

Proactive monitoring and adaptive management of social carrying capacity in Arches National Park: an application of computer simulation modeling

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Abstract

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. Scientists and managers have adopted the concept of carrying capacity to address the impacts of visitor use. In the context of outdoor recreation, the social component of carrying capacity refers to the level of visitor use that can be accommodated in parks and protected areas without diminishing the quality of the visitor experience to an unacceptable degree. This study expands and illustrates the use of computer simulation modeling as a tool for proactive monitoring and adaptive management of social carrying capacity at Arches National Park. A travel simulation model of daily visitor use throughout the Park's road and trail network and at selected attraction sites was developed, and simulations were conducted to estimate a daily social carrying capacity for Delicate Arch, an attraction site in Arches National Park, and for the Park as a whole. Further, a series of simulations were conducted to estimate the effect of a mandatory shuttle bus system on daily social carrying capacity of Delicate Arch to illustrate how computer simulation modeling can be used as a tool to facilitate adaptive management of social carrying capacity.

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1. 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 US 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 (Hammitt and Cole, 1998; Manning, 1999). Starting as early as the 1960s, outdoor recreation research has used the concept of carrying capacity to address the resource and social impacts of visitor use (Manning, 1999). In the context of outdoor recreation, the social component of carrying capacity refers to the level of visitor use that can ultimately be accommodated in parks and protected areas without diminishing the quality of the visitor experience beyond an acceptable level.

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 empirically based 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. This basic rationale of contemporary

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carrying capacity frameworks embodies both monitoring and adaptive management in that it emphasizes an incremental process of learning and management adaptation based on a continuing commitment to monitoring indicator variables (Lee, 1993).

While carrying capacity frameworks such as LAC, VIM, and VERP have been successfully applied in a number of parks and protected areas, a potential weakness of this approach to carrying capacity in particular, and adaptive management in general, is their arguably *reactive* nature. That is, management actions are ‘triggered’ when monitoring data suggest that standards of quality are violated, or are in danger of being violated. Moreover, management actions are conventionally tested through on-the-ground experimentation, which may be costly and politically risky. Carrying capacity frameworks could be applied more *proactively* by estimating the level of visitor use that will cause standards of quality to be violated, and ensuring that such levels of visitor use are not allowed through adoption of management actions that have been tested prior to implementation.

Computer simulation modeling is used in this study as a tool to help implement carrying capacity frameworks such as LAC, VIM, and VERP in a proactive manner. In particular, this study illustrates the use of computer simulation modeling as a tool to facilitate monitoring and managing social carrying capacity at Arches National Park. Previous research has led to establishment of selected indicators and standards of quality for major attractions within Arches National Park (National Park Service, 1995; Manning et al., 1995, 1996a,b). 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% of the time. A travel simulation model of visitor use throughout the Park’s road and trail network and at selected attraction sites was developed in this study, and simulations were conducted to estimate the maximum number of visitors that can be allowed to hike to Delicate Arch before this standard of quality is violated. Additional simulations were conducted to estimate the maximum number of vehicles that can be allowed in the Park before standards of quality are violated at Delicate Arch. These simulation results provide numerical estimates of social carrying capacity for Delicate Arch and for the Park as a whole. Further, simulations were conducted to estimate the effectiveness of implementing a mandatory shuttle bus system to increase daily social carrying capacity of Delicate Arch (i.e. increase the number of daily visitors to Delicate Arch without violating the crowding-related standard of quality of 30 PAOT). The shuttle bus simulations illustrate how computer simulation modeling can be used to experiment with and predict the outcomes of carrying capacity-related management actions.

2. Computer simulation modeling of outdoor recreation

Simulation modeling is the imitation of the operation of a real-world process or system over time (Banks and Carson, 1984; Law and Kelton, 1991; Pidd, 1992; Wang and Manning, 1999). 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 (e.g. a dispersed recreation setting, such as a national park or wilderness area). The approach is especially suited to those tasks that are too complex for direct observation, manipulation, or even mathematical analysis.

The first generation of simulation modeling applications to outdoor recreation, which came to be known as the Wilderness Travel Simulation Model (WTSM), was introduced in the 1970s, and continued through the mid-1980s (Borkan and Underhill, 1989; Manning and Potter, 1984; McCool et al., 1977; Potter and Manning, 1984; Schechter and Lucas, 1978; Smith and Headly, 1975; Smith and Krutilla, 1976; Underhill et al., 1986). The WTSM was designed to provide estimates of the number, type (e.g. meeting, overtaking, encounters among different types of user groups), and location of encounters between recreation groups in a park or wilderness area (Wang and Manning, 1999). Despite the early success of the WTSM, it fell into disuse largely due to the cost and difficulty of running computer simulations (Cole, 2002).

Recent advances in computing technology have made computer simulation modeling more accessible and affordable (Pidd, 1992). With improved computer simulation capabilities, a second generation of applications of computer simulation modeling to outdoor recreation management has emerged in recent years (Wang and Manning, 1999). This new generation of simulation modeling has been applied in several national parks and related areas to track visitor travel patterns and to assist managers in monitoring and managing social carrying capacity (Borrie et al., 1999; Daniel and Gimblett, 2000; Gimblett et al., 2000; Manning et al., 1998a,b, 1999; Wang and Manning, 1999; Wang et al., 2000). Simulation modeling is extended in this study to estimate a daily social carrying capacity for Delicate Arch and Arches National Park, and to test the effectiveness of a public transportation system for increasing social carrying capacity in the Park.

3. Methods

3.1. Indicators and standards of quality

A program of research, carried out in two phases, was conducted at Arches National Park subsequent to this study to develop indicators and standards of quality of the visitor

experience. Phase I of the research was conducted in the summer of 1992 and was aimed at identifying potential indicators of quality (Manning et al., 1995, 1996b). Findings from Phase I research suggested several indicators of quality for the Park, including the number of people at Park attraction sites (e.g. PAOT at Delicate Arch). Phase II of the research program was conducted in 1993 and was designed to assist in setting standards of quality for selected indicator variables (Manning et al., 1995, 1996a,b). Findings from Phase II research suggested that visitors generally find up to 30 PAOT at Delicate Arch to be acceptable, but that PAOTs over 30 are generally unacceptable. Based on these findings, 30 PAOT was selected by the National Park Service as the standard of quality for Delicate Arch. To account for occasional random surges in visitation that are unavoidable, the standard set by the Park allows for PAOT at Delicate Arch to exceed 30 up to 10% of the time (National Park Service, 1997).

3.2. Travel simulation model data collection

A variety of methods were employed to gather the baseline data used in this study to build the simulation model of visitor use in Arches National Park. A traffic counter placed at the entrance to the 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 entries for these seven days averaged 1346 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. Vehicle travel route questionnaires were administered to 426 visitor groups in private automobiles and 160 tour bus drivers as they were exiting the Park. Each respondent was asked to report their group's size, the amount of time they had spent traveling on the Park roads, and where and how long they paused during the visit (for a minimum of 5 min). 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 to visitor groups on 6 days during the period from August 14–August 30, 1997 and to tour bus drivers on 42 days between July 9 and October 22, 1998. Safety concerns pre-empted stopping cars and tour buses for surveying after dark, therefore, each sampling day started at 7:00 a.m. and ended at dusk.

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 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 (for a minimum of 5 min). 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.

The sampling period for the visitor surveys was designed to ensure that an adequate number and diversity of vehicle and hiking routes was collected. For example, a greater number of sampling days were allocated to collecting tour bus routes than personal vehicle routes because fewer tour buses enter the Park each day than personal vehicles. In addition, the sampling period was selected to occur during the peak period of the visitor use season. Lastly, while the sampling occurred over a two year period, there is no reason to believe that the distribution of visitor travel routes changed substantively from the first year to the second year as there were no changes to park infrastructure, such as roads and trails.

Data needed to validate the output of the travel simulation model were gathered through a series of vehicle counts conducted at selected parking lots in the Park. The number of vehicles in the Delicate Arch, The Windows, and Devil's Garden parking lots (the Park's three major attraction areas) 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.

3.3. Model algorithm and programming

The Arches National Park travel simulation model was built using *Extend* (1996) simulation software and can be characterized as dynamic, discrete-event, and stochastic (refer to Banks and Carson (1984); Wang and Manning (1999) for more information about the modeling approach applied in this study). The structure of the model consists of hierarchical blocks that represent specific parts of the Park's road and trail systems, including entrance, intersection, road and trail, parking lot, and attraction site blocks.

The primary purposes of the hierarchical entrance block is to generate simulated visitor groups and assign values for a set of characteristics or attributes that each visitor group 'carries with them' through their simulated park visit (Fig. 1a). The rate at which visitor groups are generated by the model is determined by traffic counter data contained in the 'Vehicle generator' and 'Headways' blocks. The blocks labeled 'Attributes' and 'Travel routes' assign attribute values to newly generated visitor groups. The values of each group's attributes direct their travel through the simulated park visit and include travel mode (automobile or bus), group size, travel speed, and travel route. The range and frequency of attribute values used in the model are based on data collected in the visitor surveys. For example, travel speeds assigned to simulated visitor groups are based on the distance of travel routes reported in the visitor surveys and the total amount of time visitors spent traveling their routes. After receiving attribute values, the simulated visitor groups are directed to the 'Entrance queue'

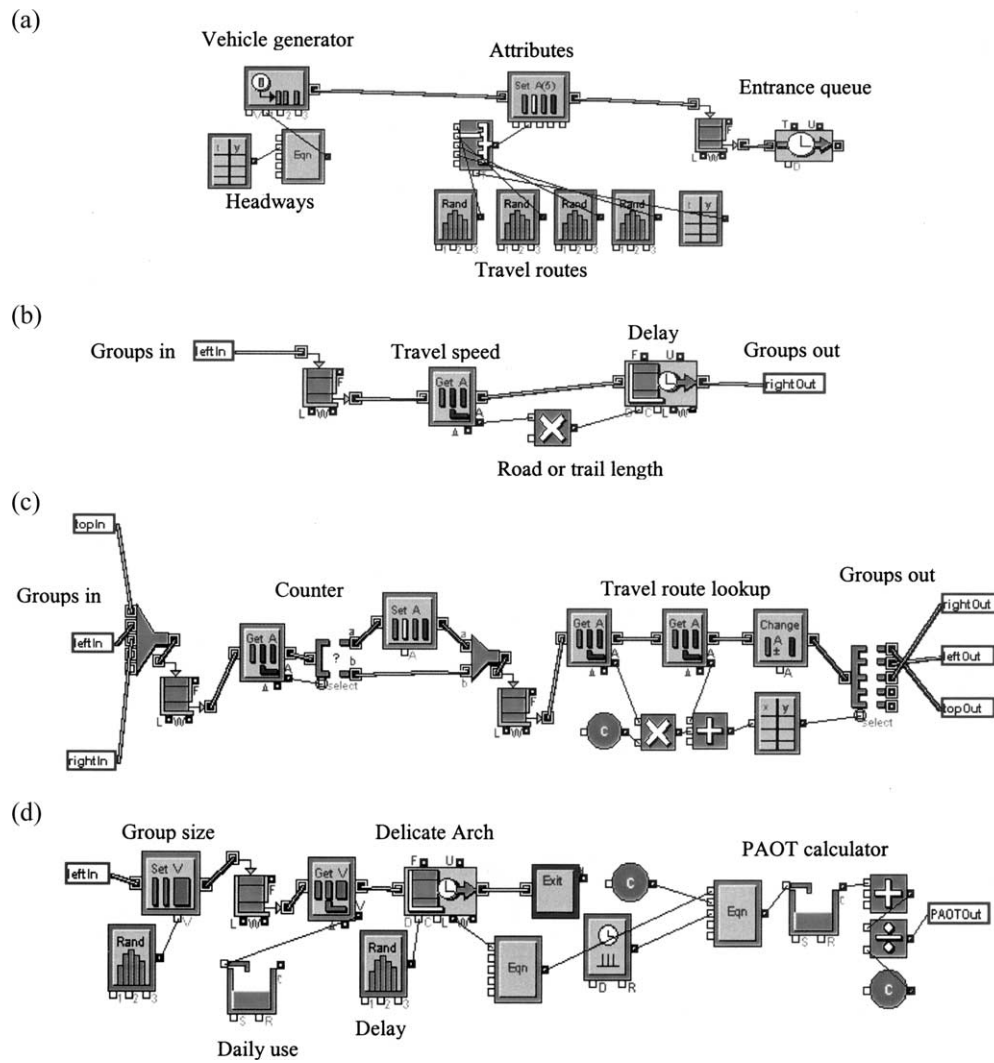


Fig. 1. Arches National Park travel simulation model hierarchical blocks. (a) Entrance blocks, (b) road and trail section blocks, (c) intersection blocks, (d) attraction site blocks—Delicate Arch.

block where they are held for a period of time designed to simulate the waiting line that develops at the Park entrance gate during the course of the day. The distribution of waiting times assigned to simulated visitor groups is based on actual waiting time data collected at the Park’s entrance gate during the peak period of the season (i.e. July and August). From the Entrance queue block, simulated visitor groups enter the Park’s road network.

Road and trail section blocks simulate travel along park roads and trails (Fig. 1b). Simulated visitor groups enter a road or trail section through the ‘Groups in’ block. The amount of time groups spend along a road or trail section is determined by their travel speed and the length of the road or trail section. Like road and trail section blocks, parking lot blocks hold simulated visitor groups for periods of time based on data collected from the visitor surveys. Parking lot blocks also output the number of visitor groups parked in the lot throughout the simulated day.

Intersection blocks direct simulated visitor groups in the direction of their assigned travel routes when they arrive at road or trail intersections (Fig. 1c). The intersection blocks are used within the simulation model for road intersections, road and parking lot intersections, and trail intersections. Simulated visitor groups enter an intersection at the Groups in block. The block labeled ‘Counter’ keeps track of the number of previous times, if any, the group has passed through the intersection. A series of blocks, unique for each intersection and labeled ‘Travel route lookup’, direct visitor groups to the next park feature based on the group’s travel route and the number of previous times, if any, the groups have passed through the intersection. Visitor groups are sent to the next location through the ‘Groups out’ block.

Attraction site blocks disaggregate vehicle-based visitor groups into sets of individual hikers and output PAOT at the attraction site throughout the simulated day (Fig. 1d). Visitor groups ‘leave their vehicles’ at the ‘Group size’

block, where they are assigned a group size, thus converting them into sets of individual hikers. The individual hikers are then directed to the attraction site, labeled 'Delicate Arch' in this example, and delayed at the site for a period of time derived from the visitor survey data. The blocks labeled 'PAOT calculator' calculate the percent of time the number of people at Delicate Arch (i.e. the number of simulated hikers within the 'Delicate Arch' block) exceeds 30 during the simulation period.

3.4. Model runs

A series of model runs was conducted to achieve five 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 daily social carrying capacity for 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 daily social carrying capacity for Arches National Park); (3) to examine the sensitivity of daily social carrying capacity estimates for Delicate Arch and for the Park to changes in the standard of quality for PAOT at Delicate Arch; (4) to estimate the effect of requiring visitors to ride a shuttle bus to the Delicate Arch trailhead on daily social carrying capacity of the Arch; and (5) to validate the simulation model by comparing actual parking lot counts to parking lot data estimated by the simulation model. 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, rather each run simulated a single day of park use from 5:00 a.m. to 4:00 p.m.

To determine the appropriate number of runs needed to capture stochastic variation within the output generated by the model, a series of preliminary simulations was conducted. In particular, output from a series of twelve simulation runs was compared with output from a series of forty simulation runs, based on the same model parameters (i.e. total number of visitors hiking to Delicate Arch and total number of vehicles entering the Park). There were no significant or substantive differences observed in the two sets of output. Therefore, in order to reduce the overall amount of computer processing time needed, the estimates of daily social carrying capacity described below are based on twelve simulation runs for each simulated use level.

To estimate a daily social carrying capacity for Delicate Arch, a series of simulations was run in which the total number of visitors hiking to the Arch was varied. 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 use level modeled.

An iterative process of increasing or decreasing the daily number of visitors hiking to the Arch was followed until PAOT at Delicate Arch exceeded 30 an average of 10% of the time. For example, a series of 12 simulations was run for a selected level of visitor use and the average percent of time that PAOT exceeded 30 was calculated from the simulation results. If PAOT exceeded 30 an average of more than 10% of the time, the next set of 12 simulations was run at a lower use level, while if PAOT exceeded 30 an average of less than 10% of the time, the next set of 12 simulations was run at a higher level of visitor use. This iterative process was repeated to estimate a daily social carrying capacity for Arches National Park (the second study objective), except that rather than varying the number of people hiking to Delicate Arch, the total number of vehicles entering the Park was varied.

To examine the sensitivity of social carrying capacity estimates for Delicate Arch and Arches National Park to changes in the standard of quality for PAOT at Delicate Arch, the iterative procedure described in the previous paragraph was repeated for two alternative standards of quality. The alternative standards of quality evaluated included allowing PAOT at Delicate Arch to exceed 30 up to 15% of the time and allowing PAOT at Delicate Arch to exceed 35 up to 10% of the time.

The fourth objective was addressed by modifying the travel simulation model to simulate the operation of a shuttle bus system designed to deliver visitors to Delicate Arch at regularly scheduled time intervals. Separate model runs were conducted to simulate alternative shuttle bus schedules designed to arrive at Delicate Arch every 15, 30, and 60 min. For each shuttle bus system simulated, the number of visitors riding the shuttle bus and hiking to the Arch was varied to estimate the maximum number of visitors that could be allowed to hike to Delicate Arch without exceeding the standard of quality for the Arch. The shuttle bus simulations were based on the assumption that the amount of time visitors spend hiking to the Arch and at the Arch itself would not change as a result of implementing a shuttle bus system. It would have been possible to alter the amount of time visitors spend at the Arch in response to a shuttle bus system. There is no reason, however, to believe that this would be more valid than assuming no change. Because the delivery schedule was fixed for each shuttle bus system simulated, it was only necessary to run the travel simulation model once for each use level modeled. That is, the results of multiple simulations of a given shuttle bus delivery schedule would always be the same, making it unnecessary to base the carrying capacity estimate for a given shuttle bus system on the average of multiple simulation runs.

To achieve the fifth objective, validating the simulation model output, a series of 48 model runs was conducted. The number of vehicles entering the Park was varied to match the number of vehicles entering the Park on the four days that parking lot counts were conducted. The model runs

were repeated twelve times for each of the four use levels to capture stochastic variation. For each of the four total use levels modeled, the average number of vehicles in selected parking lots was calculated and compared to the actual parking lot counts.

4. Results

4.1. Social carrying capacity of delicate arch and Arches National Park

Numerical estimates of daily social carrying capacity for Delicate Arch and Arches National Park are reported in the first row of Table 1. 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 exceeding 30 PAOT at Delicate Arch more than 10% of the time. Further, the model results suggest that a maximum of 720 vehicles can be allowed to enter the 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.

The second and third rows of data in Table 1 provide insight into the sensitivity of daily social carrying capacity estimates to changes in the standard of quality for PAOT at Delicate Arch. The model estimates that changing the standard of quality to allow PAOT at Delicate Arch to exceed 35 rather than 30 up to 10% of the time would result in a statistically significant increase in the carrying capacity of Delicate Arch. Further, the simulation model results suggest that it is possible to increase the carrying capacity of Arches National Park to a statistically significant degree by relaxing the standard of quality for PAOT at Delicate Arch to either of the alternatives considered in the analysis.

4.2. Simulated shuttle bus system

Results of simulation runs conducted to test the effect of implementing a mandatory shuttle bus system to Delicate Arch on the daily social carrying capacity of the Arch are reported in Table 2. The data in the third and fourth columns suggest that the daily social carrying capacity of the Arch could be increased by 29–68% if visitors were required to ride shuttle buses to Delicate Arch. For example, the model

Table 1
Numerical estimates of daily social carrying capacity

Standard of quality	Delicate Arch	Arches National Park
30 PAOT 10 percent of time	315 hikers ^a	720 vehicles ^a
30 PAOT 15 percent of time	347 hikers ^{a,b}	850 vehicles ^b
35 PAOT 10 percent of time	374 hikers ^b	865 vehicles ^b

Carrying capacity estimates represent the maximum amount of use that can be accommodated between 5:00 a.m. and 4:00 p.m. Means in the same column that do not share superscripts differ at $p < 0.05$ in the Least Significant Difference comparison.

Table 2
Numerical estimates of daily social carrying capacity of Delicate Arch with mandatory shuttle system

Arrival interval (min)	Passengers	Estimated daily social carrying capacity	Percent increase in carrying capacity
60	37	407	29
30	21	462	47
15	12	528	68

Table 3
Parking lot validation statistics

	<i>T</i> 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

* Statistically significant at $\alpha = 0.05$.

estimates that a shuttle bus system designed to deliver visitors to Delicate Arch every 60 min would increase the daily social carrying capacity of the Arch from 315 hikers between the hours of 5:00 a.m. and 4:00 p.m. to 407 hikers. Further, the results suggest that smaller, more frequent shuttle buses would increase the daily social carrying capacity of Delicate Arch to an even greater extent.

4.3. Model validation

Table 3 presents validation results based on comparisons between actual parking lot counts and model estimates. The four days of actual parking lot counts were combined and a set of four *t*-tests were performed to test for statistically significant differences among observed data and model estimates at each of the three parking lots and park-wide. There were no statistically significant differences among observed data and model outputs, except at The Windows parking lot.

5. Conclusions and management implications

This study demonstrates that it is feasible to develop a park-wide, dynamic computer simulation model of visitor use encompassing both vehicle and pedestrian travel. Moreover, by using the Arches National Park travel simulation model to quantify relationships between visitor 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), this study illustrates how computer simulation modeling can be used to estimate, monitor, and help manage social carrying capacity of the study site, and of parks and protected areas more generally.

The study findings suggest that computer simulation modeling is a useful tool for applying carrying capacity frameworks such as VERP and LAC to park and protected area management in a proactive manner. For example, in addition to having field staff conduct on-the-ground monitoring of the conditions of indicator variables under current levels of visitor use, managers can use simulation modeling to estimate the conditions of indicator variables under a range of potential future visitor use levels. By using computer simulation modeling to 'look ahead' to the effects of potential future increases in visitor use levels, managers can plan and implement proactive, preventative management actions to ensure that visitor use does not reach a level that will cause standards of quality to be violated. Estimation of carrying capacity also allows management agencies and other interest groups (e.g. commercial outfitters) to plan and design facilities and services for a predefined maximum use level. In addition to being proactive in nature, monitoring programs that reinforce field-based monitoring with computer simulation modeling are likely to be more comprehensive given the inherent versatility of simulation modeling to generate many forms of data output. Simulation modeling can also improve the effectiveness and efficiency of a monitoring program by reducing the amount of human and financial resources needed to monitor carrying capacity. While there are several advantages of adopting computer simulation modeling within a monitoring program, the technology does not replace the need for on-the-ground monitoring. For example, in addition to providing information about the condition of social and resource indicators not accounted for by a computer simulation model, field monitoring data provide the basis for validating and calibrating computer simulation model output.

Previous studies have used computer simulation modeling to model visitor use of selected features within parks and protected areas (Daniel and Gimblett, 2000; Wang and Manning, 1999). However, this is the first study to develop a park-wide computer simulation model of visitor use, capable of providing numerical estimates of social carrying capacity for selected attraction sites within the Park (e.g. Delicate Arch) and for the Park as a whole. As a result, park managers can use study findings to inform judgments concerning how to manage carrying capacity at multiple scales. For example, managers could decide to manage carrying capacity by regulating the amount of visitor use at Delicate Arch. The numerical estimates of daily social carrying capacity for Delicate Arch developed in this study provide an informed basis for deciding on the maximum number of visitors that should be allowed to hike to the Arch. In some cases, however, 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 daily park-wide carrying capacity generated by the simulation model in this study.

The results of this study suggest that simulation modeling can assist managers in 'fine tuning' standards of quality for crowding-related indicators of quality. Specifically, this study used computer simulation modeling to examine the sensitivity of numerical estimates of daily social carrying capacity to changes in standards of quality for PAOT at Delicate Arch. This type of analysis provides a useful tool for testing whether relatively minor adjustments of crowding-related standards of quality could substantively increase the social carrying capacity of a recreation area. In this way, computer simulation modeling can assist managers in selecting standards of quality that are realistic and efficient. However, while computer simulation modeling can provide descriptive information about the relationship between standards of quality and carrying capacity estimates, the technology does not replace the task of rendering prescriptive judgements about the acceptability of alternative standards of quality (Lawson and Manning, 2003a,b; Manning and Lawson, 2002).

This study addresses only selected components of carrying capacity, focusing on numbers of visitors as opposed to visitor behavior and on social rather than resource carrying capacity. Further, the numerical estimates of social carrying capacity presented in Table 1 of this paper are based on the assumption that there is no change in the temporal or spatial distribution of visitor use from the status quo or to the design of the Park's infrastructure. However, alternative forms of management, such as public transportation, permit systems, and site design may provide at least temporary solutions to social carrying capacity issues without having to limit use (Cole et al., 1987; Hendee et al., 1990; Manning, 1999). Further, there is general agreement in the field of park and recreation management that visitor use limits should normally be considered a last resort for managing social carrying capacity in national parks and related areas, and less intrusive alternatives should be considered first (Behan, 1974, 1976; Dustin and McAvoy, 1980; Hendee and Lucas, 1973, 1974; Hall, 2001). However, it is often difficult for managers to judge the effectiveness and consequences of alternative management strategies. Recognizing that management decisions are often made in the context of uncertainty, adaptive management frameworks, such as VERP, outline a process in which management actions are considered experimental in nature. Further, management outcomes are thought to promote learning about how the system being managed operates and provide guidance concerning how to adapt future management strategies. However, such an approach may not always be economically or politically feasible. Computer simulation modeling provides managers with a tool to experiment with alternative management actions in a manner that may be

more cost-effective, less labor-intensive, more comprehensive, and less politically risky than on-the-ground, trial-and-error approaches. To illustrate this point, the Arches travel simulation model was used to experiment with an alternative mode of transportation (i.e. a shuttle bus system) as a means to increase daily social carrying capacity of Delicate Arch. The findings from this study suggest that requiring visitors to ride a regularly scheduled shuttle bus to Delicate Arch would increase the number of people that could be allowed to hike to the Arch without exceeding the standard of quality for PAOT. A similar approach can be used to experiment with and inform judgments concerning other strategies for managing social carrying capacity at Arches National Park. For example, the simulation model could be modified to estimate the degree to which spatial and/or temporal redistribution of use patterns through a permit system would affect PAOT at attraction sites. In this way, computer simulation modeling is a tool that improves the ability of park and protected area managers to apply adaptive management frameworks, while reducing the political and financial costs associated with such an approach.

There are at least two potential limitations concerning the travel route data used to develop the computer simulation model in this study. First, the data were collected as part of an exit survey, allowing for the possibility of 'recall error'. That is, by the time visitors reached the end of their Park visit, they may have had difficulty accurately remembering some parts of their travel route. To address this concern, survey staff were available to answer respondents' questions and to orient them to the Park map. An alternative approach would have been to give respondents diaries to carry with them and complete during the course of their visit. This approach would be particularly suitable for collecting route information from respondents completing multiple day trips, but was considered unnecessary in this study, given that respondents were only being asked to recall a single day trip. Second, as noted earlier in the paper, safety concerns prevented the collection of travel route data after dark, limiting the ability of the model to simulating visitor use between the hours of 5:00 a.m. and 4:00 p.m. While the majority of visitor use occurs during these hours of the day, a substantial proportion of visitor use occurs in the evening. In fact, during the peak period of the visitor use season, nearly one-third of visitor use occurs after 4:00 p.m., in part due to the popularity of watching the sunset from Delicate Arch. This limitation could be addressed by collecting additional route data from visitors during the evening hours. In order to overcome safety concerns with sampling after dark, diaries could be administered to visitors at the Park entrance gate, rather than stopping vehicles as they are exiting the Park.

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. Further, while 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, there is the potential for Type II error associated with these tests. However, even at relatively high levels of α (e.g. 0.5), there is no significant difference between model output and actual parking lot counts for the 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.

Lastly, the focus of this study is on demonstrating the potential usefulness of computer simulation modeling as a tool for applying carrying capacity frameworks such as LAC, VIM, and VERP. Given this focus, our results are designed to illustrate how computer simulation modeling allows estimation of numerical social carrying capacities. There are, however, a wide variety of other potentially useful outputs that can be generated with computer simulation modeling. For example, simulation modeling can be used to generate detailed information concerning the spatio-temporal distribution of visitor use within a dispersed recreation setting. This type of information, coupled with spatially explicit natural resource data, could form the basis of overlay analyses for zoning, assessment of threats to critical resources, and other planning and management purposes. Simulation modeling also provides managers with a tool to monitor the condition of a range of social indicators of quality. For example, previous applications of computer simulation modeling have been used to estimate waiting times to visit park attractions (Manning et al., 1998a,b), hiking encounters by type of visitor group and location (Gimblett et al., 2000), river encounters (McCool et al., 1977), and campsite sharing (Lawson and Manning, 2003a). Further, as the shuttle bus example in this paper suggests, simulation modeling can be used to play 'what if' games. That is, simulation modeling can be used to estimate the effect of alternative management strategies on the spatio-temporal distribution of visitor use and the condition of social indicators of quality like those described above. This type of information can assist managers in assessing the feasibility and relative merit of alternative management actions.

While progress has been made in applying computer simulation modeling to park and wilderness management, more research is warranted. For example, future research could examine the relative strengths and weaknesses of alternative methods of validating computer simulation model output. Further research should also focus on identifying the types and formats of model outputs that are most relevant to managers of parks and wilderness. Efforts to apply computer simulation modeling at multiple levels of park and wilderness planning, from broad, general management planning, to more specific planning efforts, including carrying capacity and visitor use management, are also warranted.

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