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Using Simulation Modeling to Facilitate Proactive Monitoring and Adaptive Management of Social Carrying Capacity in Arches National Park, Utah, USA

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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 protected areas. The process outlined in contemporary carrying capacity frameworks embodies the principles of adaptive management. That is, management decisions are guided and adapted within these frameworks by 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, simulation modeling might facilitate proactive monitoring and adaptive management of social carrying capacity of parks and protected areas.

INTRODUCTION

Public visits to parks and protected areas continue to increase and may threaten the integrity of natural and cultural resources and the quality of the visitor experience. For example, annual visits to the U.S. national park system are approaching 300 million, and this level of use may disturb fragile soils, vegetation and wildlife, and may cause unacceptable crowding and visitor conflicts. Starting as early as the 1960's, outdoor recreation research has adapted and developed the concept of carrying capacity to address these issues related to visitor use (Manning, 1999). In the context of outdoor recreation, social carrying capacity refers to the amount of visitor use that can ultimately be accommodated in parks and outdoor recreation areas without diminishing the quality of the visitor experience beyond an acceptable level.

This study addresses the application of computer simulation modeling to defining and managing social carrying capacity in 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., 1995; Manning et al., 1996a; Manning et al., 1996b). 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? A computer simulation model of visitor use was developed to help answer these and other carrying-capacity related questions.

CARRYING CAPACITY AND ADAPTIVE MANAGEMENT

A number of frameworks have been developed to provide managers with a basis for making decisions about the carrying capacity of parks and protected areas, including 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). Common to all of these frameworks is formulation of management objectives concerning the degree of resource protection and the type of recreation experience desired. 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 actions are applied as needed to ensure that standards of quality are maintained.

The process outlined in contemporary carrying capacity frameworks embodies the principles of adaptive management. Adaptive management has been characterized as a form of experimentation and learning in which a team of managers, planners, and experts formulate hypotheses concerning the relationship between management actions and corresponding outcomes (Lee, 1993). A management "experiment" is carried out by taking management actions, monitoring the outcomes of the actions, and comparing the monitoring data to hypothesized outcomes. Managers adapt to differences among expected and actual outcomes of management actions by reformulating their hypotheses and implementing new management actions. Management outcomes are monitored to test revised hypotheses, and additional learning about the system under management takes place. This process continues in an incremental cycle of experimentation and learning. For example, consider a park or related area where crowding-related indicators of quality (e.g., the number of people seen at one time at popular attraction sites) have been monitored and are not within standards of quality. Managers of the area may hypothesize that these indicators of quality can be brought within standards of quality by limiting the number of people who enter the park or by implementing a permit system that controls the temporal and/or spatial distribution of visitors to the area. In order to test these hypotheses, visitor use limits or a permit system are implemented for the park. Monitoring is conducted to test the hypothesis that crowding-related indicators of quality are within standards of quality given the new management action. Through this process the manager learns about the effectiveness of management actions and adapts future management decisions accordingly.

While carrying capacity frameworks such as LAC, VIM, and VERP have been successfully applied in a number of park and recreation areas, a potential weakness of this approach to carrying capacity in particular, and adaptive management in general, is their arguably <u>reactive</u> nature. That is, they rely 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 managing 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. Specifically, simulation modeling provides managers with a tool to experiment with and predict the outcomes of a range of management actions that might otherwise be too costly to consider and/or may lead to potentially undesirable consequences. In this way, outdoor recreation managers can capitalize on the strengths of adaptive management, decision-making guided by experimentation and learning, while avoiding potential constraints associated with such an approach.

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 & Carson, 1984; Law & 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 & Potter, 1984; McCool et al., 1977; Potter & Manning, 1984; Schechter & Lucas, 1978; Smith & Headly, 1975; Smith & 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 groups 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 groups 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). 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 (Pidd, 1992). These advances have led to wide proliferation of simulation in the fields of business management and manufacturing.

In recent years there has been renewed interest in applying simulation modeling to outdoor recreation management, resulting in the development of two related approaches. Research at Grand Canyon National Park (Daniel & Gimblett, 2000) and Broken Arrow Canyon near Sedona, Arizona (Gimblett, Daniel, & Meitner, 2000; Gimblett, Richards, & Itami, 2001) combined simulation modeling with artificial intelligence technologies and geographic information systems (GIS) to address social carrying capacity-related issues at the study areas. Studies at Acadia National Park (Wang & Manning, 1999), Yosemite National Park (Manning et al., 1998b, Manning et al., 1999), Yellowstone National Park (Borrie et al., 1999), and Alcatraz Island (Manning et al., 1998a) 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. This paper presents an application of the latter approach to simulation modeling at Arches National Park. Specifically, a computer simulation model of visitor use of Arches National Park was developed to estimate the maximum use level that can be accommodated at Delicate Arch and within the park more generally without violating standards of quality for a crowding-related indicator of quality (PAOT at Delicate Arch). The results provide numerical estimates of social carrying capacity of Delicate Arch and Arches National Park.

METHODS

Data Collection

A variety of methods were employed to gather the baseline data used to build the simulation model of visitor travel in Arches National Park, including vehicle counts with traffic counters, on-site visitor surveys, field visits, and map analysis. In addition, parking lot counts were conducted to validate model outputs. The following paragraphs describe the data collection methods in more detail.

A traffic counter placed at the entrance to Arches National Park was used to record the number of vehicles entering the park and the time each vehicle entered. These traffic data were collected during a seven-day period from August 19 - August 25, 1997. Total daily vehicle entries for these seven days averaged to 1,346 vehicles.

Data concerning visitor characteristics and their travel patterns within Arches National Park were collected through a series of on-site surveys administered to park visitors during the summers of 1997 and 1998. During the summer of 1997, vehicle travel route questionnaires were administered to 426 visitor groups as they were exiting the park. One visitor from each group was asked to report their group's size, the total amount of time they had spent traveling on the park roads, 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 vehicle travel route questionnaires were administered on 6 days during the period from August 14 – August, 30, starting at 7:00 a.m. and ending at dusk. Safety concerns pre-empted stopping cars and surveying visitors after dark.

A second questionnaire was administered during the summer of 1997 to a total of 180 visitor groups returning from their hikes to Delicate Arch. One visitor from each group was asked to report the group's size, the total amount of time they had spent on the trail to Delicate Arch and at the Arch, and where and how long they paused during the hike. The Delicate Arch hiking questionnaires were administered on 3 days during the period from August 15 – August, 24, starting at 7:00 a.m. and ending at 10:00 p.m..

During the summer of 1998, 160 questionnaires were administered to tour bus drivers on 42 days between July 9 and October 22. Bus drivers were asked to provide the same type of information that was collected in the vehicle travel route survey the previous summer. Tour bus travel route data were collected during the daylight hours from 7:00 a.m. to dusk.

Hiking questionnaires were administered during the summer of 1998 at The Windows and Devil's Garden sections of the park. Similar to the hiking questionnaire administered at Delicate Arch during the previous summer, visitor groups at The Windows and Devil's Garden areas were asked to report information about their group size, the route they hiked, and the places and amount of time they paused during the hike. A total of 245 questionnaires were completed by visitors returning from their hikes around The Windows on 5 days during the period from July 18 - August 3, and 320 questionnaires were administered to hikers returning from their hikes in the Devil's Garden section of the park on 5 days during the period from July 5 - August 6. Surveys in both locations started at 7:00 a.m. and ended at 10:00 p.m..

Additional data needed to construct the model were gathered through analysis of park maps. Specifically, the lengths of road and trail sections between intersections were calculated from maps provided by the park.

Data needed to validate the output of the simulation model were gathered through a series of vehicle counts conducted at selected parking lots in the park. 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 four days during the period from August 19 – 25, 1997. The total number of vehicles entering the park was recorded with traffic counters on each of the days that parking lot counts were conducted. The parking lot count data were compared to parking lot values output by the simulation model run at total use levels equivalent to the number of vehicles entering the park on the days validation data were collected.

Model Algorithm and Programming

The Arches National Park travel simulation model was built using the object-oriented dynamic simulation package, Extend (1996). The structure of the model was built with hierarchical blocks that represent specific parts of the park's road and trail systems. The simulation model is comprised of three main types of hierarchical blocks, including entrance/exit blocks, intersection blocks, and road and trail section blocks.

Entrance/exit blocks were built to generate simulated visitor parties. Visitor parties are generated by the simulation model based on an exponential distribution varying around mean values calculated from the park entrance counts recorded by the traffic counter. The exponential distribution has been demonstrated to accurately simulate arrival rates at park areas with random arrival patterns (Wang & Manning, 1999). Within the entrance/exit block, newly generated visitor parties are assigned values for a set of attributes designed to direct their travel through the simulated park visit. First, visitor parties are randomly assigned travel modes (automobile or bus) and group size, both according to probability distributions derived from the visitor surveys. Next, travel speeds are assigned to visitor parties according to a lognormal distribution. The mean travel speed and standard deviation of the distribution were calculated from the travel times reported by survey respondents and the lengths of their travel routes. The lognormal distribution has been demonstrated to accurately simulate different travel speeds in parks (Wang & Manning, 1999). Lastly, the visitor parties are randomly assigned a route identification number that directs groups through their simulated park visit. Travel route identification numbers are assigned to visitor parties according to frequency distributions of actual routes reported in the visitor surveys.

Intersection blocks were designed to direct simulated visitor parties in the right direction when they arrive at road and trail intersections. Lookup tables unique for each intersection direct visitor parties to the next park feature (e.g., road section, trail section, parking lot, attraction site) selected from the set of alternatives at the intersection. The direction of travel selected for a visitor party at each intersection is based on the value of the group's route identification number and the number of previous times, if any, the group has been through the intersection.

Road section blocks were built to simulate travel along park roads. Simulated visitor parties are delayed within each road section they enter for a length of time determined by their assigned travel speeds and the length of the road section. Similar to road section blocks, parking lot and attraction site blocks were designed to hold simulated visitor parties for periods of time based on data collected from the visitor surveys. Parking lots were also designed to output the number of visitor parties parked at each parking lot throughout the simulated day. Attraction site blocks were designed to output PAOT at selected attraction sites throughout the simulated day.

Model runs

A series of model runs were conducted to achieve three purposes; 1) to estimate the maximum number of visitors that can be allowed to hike to Delicate Arch between the hours of 5:00 a.m. and 4:00 p.m. without violating the standard of quality for PAOT at Delicate Arch (i.e., to estimate a social carrying capacity of Delicate Arch); 2) to estimate the maximum number of vehicles that can be allowed to enter Arches National Park between the hours of 5:00 a.m. and 4:00 p.m. without violating the standard of quality for PAOT at Delicate Arch (i.e., to estimate a social carrying capacity of Arches National Park); and 3) to validate the simulation model by comparing actual parking lot counts with parking lot data generated by the simulation model. Each run simulated park use from 5:00 a.m. to 4:00 p.m. As noted earlier, safety concerns (i.e., stopping vehicles after dark) prevented vehicle and tour bus travel route surveys from being administered after dark. Therefore, the model does not simulate visitor use during the evening hours.

For the first objective, estimating a social carrying capacity of Delicate Arch, the model was run at a range of total use levels representing the number of visitors hiking to the Arch. Twelve runs were made for each use level to capture stochastic variation. The average percent of time that PAOT at Delicate Arch exceeded 30 (i.e., the maximum acceptable level of PAOT at Delicate Arch) was recorded for each total use level modeled. This process was repeated to estimate a social carrying capacity of Arches National Park, except that the total number of vehicles entering the park was modeled.

To achieve the third objective, validating the simulation model output, a series of 48 model runs were conducted. Model runs were conducted for each of the total park use levels recorded during the four days that parking lot counts were recorded. The model runs were repeated twelve times for each of the four simulated days to capture stochastic variation. The number of vehicles in selected parking lots was tracked through each simulated day. For each of the total use levels modeled, the average number of vehicles in the selected parking lots was calculated at time intervals that matched the actual parking lot count times and compared to observed data.

RESULTS

Social Carrying Capacity of Delicate Arch and Arches National Park

Numerical estimates of social carrying capacity of Delicate Arch and Arches National Park are reported in Table 1. The figure in the first column of Table 1 indicates that the estimated social carrying capacity of Delicate Arch is 315 hikers. That is, the model estimates that a maximum of 315 people can be allowed to hike to Delicate Arch between the hours of 5:00 a.m. and 4:00 p.m. without violating the standard of quality for PAOT at Delicate Arch. The social carrying capacity of Arches National Park is estimated to be 750 vehicles. In other words, the model results suggest that a maximum of 750 vehicles can be allowed to enter the park between the hours of 5:00 a.m. and 4:00 p.m. without having PAOT at Delicate Arch exceed 30 more than 10 percent of the time.

Delicate Arch	**Arches National Park**
315 hikers (5:00 a.m. - 4:00 p.m.)	**750 vehicles (5:00 a.m. - 4:00 p.m.)**

Table 1. Numerical Estimates of Social Carrying Capacity

	T statistic
Windows parking lot counts	**-3.00***
Delicate Arch parking lot counts	**1.46**
Devil's Garden parking lot counts	**-0.28**
Park-wide parking lot counts	**-0.40**

Table 2. Parking Lot Validation Statistics

Model Validation

Table 2 presents validation results based on comparisons between actual parking lot counts and model outputs. The four days of counts were combined and a set of four t-tests were performed to test for statistically significant differences among observed data and model outputs at each of the three parking lots and park-wide. There was a statistical difference found among observed data and model outputs only at the Windows parking lot.

CONCLUSIONS AND MANAGEMENT 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 use (e.g., the number of vehicles entering the park each day and the number of visitors hiking to Delicate Arch each day) and the condition of indicator variables (e.g., PAOT at Delicate Arch). Such a model can be used to provide numerical estimates of social carrying capacity of an attraction within a park or protected area. Further, as this study demonstrates, a travel simulation model can be used to estimate a park-wide social carrying capacity.

While monitoring is incorporated as an important element of contemporary carrying capacity frameworks, constraints on human and financial resources often limit the ability of park and protected area staff to conduct comprehensive monitoring of crowding-related indicators of quality. Further, due to the dispersed nature of visitor use of parks and protected areas it is often difficult to conduct monitoring through conventional means such as field observations. The application of computer simulation modeling to defining and managing social carrying capacity of parks and protected areas facilitates a proactive approach to monitoring. Specifically, rather than monitoring the field conditions of indicator variables as they <u>change</u> in response to expanding visitor use, simulation modeling can estimate the condition of indicator variables under a range of visitor use levels. While simulation modeling does not eliminate the need for on the ground monitoring of indicator variables, it has the potential to reduce the costs, time, and related challenges associated with monitoring crowding-related conditions of parks and protected areas. In this way, simulation modeling makes it more feasible for park and protected area staff to engage in the process of experimentation and learning that is characteristic of adaptive management.

Findings from this study suggest that managers at Arches National Park can use the simulation model to inform decisions about how to manage social carrying capacity. Among the options available for managing social carrying capacity at the park is the alternative to regulate the amount of visitor use at specific attraction sites within the park. As mentioned previously in this paper, the simulation model provides managers with numerical estimates of social carrying capacity at Delicate Arch. Managers could use this information to guide decisions concerning the appropriate number of visitors to allow to hike to Delicate Arch. However, in some cases, regulating where visitors are allowed to travel within a park or protected area may limit visitors' choices to an undesirable extent and may be difficult for managers to implement. An alternative approach would be to regulate the amount of visitor use at the park-wide level. That is, it may be preferable to visitors and easier for managers if the number of people allowed to enter the park is regulated, rather than limiting where visitors may go once they are in the park. Decisions about how to regulate the total number of visitors entering Arches National Park can be informed by the numerical estimates of park-wide carrying capacity generated by the simulation model in this study.

Visitor use limits should be considered a last resort for managing social carrying capacity in national parks and related areas. Other forms of management, such as public transportation, permit systems, and site design may provide adequate solutions to social carrying capacity issues without having to limit use. Further research should explore the use of simulation models to estimate the effectiveness of alternative visitor management practices. For example, to what degree does redistribution of spatial and temporal visitor use patterns through a permit system affect PAOT at attraction sites and/or the number of encounters among hiking groups? To what extent are crowding-related conditions of national parks and related areas affected by the use and design of public transportation systems? Additional research should assess the capacity of simulation modeling to address these and related questions.

As noted earlier in this paper, statistical tests used to validate the simulation model indicated a significant difference between actual and model vehicle counts for the Windows parking lot. However, statistical tests supported the validity of model output based on parking lot counts at Delicate Arch, Devil's Garden, and all three parking lots combined. While these results are encouraging, further efforts to validate the model are warranted. Specifically, additional parking lot counts, as well as PAOT counts at selected park locations, would provide the basis for further comparisons with simulation model output and strengthen conclusions about the validity of the model output.

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