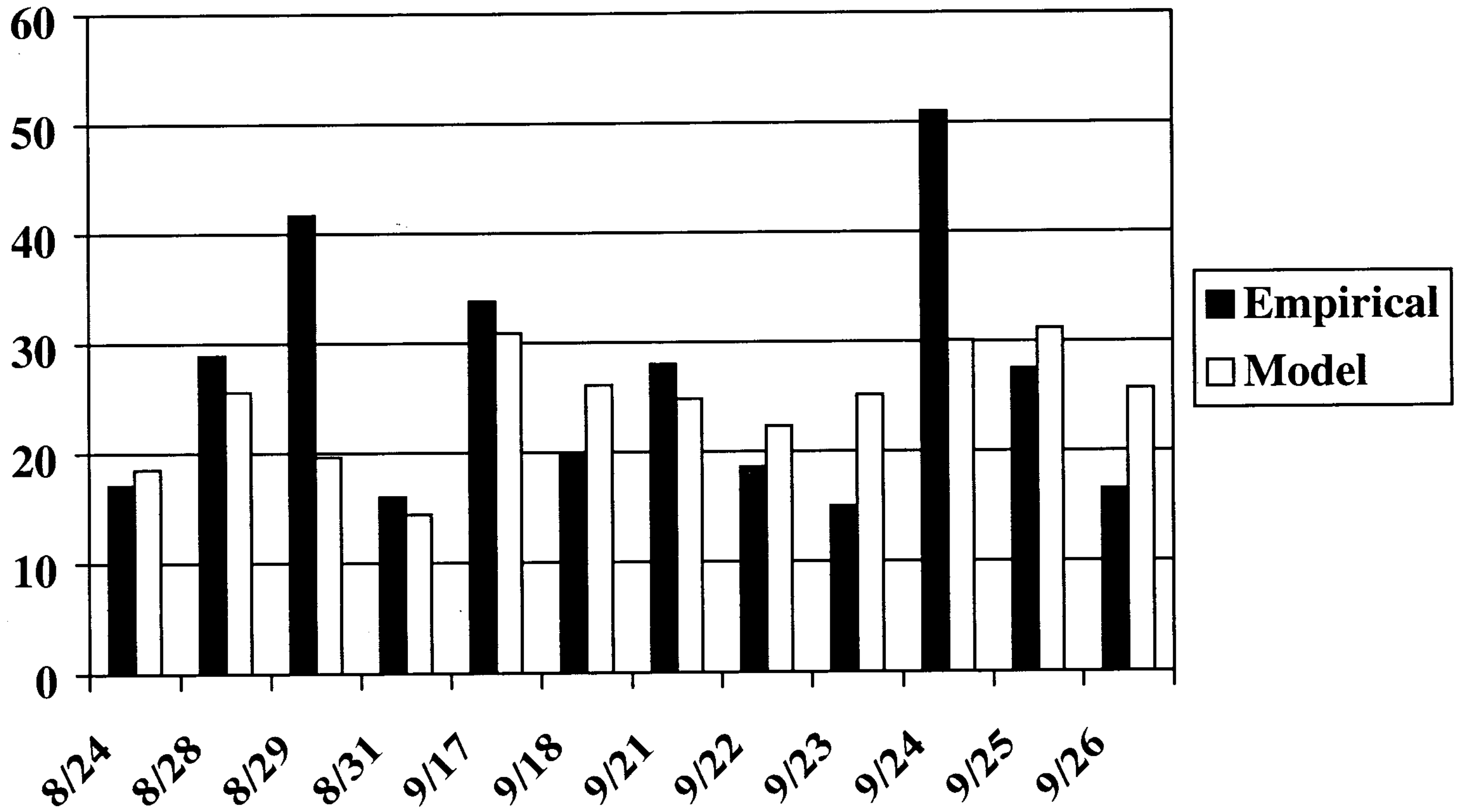
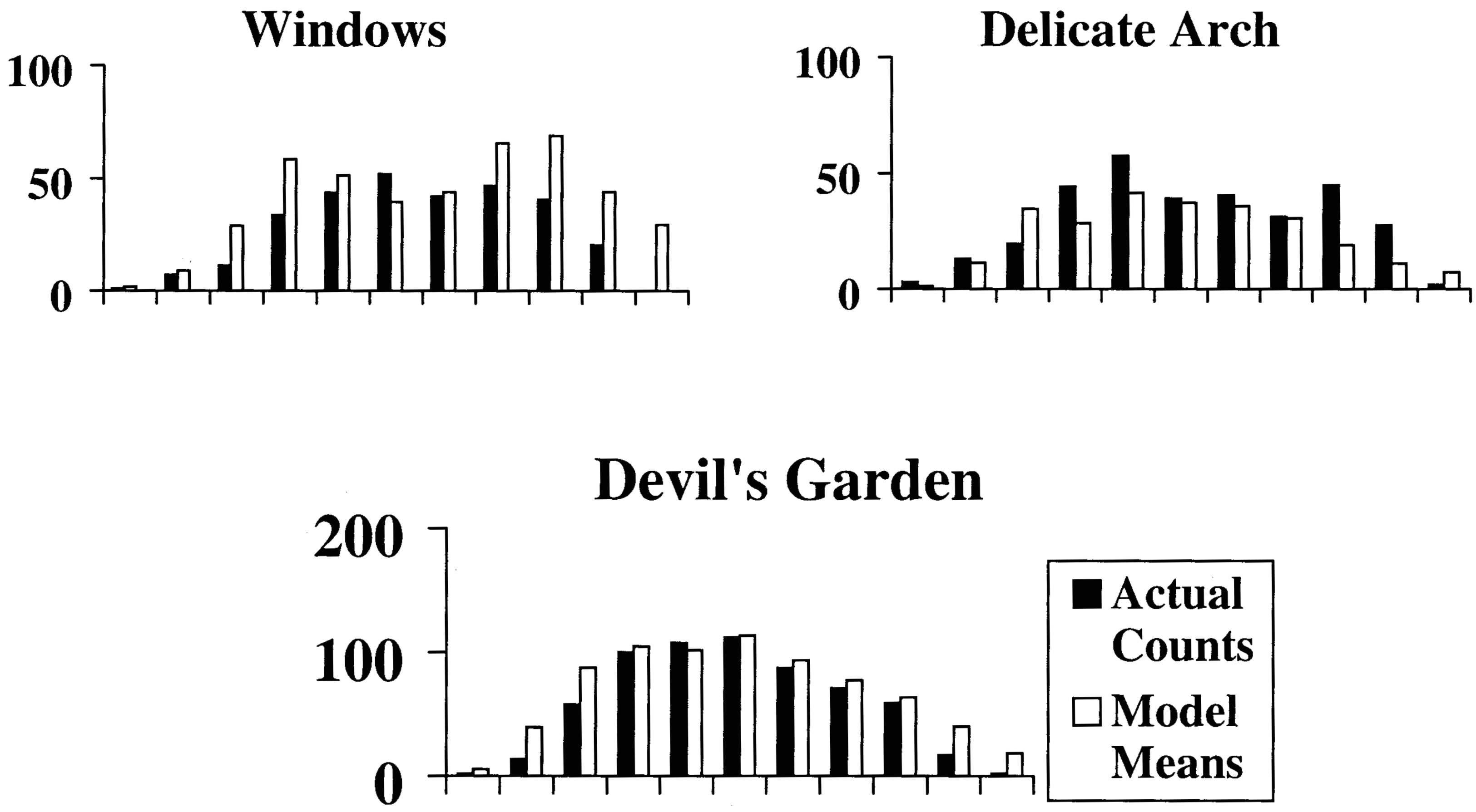


Figure 3. Parking Lot Count Comparisons Through the day on 8/23/98



The model was run a total of 32 times to compare with the empirical parking lot counts for validation purposes. Each run simulated Park use from 5:00 a.m. to 10:00 p.m., but only recorded output from 6:00 a.m. to 10:00 p.m. Output from the first hour was considered unreliable because people who would have entered the Park before 5:00 a.m. were not simulated. The model was run based on the total use levels of the four days on which the parking lot counts were done. The model runs were repeated eight times for each of the four simulated days to capture stochastic variation. The number of vehicles in each parking lot was tracked through each simulated day.

The model was also run for comparison against the PAOT counts at Delicate Arch. The model runs were repeated four times for each of the twelve simulated days to capture stochastic variation. The number of visitors at Delicate Arch was tracked through each simulated day.

Results

Figure 1 shows the relationship between the number of vehicles entering the Park each day and the highest PAOT at Delicate Arch. This relationship allows estimates of the maximum number of vehicles that can be accommodated in the Park without violating selected standards of quality.

Figure 2 shows comparisons between average observed PAOT and model outputs for estimated PAOT for twelve days at Delicate Arch. A visual inspection shows that the results match closely except for August 29 and September 24. Chi-square tests showed significant differences between the distributions.

Figure 3 shows representative output validation results for parking lot counts. Results are shown for comparisons of observed data and model outputs at the three parking lots on August 23. A visual inspection shows that the model matches empirical data closely except for the evening hours at each site. The model underestimates the number of visitors at Delicate Arch and overestimates the number of visitors at the other two sites. Chi-square tests showed significant differences between the distributions.

Conclusions and Implications

Study findings suggest that it is feasible to develop a park wide model of visitor use encompassing both vehicle and pedestrian travel. Moreover, such a model can be used to develop relationships between total park use (e.g., the number of vehicles entering the park each day) and the condition of indicators variables (e.g., PAOT at Delicate Arch). Such a model can be used to estimate the social carrying capacity of a park. While continued monitoring of indicator variables is warranted, modeling can more proactively estimate the point at which standards of quality will be violated, and can reduce needed intensity of monitoring activity.

Discrepancies between model output and field observations designed to validate the model are due primarily to the lack of visitor surveys conducted in the later hours of study days. As noted above, safety concerns (stopping vehicles after sunset) did not allow surveys to be conducted after dark. In the case of PAOT at Delicate Arch, the August 29 and September 24 field counts were conducted during the evening hours. The parking lot counts also showed the greatest discrepancies in the evenings. This problem will be rectified in the summer of 2000 when additional visitor surveys will be conducted during the evening hours at Delicate Arch, The Windows, and Devils Garden.

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