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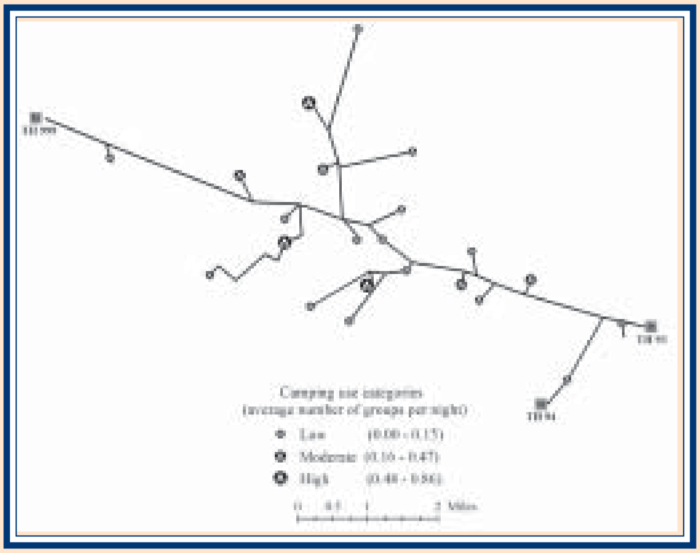
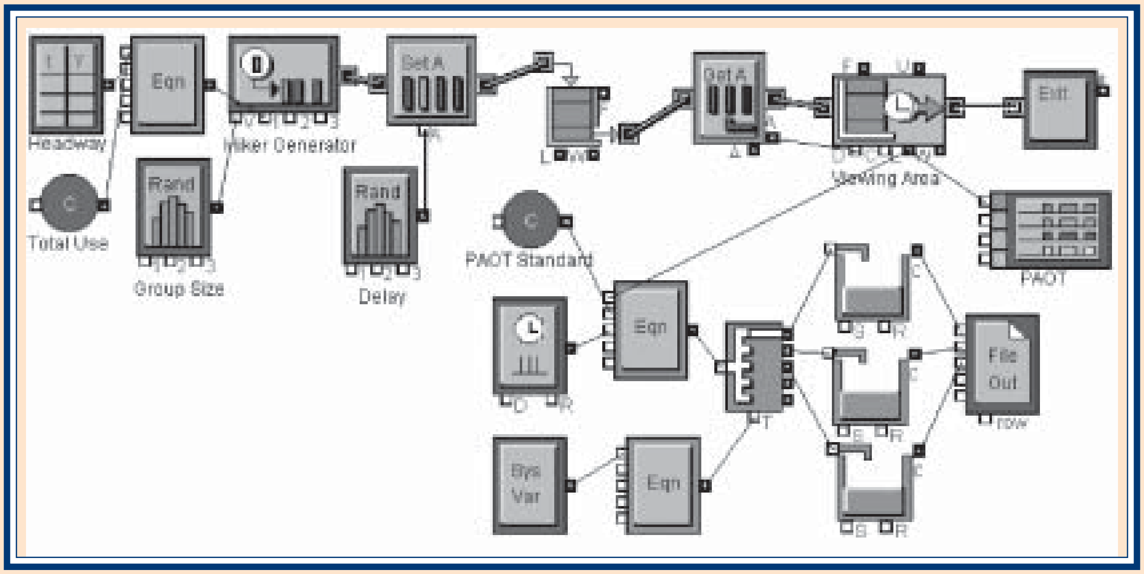
Computer Simulation Modeling of Recreation Use: Current Status, Case Studies, and Future Directions

David N. Cole, Compiler





Abstract

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This report compiles information about recent progress in the application of computer simulation modeling to planning and management of recreation use, particularly in parks and wilderness. Early modeling efforts are described in a chapter that provides an historical perspective. Another chapter provides an overview of modeling options, common data input requirements, and useful model outputs. The bulk of the report consists of case studies that illustrate a broad array of recreational situations and management applications for simulation modeling. A final chapter describes some future directions for modeling work. Although simulation of recreation use is already a tool for planning and management, its utility could be greatly enhanced with further work in software development, increased understanding of appropriate methodologies, and greater attention to model verification and validation.

Keywords: computer simulation, park planning, recreation management, simulation modeling

Contributors

Suzanne Cable is Wilderness Ranger, USDA Forest Service, Salmon-Challis National Forest, North Fork Ranger District, North Fork, ID.

Kerri Cahill is Planner, National Park Service, Denver Service Center, Denver, CO.

David N. Cole is Research Biologist, USDA Forest Service, Rocky Mountain Research Station, Aldo Leopold Wilderness Research Institute, Missoula, MT.

Randy Gimblett is Professor, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

Jeffrey C. Hallo is Graduate Research Assistant, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT.

Marilyn Hof is Planner (retired), USDI National Park Service, Denver Service Center, Denver, CO.

Robert M. Itami is Director of GeoDimensions Pty Ltd, Sorrento, Victoria, Australia.

Ann Mayo Kiely is Resource Management Specialist, Isle Royal National Park, Houghton, MI.

Steven R. Lawson is Assistant Professor, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Robert E. Manning is Professor, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT.

Peter Newman is Assistant Professor, Department of Natural Resource Recreation and Tourism, Colorado State University, Fort Collins, CO.

William A. Valliere is Research Specialist, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT.

Mark E. Vande Kamp is Research Associate, Protected Area Social Research Unit, College of Forest Resources, University of Washington, Seattle, WA.

Jan W. van Wagtendonk is Research Forester, U.S. Geological Survey, Yosemite Field Station, El Portal, CA.

Benjamin Wang is Graduate Research Assistant, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT.

Cover captions: (1) Use levels of campsite clusters in a portion of the John Muir Wilderness, based on output from a computer simulation model. (2) Computer-edited photograph of hikers on the trail to Yosemite Falls, used to obtain visitor evaluations of hiker density. (3) Schematic diagram of the top layer of a simulation model developed for Glacier Point, Yosemite National Park.

Preface

This General Technical Report was made possible by a generous grant from the Washington Office of the U.S. Department of the Interior, National Park Service. The purpose of the grant was to further development of computer simulation modeling of recreation use as a tool for park and wilderness management. The grant was used to bring together people who had worked or were working on simulation of recreation use in two workshops: to support a collaborative project in the John Muir Wilderness, California, and to support data gathering related to development of a General Management Plan for Saguaro National Monument, Arizona (work that is not reported here).

The first workshop was held in Tucson, AZ, March 19 to 21, 2003, to examine the utility of visitor simulation modeling to park planning and management. The School of Renewable Natural Resources at the University of Arizona, and the Aldo Leopold Wilderness Research Institute hosted the workshop, which was attended by a selected group of academics and agency personnel from the USDA Forest Service, USDI Bureau of Land Management, National Park Service, U.S. Geological Survey, and Parks Canada. Major topics discussed at the workshop included the historical context for simulation modeling; two current modeling approaches—Extend and RBSim; other simulation modeling approaches; data collection needs and issues; and identification of possible applications for planning and management. A second workshop was held in September 2003 at the National Park Service's Denver Service Center to inform Park Service planners about the opportunities and benefits of using visitor monitoring and simulation in the development and evaluation of general management plans. This 1-day workshop was attended by approximately 40 planners and designers.

The collaborative simulation project used the two most prominent modeling approaches (Extend and RBSim) to analyze a single dataset developed for Humphrey's Basin in the John Muir Wilderness. It received funding from the Rocky Mountain Cooperative Ecosystem Studies Unit and the Aldo Leopold Wilderness Research Institute, as well as the National Park Service. This effort was originally conceived as a comparison of the two approaches. Rapidly it became apparent that even more value could be derived from lessons learned through collaboration between the two efforts and approaches. Definitional issues surfaced and were resolved. Unforeseen problems surfaced and were dealt with. Some of the most prominent lessons learned dealt with appropriate run lengths for steady-state simulations, development of output statistics, and validation statistics.

After the first workshop, the group decided that a General Technical Report would be the best way to communicate progress to date on computer simulation modeling of recreation use. Case studies of recent modeling efforts were compiled, and chapters were written that provide an overview of how modeling works, its historical development, and issues for the future. Funding for writing and for the work presented in the case studies was provided by the Aldo Leopold Wilderness Research Institute, Pacific Northwest Cooperative Ecosystem Studies Unit, the U.S. Geological Survey, University of Arizona, University of Vermont, and several National Park Service and Forest Service units. Publication costs were provided by the Aldo Leopold Wilderness Research Institute, University of Arizona, and University of Vermont.

David N. Cole

Pesticide Precautionary Statement

Computer Simulation Modeling of Recreation Use: Current Status, Case Studies, and Future Directions

David N. Cole

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Chapter 1:
Why Model Recreation Use?

David N. Cole
Kerri Cahill
Marilyn Hof

Planners Need Better Data

As the demographics of public land recreational visitors change, planners and managers of public lands face the challenge of protecting resources while providing high quality visitor experiences. Because our political environment demands ever more reliance on scientific data and transparent decisionmaking, planners and managers need better tools to help them understand current visitor use, analyze potential alternatives for future use, and communicate the implications of various alternative decisions in ways that are meaningful to the public.

An understanding of the temporal and spatial distribution of visitor use is fundamental to many of the questions that planners and managers ask. Are existing use patterns sustainable and appropriate to resource and experience goals? Are existing spatio-temporal distributions optimal for visitor experience, resource protection, and efficient operations? Such questions cannot be answered without knowledge of the kinds, amount, and distribution of visitor use. Particularly in large areas and in areas with complicated access and circulation patterns, planning staff may only have anecdotal information about use concentrations, lengths of stay in various areas, crowding, underused or overused facilities, and other factors. Further, staff and public perceptions of use patterns are often at odds.

Public land planners often have little information to help them assess the likely success and efficiency of alternative approaches to visitor use management. Impact analysis often consists of educated guesses by planners and managers. For example, if changes to access and circulation patterns are needed in one place, how can planners assess how those changes will affect use patterns and associated impacts in other places? How can planners assess possible effects of management decisions on adjacent lands? How can planners identify the management strategies (area closures, use limits, additional facilities or access, for example) that could be most effective in achieving desired modifications in visitor behavior and use patterns?

Another difficulty in planning for management of public lands is that many of the impacts and tradeoffs associated with various planning alternatives are qualitative, value laden, and difficult to demonstrate. Yet we ask the public to “buy in” to future conditions that can profoundly effect their visitation and experiences, sometimes without clear understanding of the implications of various choices. How might planning alternatives affect a visitor’s ability to move about at his or her own pace? How might the alternatives affect visitors’ chances of coming to the area whenever they want? What kinds of tradeoffs or sacrifices (using a reservation system or permit system, for example, or riding a shuttle bus) might we ask the public to make to protect resources? Are the goals “worth it” to the public?

To answer these sorts of questions, more tools are needed to help understand and monitor baseline conditions, estimate appropriate use levels, describe the consequences of management alternatives, and more effectively communicate these consequences to the public. Increasingly, visitor use simulation modeling is gaining recognition as a critically important tool for professional planning and management of recreation on public lands.

What Is Simulation Modeling and What Can It be Used For?

Visitor use simulation models replicate visitor use patterns as they relate to an area’s natural and developed environments. These computer models allow managers to better understand the spatial and temporal visitation patterns and “experiment” with different management strategies. Specifically, simulation models can be used to

- Better understand the baseline spatial and temporal patterns of visitor use.

- Predict how distributions of visitor use are likely to change in response to both management actions and factors not subject to managerial control.
- Test the feasibility and effectiveness of management plan alternatives.
- Monitor hard-to-measure parameters (such as people at one time at a certain attraction or walking on particular trails) by using easily measured indicators (such as number of cars entering the area or parking at a trailhead).
- Support the planning and management of visitor use in situations where monitoring and predicting visitor flow are difficult.
- Improve communication of implications of management prescriptions to the public.

Past and Present Simulation Modeling Efforts

As detailed in Chapter 2 of this report, the potential utility of simulation modeling as a public land and wilderness management tool has been recognized for decades. In a major developmental effort in the 1970s, International Business Machines (IBM), Resources for the Future, and the Forest Service collaborated to develop a travel simulation model for wilderness—the Wilderness Use Simulation Model. This model was successfully applied in several wilderness areas, and was adapted to river recreation (McCool and others 1977) and a long-distance trail (Potter and Manning 1984). On the Colorado River in Grand Canyon National Park, Arizona, Underhill and others (1986) used the model to evaluate the effect of upstream dam operations on downriver whitewater boating patterns.

Despite this promising beginning, the cost and difficulties of running computer simulations in the 1970s and early 1980s were simply too great. Simulations often had to be run on remote mainframe computers, with individual simulations costing $1,000. With the advent of the personal computer, however, costs and difficulties have declined dramatically. Consequently, interest in recreation travel simulation modeling is now increasing.

Overview of Report

The intent of this report is to describe the current status of simulation modeling of recreation behavior, illustrate its utility, and comment on its future. Chapter 2 provides an historical perspective on work to date, particularly the pioneering work conducted in the 1970s and 1980s. Chapter 3 provides an overview of modeling options, common data input requirements, and useful model outputs.

Chapter 4 presents case studies drawn primarily from the work of the two groups of people who have been most active in this arena: Dr. Robert Manning and his associates at the University of Vermont (particularly Dr. Steven Lawson, now at Virginia Tech), Dr. Randy Gimblett, University of Arizona, and Dr. Robert Itami, Geodimensions Pty Ltd. Manning and his associates have taken a commercially available general-purpose simulation package (Extend 1996), designed to simulate manufacturing and business systems, and used it to model recreation systems. Their case studies demonstrate the wide variety of situations that can be modeled. The utility of model output to addressing questions about appropriate use levels and the consequences of alternative management scenarios are clear in these examples.

Gimblett and Itami developed a special purpose simulator (RBSim), designed specifically to model recreation behavior. RBSim is integrated with GIS technology and allows for rule-based agent simulations (see Chapter 3) in addition to the probabilistic simulations used in the Wilderness Use Simulation Model and in the applications using Extend that Manning, Lawson, and others have conducted. More recently Manning, Lawson, and others have been exploring GIS linkages and rule-based simulation using Extend.

Chapter 5 discusses future directions in recreation simulation modeling.

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Chapter 2: Historical Development of Simulation Models of Recreation Use

Jan W. van Wagtendonk
David N. Cole

The potential utility of modeling as a park and wilderness management tool has been recognized for decades. Romesburg (1974) explored how mathematical decision modeling could be used to improve decisions about regulation of wilderness use. Cesario (1975) described a computer simulation modeling approach that utilized GPSS (General Purpose Systems Simulator), a simulation language designed to deal with scheduling problems. He identified a number of potential uses and the advantages of using simulation instead of trial and error. In this chapter, we review many of the most important applications of computer simulation modeling to recreation use, and the major lessons learned during each application.

Wilderness Use Simulation Model

In the early 1970s, International Business Machines (IBM), Resources for the Future, and the Forest Service began to collaborate in the development of a wilderness travel simulation model. The Wilderness Use Simulation Model was stimulated by Stankey's (1972) hypothesis that a visitor's satisfaction with a wilderness experience is inversely related to the number of encounters with members of other parties. Based on this notion, Fisher and Krutilla (1972) suggested that the optimum use of a wilderness area should be the level at which the incremental benefit of an additional party is offset by the decrease in satisfaction resulting from encountering additional parties. To define this optimum level, one had to establish an empirical relationship between the benefits enjoyed during an outing and the number of parties encountered, making it necessary to quantify encounters. Numerous sociological studies were launched to elicit the relationship between benefits and encounters, but, other than laborious field work, no means existed for enumerating encounters.

To overcome this obstacle, researchers from Resources for the Future began to develop a computer model that would simulate travel behavior in a wilderness and track encounters between parties. They soon found that the programming expertise needed far exceeded their capabilities, so they approached IBM for assistance. The result was a simulation program written by Heck and Webster (1973) in the General Purpose Simulation System (GPSS) language running on an IBM mainframe computer. The model was dynamic, stochastic, and discrete, meaning that it represented a system that evolves over time, incorporates random components, and changes in state at discrete points in time (Law and Kelton 2000).

The model included a replica of an area's travel network, its entry points, trails, cross-country routes, and campsites. It distinguished between the travel patterns of different kinds of users (different group sizes and modes of travel) and of groups arriving at various times (different weeks, different days of the week, and different times of the day). Each simulation involved generating groups of different kinds and different travel patterns arriving at various entry points where they are assigned a specific travel route (set of trail segments and campsites). The groups move along their route, overtaking and passing other groups, encountering groups moving in the opposite direction. They stay at campsites, where they also may encounter other groups. By keeping track of parties, the model recorded the number of encounters for each party, with whom each encounter occurred, the location of those encounters, and the types of encounters (meeting, overtaking, or camp).

Output from the model included numerous tables showing encounters by party type, location, trip length, and total use level.

The data required to build the model included information about both the area and wilderness visitors. Area information consisted primarily of information about the network of trail segments and overnight campsites. Visitor data included weekly, daily, and hourly distributions of use, party size distributions, and mode of travel mix. For example, small parties on horseback were distinguished from large hiking parties. The various routes that visitors took (combinations of trail segments and campsites) were enumerated along with their probability of being selected. Finally, the model required information about the time it took parties of different sizes to hike or ride each trail segment in each direction.

The prototype model was tested in the Spanish Peaks Primitive Area (Smith and Krutilla 1976) and the Adirondack Forest Reserve (Smith and Headly 1975). The Spanish Peaks Primitive Area, now a 25,320-ha unit of the Lee Metcalf Wilderness Area, is located in the southwest corner of Montana, USA, just northwest of Yellowstone National Park. Data collected by the Forest Service in 1970 and 1971 were used to initialize the model and develop different simulation scenarios. Examination of U.S. Geological Service and Forest Service maps identified eight trailheads, 79 trail segments, and 34 campsites. Diaries and sketch maps from some 400 parties were used to determine arrival patterns, party sizes, modes of travel, routes, and route selection probabilities by mode of travel. One hundred and four unique routes of various lengths were identified, with up to 6 nights of stay. Segment travel times were derived by applying results from a previous study (Cunningham 1971) and through discussions with users and wilderness staff.

The base case simulation was run with 177 hiking parties and 48 riding parties entering during a 4-week period (Smith and Krutilla 1976). Hiking parties had a total of 390 encounters with other hiking parties and 112 trail encounters with riding parties, while riders recorded an additional 32 encounters with other riding parties. Hikers had 60 total camp encounters, while riders had 20 camp encounters.

Smith and Krutilla (1976) validated the model by having managers who were familiar with the Spanish Peaks judge the reasonableness of the inputs and outputs by looking at the variance of the outputs. Sensitivity analyses using 10 replications each of nine different scenarios showed that the model was relatively insensitive to variation in travel times, that use levels were directly related to encounters, and that evenly distributing arrival patterns reduced encounters. The authors thus considered the model to be valid, but recommended further testing.

As a result of the Spanish Peaks experiment, Smith and Krutilla (1976) suggested that a large-scale field test be conducted. A workshop was convened to recommend changes to the simulation model. Suggested modifications included the ability to track visible encounters that occur when two parties are close enough to see each other but are not occupying the same trail or campsite, additional output tables on camp and trail use levels, the ability to simulate large numbers of parties for extended periods of time in complex trail networks, and the ability to set probabilities for trailhead selections before routes are selected (van Wagtendonk 2003). Subsequently, a second-generation model was developed by Resources for the Future, under contract with the Forest Service, to accommodate a wider range of situations and provide additional outputs (Schecter 1975).

Desolation Wilderness Application

This new model was demonstrated in the Desolation Wilderness in California (Shechter and Lucas 1978) and in the complex of wilderness areas surrounding and including Yosemite National Park (van Wagtendonk 1979). The Desolation Wilderness is located in the Sierra Nevada Mountains of California east of Lake Tahoe. The 25,390-ha wilderness was originally established as a primitive area in 1930 and was designated as a wilderness area in 1969. Visitor use exceeded a quarter million visitor-days in 1975, and the wilderness continues to be heavily used today. Data were gathered from mandatory wilderness permits, trip maps and diaries returned by 4,400 visitors, and new field surveys (Shechter and Lucas 1978). These sources provided information on arrival patterns, hiker-rider ratios, party sizes, trails and campsites, routes, travel times, and trailhead and route selection distributions. Ninety-nine percent of parties were hiking parties, and more parties arrived on Friday or Saturday than other days of the week. A review of existing maps showed 16 trailheads feeding a network of 178 km of trails, 286 trail segments, and 125 campsites. Out of this network, the groups used 797 unique routes. All of these data were laboriously encoded on punch cards and incorporated into the model deck that was then taken to the U.S. Mint computer in San Francisco to be run at night (van Wagtendonk 2003).

Thirteen different scenarios were run on the model depicting various use levels and trailhead allocation patterns (Shechter and Lucas 1978). The base case simulated 1,400 hiking parties per week using arrival patterns and route selections as recorded in the visitor diaries and travel times from the field survey. The average number of trail encounters per party-day for these parties was 10.8, and the average number of camp encounters per party-night was 6.4. When use was increased or decreased by 25 percent and 50 percent, both types of encounters changed proportionally; for example, a 50 percent increase in use resulted in roughly a 50 percent increase in trail and camp encounters. Regressing camp encounters per party-night over party-nights yielded the following equation:

$$\text{Encounters/Party-Night} = -0.14 + 0.024(\text{Party Nights}).$$

Total use for eight scenarios that dealt with different trailhead selection patterns ranged from 1,278 parties to 667 parties. The highest use occurred when trailhead quotas were implemented for only the five most heavily used trailheads as prescribed in the wilderness management plan. The lowest use occurred when the heavily used trailheads were limited to 10 parties per day and the lightly used trailheads to five parties per day. Trail encounters for these two scenarios ranged from 9.1 to 3.5 per party-day, while camp encounters ranged from 5.6 to 3.1 per party-night. The scenario that allowed 10 parties per day to enter all trailheads had 10.8 camp encounters per night even though total use was only 1,120 parties. This resulted from an increase in longer trips being taken from lightly used trailheads and a decrease in short trips taken from heavily used trailheads.

Shechter and Lucas (1978) concluded that the simulator had great potential for application to actual management situations. The combination of managers and scientists on a team to gather the data and develop and test scenarios proved useful and realistic. Output from the simulator provided an accurate picture of use and encounters that could not be obtained by other means, replacing guesses and intuition. In addition, it was thought that an indirect benefit of the simulator was the acquisition of the information required to run it; data about the area and its use would be valuable for making management planning decisions.

Yosemite National Park Application

Simultaneous with the effort to apply the simulator to the Desolation Wilderness, scientists and managers at Yosemite National Park began assembling the necessary information to run the simulator (van Wagtendonk 1979). The Yosemite Wilderness was designated in 1984 and encompasses 281,855 ha of the park. Contiguous wilderness areas include the 44,891-ha Emigrant Wilderness on the Stanislaus National Forest, the 19,440-ha Hoover Wilderness on the Toiyabe and Inyo National Forests, and the 37,583-ha Ansel Adams Wilderness on the Inyo and Sierra National Forests. There are 55 trailheads that lead to 1,112 km of trail and 375 traditional campsites in the Yosemite Wilderness. An additional 46 trailheads feed 666 km of trail and 197 campsites on Forest Service wilderness areas adjacent to the park. Use peaked in the Yosemite Wilderness in 1975 when nearly 219,000 visitor-nights were recorded (van Wagtendonk 1981). Approximately 4 percent of the use in Yosemite originates on adjacent Forest Service wilderness. Wilderness use in the Yosemite complex has been regulated through the use of wilderness permits since 1971.

The Yosemite application was unique in its use of permit data as the primary source of visitor information (van Wagtendonk 1978). Party size, mode of travel, arrival patterns, and the zones through which a party plans to travel are all easily obtained from the permit. Zone information was converted into routes using methods described by van Wagtendonk (1978). Permits avoided the costs associated with visitor surveys, and allowed all routes actually recorded to be simulated rather than just a sample of possible routes. The validity of the information on the permits and the travel behavior of parties who do not get permits were also determined. In Yosemite, van Wagtendonk and Benedict (1980a) found that 92 percent of the parties had permits and that 62 percent of them made changes to their trips. The average trip was shortened by one-half day, and spatial changes were common.

A special study was conducted in Yosemite to determine trail travel times for parties on 1-mile trail segments (van Wagtendonk and Benedict 1980b). It took an average of 34.8 minutes for backpacking parties, 36.4 minutes for day hiking parties, and 27.3 minutes for horse riding parties to travel the sample trail segments. Party size was not significant for all three types of parties, and slope-direction class was significant for only backpacking parties. For these parties, average times for uphill travel were greater than downhill travel, and time increased as slope increased. These data were used as input to the simulator.

Modifications to the simulator made for the Desolation Wilderness allowed the Yosemite study to focus on trailheads, campsite encounters, and campsite use levels (van Wagtendonk 2003). The decision to concentrate on campsites was based on work by Absher and Lee (1981), which indicated that the sociological effect of trail encounters depended more on the behavior of the encountered party and the location of the encounter than on the number of encounters. A single encounter with an ill-behaving party could have much more impact than meeting numerous parties exhibiting acceptable behavior. The impact of an encounter was less in areas where people expected to meet others than in areas where encounters were not expected. Managers preferred trailhead quotas for rationing use because external controls allowed maximum freedom to visitors consistent with wilderness experience and resource constraints (van Wagtendonk and Coho 1986).

The 20,000 wilderness permits issued in 1973 were used for the base case simulation because travel behavior that year was not limited; use in subsequent years might have been affected after use limits were imposed (van Wagtendonk 1981). Two use levels and two trailhead allocation patterns were examined and compared to the base case. The use levels were a 50 percent increase from the base case and a 50 percent decrease. The first trailhead allocation scenario was based on daily entry quotas derived from a computer program called QUOTA (van Wagtendonk and Coho 1986). The program compared actual levels of use in zones to desired levels, and reallocated entries until no zone exceeded its limit. Desired zone-use limits were based on van Wagtendonk (1986). The second trailhead scenario rounded the daily quotas up to the nearest number divisible by 5.

As at Desolation Wilderness, there was a linear relationship between amount of use and number of campsite encounters (van Wagtendonk 2003). Across all runs, the relationship between camp encounters per party-night and party-nights yielded the following equation:

$$\textit{Encounters/Party-Night} = -0.02 + 0.011(\textit{Party-Nights}).$$

However, the number of campsite encounters per unit of use was less than half that predicted for the Desolation Wilderness. There are at least two potential reasons for this difference. First, a greater number of trailheads gives visitors more opportunities to disperse and, consequently, have fewer encounters per party-night. Second, the wilderness permits provided thousands of potential routes compared to only hundreds from the diaries used for the Desolation Wilderness. This diversity of routes dispersed parties during the simulations, resulting in fewer encounters per party-night.

Trailhead entries for the base case scenario ranged from one person per day through the most lightly used trailheads to over 100 people per day through three of the most popular trailheads (van Wagtendonk 2003). Scenarios based on trailhead quotas reduced the peaks both temporally and spatially, but increased encounter levels in the more sparsely used areas. These results were similar to the results from the Desolation Wilderness, as would be expected when use is dispersed.

Combined with the trailhead quota program, the simulation results provided the information needed by managers to implement quotas for the Yosemite complex of wilderness areas. In that sense, the simulator was a success. However, the cost of running simulations on a remote mainframe computer exceeded U.S. $1,000 per scenario, limiting the feasibility of further experiments.

Applications on Rivers

Modification of the model for river settings allowed it to be applied to the Green and Yampa Rivers in Dinosaur National Monument (Lime and others 1978) and to the Colorado River in Grand Canyon National Park (Underhill and others 1986). Rivers present unique situations for simulating wilderness use. A river represents a single trail with only a few entry and exit points, there is only one direction of travel, and travel times are similar because they are largely determined by the flow.

The Green River runs for 85 km through Dinosaur Monument and is joined there by a 69-km segment of the Yampa River. Each river has one primary launch site, and there are three access points below their confluence. Twelve developed campgrounds and 14 primitive campsites are designated along the rivers. Parties wishing to float the rivers apply for reservations and are assigned launch dates and campsites (McCool and others 1977). In 1973, a seasonal use limit of 17,000 people was implemented. Most of the information necessary to run the simulator was available from records kept by the National Park Service. Diaries from sample parties provided information on travel times and routes for private and commercial trips by group size, and details on travel behavior including lunch stops, stops to scout rapids, and hikes up side canyons.

A 1-week period in June 1975, when 44 parties launched trips, was chosen for the simulation. In addition to the base case, six different scenarios were run that increased the number of parties, redistributed launches over the days of the week, and added or eliminated campsites (Lime and others 1978). Occupancy rates at one heavily used campsite and overall encounter rates in camp and on the river were the focus of the experiments. Increasing use had a proportional effect on both camp encounters and river encounters, and reduced the number of days and nights without encounters. Redistributing daily launches increased use at the heavily used site slightly but did not appreciably change encounter rates. Adding new campgrounds and closing others had little effect on encounters, but did shift use from the heavily used site to the new sites.

Lime and others (1978) concluded that the simulator was useful as an aid to river planning and management. In particular, simulating the effect of different launch dates and times allowed managers who have control over access points the ability to see the effects of those actions before implementing them. Lime and others (1978) recommended that efforts be made to monitor and evaluate the resulting use patterns if the model is to be used to test management policies.

Underhill and others (1986) adapted the wilderness use simulation model for application to the Colorado River. The Colorado River runs through Grand Canyon National Park in Arizona for 360 km from Lees Ferry in Utah to Diamond Creek in Arizona. They used National Park Service records, trip logs kept by rafters, river patrol records, and their own records to develop the input data for the model. Trip itineraries from 1984 for oar boats and motor boats were based on actual frequencies of use for the 199 river segments, 110 stopping points, and 141 campsites. A computer program took these data, calculated routes, and coded them for input to the simulator. Like the Yosemite example, this method provided a myriad of possible routes rather than a limited set based on trip diaries. Forty-eight routes were generated for the 29 parties that launched each week of the 5-week simulation period. Of these parties, 18 were commercial motor trips, six were commercial oar trips, and five were private oar trips.

Use and encounter levels were evaluated for the base case and five scenarios that varied the mix between oar boats and motor boats, the total number of boats, and the launch schedule (Underhill and others 1986). Because the Park Service was considering phasing out motor boats, two of the scenarios were for different number of oar boats only. Two more scenarios increased use for both oar boats and motor boats and changed the ratio between the two types of boats. The fifth scenario evenly distributed launches over days of the week and hours of the day. The relationship between number of parties per week and encounters was linear, with each party averaging approximately 0.5 encounters per day. Changing launch days and times to an even schedule decreased encounters by 25 percent. The scenarios with only oar boats resulted in more visitor days of use, of course, because these boats took longer to float the canyon. The authors felt that the model was useful for predicting changes in the use of sensitive areas and the encounter rates between parties. Their modification for deriving itineraries provided a realistic suite of routes at a reduced cost.

Borkan and Underhill (1989) used the simulator to study the impacts of flow releases from the Glen Canyon Dam on Colorado River raft trips in the Grand Canyon. In this case they modified the time it would take to float the various segments on the river given different flow releases. Flow rates were determined by the Streamflow Synthesis and Reservoir Regulation Model developed by the U.S. Bureau of Reclamation. Oar boat and motor boat parties had their travel times changed by flows in two ways: the time it would take to float a segment and the delay time at rapids due to low water. Five flow alternatives were tested with the model: (1) variable releases from month to month with no daily or weekly fluctuations, (2) wide fluctuations consistent with maximum power production, (3) higher minimum and lower maximum flows than alternative two, (4) steady flows during the rafting season with fluctuations the rest of the year, and (5) low winter flows and higher summer flows with moderate fluctuations.

Borkan and Underhill (1989) concluded that higher flows allowed more time at attraction sites, that low flows increased delays at rapids, and that an increase in the number of parties increased the encounter rates. This study showed that the simulator was useful for evaluating management alternatives that cannot cheaply be evaluated through trial and error.

Application on the Appalachian Trail

Evaluation of alternative management scenarios was the focus of an application of the model to a trail (Potter and Manning 1984). The Appalachian National Scenic Trail traverses 3,456 km in 14 States from Georgia to Maine. From a simulation standpoint, a linear trail system is similar to a river except that movement is in two directions rather than one. Potter and Manning (1984) applied the simulator to a heavily used 100-km section of the Appalachian Trail in Vermont. Access to this section is through five roads and 10 maintained side trails. There are three heavily used camp areas by ponds and 16 primitive shelters. Data for the simulator were obtained in the summer of 1979 from a sample of hiking parties stratified by trailhead use levels. A questionnaire and a map diary were used to determine party characteristics, entry points, arrival and departure patterns, and routes including campsites and rest stops.

Simulation of actual use of 550 parties during a 2-week period resulted in an average of 3.3 trail encounters per party-day and 2.3 camp encounters per party-night. Management scenarios included evenly distributing entries over access points, evenly distributing entries over days of the week, and reducing use by 100 parties. Potter and Manning (1984) felt that temporal and spatial redistributions of use were more effective than decreasing overall use for reducing trail and camp encounters. They also concluded that camp encounters appeared to be a more limiting factor than trail encounters.

Manning and Potter (1984) used the Wilderness Use Simulation Model as a teaching tool in a recreation class at the University of Vermont. Their experience showed that the model reduced the complexity of the system under study, allowed students to devise and test various management strategies, and provided the opportunity for students to become familiar with actual parks and wilderness areas.

Beyond the Wilderness Use Simulation Model

The Wilderness Use Simulation Model proved its usefulness in applications from simple, linear river systems to large, heavily used wilderness areas. All of these studies showed that trail and camp encounters are directly related to total use level, and that management alternatives that reduce use will lead to reduced encounter levels. In addition, the model was effective in evaluating the temporal and spatial effects of various trailhead allocation patterns that were then used to establish trailhead use quotas for a complex of wilderness areas in California. Those trailhead quotas are still in use 27 years later. Equally effective was a test of the impact of fluctuating dam releases on encounters and use levels in the Grand Canyon.

Despite this promising beginning, however, the Wilderness Use Simulation Model never lived up to its original promise and fell into disuse. Much of this can be blamed on the cost and difficulties of running computer simulations in the 1970s and early 1980s. Simulations often had to be run on remote mainframe computers, with individual simulations costing U.S. $1,000. With the advent of the personal computer, all this has changed. By the mid-1980s, Rowell (1986) reported that he had modified the Wilderness Use Simulation Model so that it could be run on a personal computer. He also built in the capability to graphically represent output data in map form, making it spatially explicit. However, there was little effort to encourage use of this model, and land managers apparently have never used it.

Renewed interest in recreation travel simulation modeling developed in the 1990s. Two different groups of people, utilizing two different approaches, have been most active. Manning and his associates at the University of Vermont have used a commercially developed general-purpose simulation software package designed to simulate manufacturing processes and business systems. They used the software package Extend (1996), although there are a number of other general-purpose simulation software packages that could also have been used. They adapted the software to build simulation models for use in their “carrying capacity” research in several National Parks. Their models have much in common with the Wilderness Use Simulation Models developed in the 1970s, but can be run inexpensively on personal computers. In particular, this approach uses probabilistic simulation models in which simulated groups are assigned entire travel routes. As described in other chapters of this report and elsewhere, these models have been used to simulate numerous situations, including frontcountry hiking (Lawson and others 2002); backcountry camping (Lawson and Manning 2003a,b); bicyclers, hikers, and horses on multiuse roads (Wang and Manning 1999); and public transportation systems in parks (Budruk and others 2001). Limited validity testing suggests the models may provide a reasonably accurate representation of the system. Moreover, these studies have been exemplary in illustrating the varied management applications of the models.

Gimblett and Itami have developed a special purpose simulator (RBSim) designed specifically to build simulations of recreation behavior (Gimblett 2002; Itami and others 2002). Their simulator is integrated with GIS technology and currently allows for both probabilistic simulations (like the Wilderness Use Simulation Model and models using Extend) and rule-based agent simulations. With rule-based simulations, instead of assigning groups entire travel routes, autonomous agents make decisions, on the basis of behavioral “rules” along the way, responding to what is encountered (Gimblett and others 2000, 2001, 2002). Rules can be developed based on observation, interviews, visitor surveys, and common sense. The possibility of employing rule-based simulations, in addition to probabilistic simulations, provides the opportunity to use modeling in even more diverse situations and for more diverse purposes. RBSim also provides spatially explicit visualization capabilities that can be helpful in gaining insight into the behavior of recreationists, as well as the spatial pattern of use. Interestingly, RBSim models have been developed for portions of the Sierra Nevada and for the Colorado River in the Grand Canyon (Daniel and Gimblett 2000), two of the places where the original Wilderness Use Simulation Model was applied. Limited validity testing suggests that the models may provide a reasonably accurate representation of the system.

Conclusion

Computer simulation modeling is a well-established technology. Even for recreation applications, it has been sporadically used for more than 30 years. Initial applications demonstrated the validity and utility of modeling, but further progress was hampered by the primitive state of technology and the expense of building and running the models. Although vast improvements in technology over the past 30 years have greatly reduced the cost of simulating recreation use, there are still costs associated with data collection, model building, and validation. To us, these costs seem small in relation to the benefits that can be gained by routinely applying computer simulation modeling to improve visitor management programs.

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Chapter 3: Overview of Computer Simulation Modeling Approaches and Methods

Robert E. Manning
Robert M. Itami
David N. Cole
Randy Gimblett

Capturing Behavior of the System

The field of simulation modeling has grown greatly with recent advances in computer hardware and software. Much of this work has involved large scientific and industrial applications for which substantial financial resources are available. However, advances in object-oriented programming and simulation methodology, concurrent with dramatic increases in computer capabilities and reductions in computer hardware costs, have meant that the benefits of simulation can be extended to areas that previously have been impractical. This includes recreation management.

The challenge of simulation modeling is to capture the essential behavior of the system being modeled. In outdoor recreation, this means capturing and representing the characteristics of the physical environment (for example, a system of trails, roads, waterways, and/or facilities) and modeling the behavior of visitors as they interact with the environment and with each other. In the most basic sense, models have three components: (1) input variables that describe the system being modeled, (2) software and associated modeling approaches designed to process these input variables, and (3) output variables that are useful to planners, managers, and scientists. This chapter outlines these components for recent modeling efforts in park and wilderness management. Chapter 4 provides a series of case studies designed to illustrate these basic components of simulation modeling and demonstrate their potential usefulness.

Modeling Approaches and Software

Simulation modeling software is needed to process input variables, generate data analyses, and produce output. Three approaches to modeling and simulation of relevance to recreation travel simulations are trace, probabilistic, and rule-based agent models.

Trace, Probabilistic, and Rule-Based Agent Simulations

Trace simulations directly simulate travel itineraries collected in the field. Visitor arrival, trip itineraries, and duration of stay at destinations are simulated directly from survey data rather than using probability distributions or random numbers. These simulations are useful for examining existing pattern of use, and are often used to validate probabilistic and rule-based simulation models that are derived from the same data. Probabilistic simulation models are based on a representative sample of visitor trip itineraries. Visitors' trips are then modeled based on the probability of a visitor selecting a single trip itinerary out of the entire sample, or alternatively, the probability of selecting the next destination based on the probability distribution of all destinations originating from the current destination. Probability models are the standard method for modeling baseline conditions. Probability distributions for either trip itineraries or origin-destination pairs are a convenient way to "ramp up" numbers of visitors (increase visitor use levels) in a simulation, since a standard assumption is that as the number of visitors increase, the distribution of trip itineraries will remain the same.

Probabilistic simulation assumes that the distribution of trip itineraries in the future will remain similar to the distribution today, regardless of how the system changes. This may be an inappropriate assumption for a system that is changing dramatically. Consequently, probabilistic simulation may not be an appropriate way to model behavior in new recreation settings or in existing settings where management policies may introduce new travel networks, delete existing travel networks, or where behavior may change due to changes in recreation mode or mix of recreation types. For these situations, rule-based simulation may be more appropriate (Itami and others 2004).

Rule-based simulations use autonomous agents. The agents are autonomous because once they are programmed, they can move about their environment, gathering information and using it to make decisions and alter their behavior according to specific environmental circumstances generated by the simulation. Each individual agent has its own physical mobility, sensory, and cognitive capabilities. Because autonomous agents have their own reasoning system for navigating a travel network, the travel network must be attributed with properties to which the agents respond. These attributes may be in the form of attractions such as scenic views, interpretive centers, picnic areas, or playfields, and detractors such as hazardous areas, extreme weather events, or other environmental factors that would constrain movement or cause visitors to avoid an area. It is these attributes and the attributes of other agents that determine agent rules.

Terminating and Steady-State Simulations

A second important choice in simulation modeling approaches is whether to design simulations to be terminating or nonterminating (steady-state). Terminating simulations model events that have a specified length, while a steady-state simulation models situations in which there is no natural event to specify the length of a simulation run (Law and Kelton 2000). The choice between these two should be made on the basis of the situation being modeled and the desired modeling outputs. A terminating simulation has a known initial state (usually zero) and a known ending state. For day use issues, it is clearly appropriate to use terminating simulations to describe what happens over a given day, based on data representing the typical arrival sequence for a day.

When the situation of interest involves people on multiday trips, modeling individual days makes little sense. Nor does it make sense to model the entire year or season of use. What we are usually interested in understanding is how the system operates when at its full operating level (often at its maximum or peak). This type of situation might be modeled using a steady-state simulation. A simulation is called steady-state because the simulation, after an initial “warm up” period, is designed to replicate system behavior over the long run at a given level of production or capacity.

It is currently unclear whether it is more appropriate to model multiday backpacking trips using terminating or steady-state simulations (see for example the John Muir Wilderness case study in Chapter 4). This situation has some characteristics that seem best handled with steady-state simulations and some that seem best handled with terminating simulations. Regardless of appropriateness, steady-state simulations are more challenging to conduct and analyze. They must be run over long periods to get a reliable average measure of system behavior that is not biased by short-term effects of random variables and auto-correlation. The results of steady-state simulations must be carefully interpreted since they can overestimate parameters if the actual duration of steady-state conditions in the field is relatively short in comparison to the run-lengths required to get valid simulation results (Law and Kelton 2000). Currently, we do not have a good understanding of how to use steady-state simulations in recreational contexts.

General Purpose Simulation Software and Special Purpose Simulators

Commercially available general purpose simulation software packages are usually developed with business, industry, and government applications in mind. However, it is possible to use this general software to model outdoor recreation behavior. For example, several of the case studies described in the next chapter have adapted the simulation software, Extend, developed by Imagine That, Inc., to recreational applications. Special purpose simulators, however, are developed specifically to handle specialized applications. Several of the case studies described in the next chapter have used RBSim, developed by GeoDimensions Pty Ltd. This is a special-purpose simulator designed to build simulations of recreation behavior on linear networks. Special-purpose simulators will have more automated features specific to the application of concern. General-purpose simulation software can also be modified to include automated features specific to the application of concern (modeling outdoor recreation behavior).

Model Inputs

Simulation models require several types of input data that can be obtained from several sources. Principal types of input include data on the travel network, the environment, visitor characteristics, and, in some cases, decision rules.

Travel Network

In all of the applications of simulation modeling to park and wilderness management to date, recreation use is constrained to linear travel networks. The travel network may be represented by a road or trail system, river, or flight path. Travel networks are described as a series of connected links that are terminated or joined by nodes. In lay terms, links are referred to as trail, road, or river segments. Nodes are points that terminate a link or join three or more links at an intersection, or may be points that mark a destination along a single link (for example, a campsite or an attraction site). Travel networks are complete if there is a path from any node in the network to any other node in the network. All simulations described in Chapter 4 require complete travel networks.

Links and nodes can have properties or attributes assigned to them. For links, associated attributes might include name, maximum travel speed, average travel time, number of travel lanes, surface type and condition, steepness, length, and width. Node attributes might include name, a list of one or more facilities, visitor capacity, or average visit duration.

Travel networks can be derived from existing maps, or collected using traditional land survey techniques, downloaded from Geographic Information Systems (GIS), or collected using Global Positioning Systems (GPS).

Environmental Data

Environmental data may be required for specific models depending on the nature of the simulation. For example, a Digital Elevation Model (DEM) may be required if visual encounters are recorded or if pedestrian speeds are to be affected by uphill and downhill travel directions. Visual encounters occur when two groups see each other only from a distance. The DEM is represented by an evenly spaced grid of elevations. It is normally imported from a GIS system in a standard exchange format.

If simulation is used for facilities management (for example, to size parking lots, campgrounds, viewing platforms, or other facilities), additional information on each facility must also be collected, including the location and capacity of the facility and the typical duration of stay. Also, if queuing behavior at a facility is to be simulated, information about the service times and maximum queue length might also be required.

Visitor Characteristics

In its simplest form, for probabilistic models, a simulation model of recreation behavior requires information about travel mode characteristics (for example, foot, car, bus, or horse), travel speed, and a trip itinerary. In all cases, data collected must be in the form of a census or a representative sample. The sampling period must be appropriate to the needs of the simulation. For terminating simulations, the sample should be over the complete day or other period of interest. For steady-state simulations of peak use, sampling should be done during the peak period of use.

Visitor characteristics are generally collected using either direct observation or survey techniques. The trip itinerary is a list of destinations and visit durations (or “delays”) at destinations. The trip itinerary will usually have the following:

- An entry node (trailhead, park entry, and so on)
- A series of one or more destination nodes.
- An exit node (may be the same as the entry node for round trips).
- Arrival time (the date and/or time the visitor arrives). Often the arrival time is represented by an arrival curve or arrival sequence in which the number of visitors arriving per hour or day is provided.
- Visit duration (or “delays”) at nodes. This may be represented by a mean duration or a statistical distribution.
- Overall trip duration.

In a single simulation there may be many different itineraries (as many as one itinerary per visitor) or itineraries may be generalized as a set of probabilities for moving from one destination to another. Probabilistic itineraries are generated using statistical analysis of groups of itineraries, with probabilities generated from one destination to another.

Travel itineraries can be obtained from reservation systems where trip itineraries are specified (such as backcountry permits), or can be collected from trip diaries, GPS tracking, race timing equipment, video monitoring, or self-administered trip recording. Chapter 4 includes a case study in which waypoint signs were used to establish travel itineraries for a complex frontcountry trail system at Mount Rainier National Park.

Arrival times can be collected from traffic counters, survey data, pedestrian counting systems such as turnstiles, pressure-sensitive pads, or infrared counters. Delay times at facilities and destinations can be obtained by trip diaries, onsite observation, video monitoring, GPS tracking, race timing equipment, or directional pedestrian counters.

Decision Rules

Decision rules are required for rule-based simulation models. In this type of simulation, trip itineraries may not be known because the travel network may not yet be developed or because management conditions have changed (such as trail or road closures), which alter existing itineraries. Decision rules may also be required where the behavior or itinerary of a visitor may change based on conditions that are generated through the course of the simulation, such as parking areas becoming full, crowded conditions at visitation sites, weather changes, or other events that may alter onsite behavior.

Agent rules are a set of user-defined behaviors using a stimulus/response or event/action framework. Rules are determined by observing onsite behavior, surveys or interviews, or “walkthroughs” whereby visitors or people familiar with the pattern of use are asked to systematically trace a trip on a map and identify decision points, destinations and attractions, site detractors, or other visitor- or site-related conditions that would alter path selection. This process is repeated for each visitor type or itinerary. Generally the rules must be tested, by simulating one agent at a time, to fine-tune the rule conditions, the sequence of rules, and the complexity of rules needed to achieve the desired path selection behavior. A rule of thumb is to keep rules as few and simple as possible.

Boolean logic can be used to combine two or more stimuli to create complex conditions for behavior. Broolean logic organizes concepts in sets that are controlled by the operators OR, AND, and NOT. An example of a rule is:

> *If (TravelMode = ‘Car’ AND Locale = ‘Twelve Apostles’ AND LocaleEntry = True) THEN Find Carpark*

In this example, the rule would only apply to agents arriving in a car at the entry to the Twelve Apostles Locale. If these three conditions are met, then the agent is directed to find a carpark. This directive then triggers the agent to execute its complex wayfinding logic to create a new itinerary.

It is also possible to have probabilistic rules. For example, we may know from count data that 60 percent of all visitors stop at the visitors center. We could construct a probabilistic rule by assigning the rule a probability of 0.60. When the agent triggers a probabilistic rule, it generates a random number in the range of 0 to 1. If the number generated is less than or equal to the probability assigned to the rule, then the rule is executed. If it is greater than the probability assigned to the rule, then the rule is ignored. Refer to the Port Campbell National Park (Twelve Apostles) case study for more detailed information on rule-based agent modeling.

Model Outputs

Simulation models can generate a great variety of output variables. These variables should be specified prior to model design and development, and should be formulated on the basis of their potential usefulness to park and wilderness managers. Commonly used output variables include use density, encounter, and queuing time measures. Use density measures report the number of visitors related to space or time. For example, a simulation model of a backcountry trail and campsite network could report the number of visitors (hikers, bikers, horseback riders) that traverse each trail segment per day or the number of visitor groups at each campsite per night. Other related output variables include people-at-one-time (PAOT) at attraction sites and people-per-viewscape (PPV) along heavily used trails. A simulation model of a trail and campsite network can also report the number of times visitor groups encounter one another along trails or at campsites. Encounters can be recorded by type of visitor (hikers, bikers, horseback riders), by type of encounter (meeting, overtaking, visual), by place, and by unit of time. Encounter estimates are a particularly important output. Because encounter type and number can influence visitor experience, standards are often written for encounters, which are difficult to directly monitor. Finally, models can output queuing or waiting times for visitor facilities or services. A variety of output variables are included in the case studies described in Chapter 4.

Since models are driven by random samples from probability distributions, the output from two different simulation runs can be quite divergent. Consequently, it is important to incorporate replication into simulation modeling. Replication can involve either running many different simulations or, for steady-state simulations, running a single long simulation that is divided into “batches” that serve as replicates (Law and Kelton 2000). In either case, outputs should be reported as means with confidence intervals.

Model Validation

An oft-neglected step in the model-building process is validation of the model. Validation is the process of making certain that the simulation model provides an accurate representation of the system being modeled. As Law and Kelton (2000) note, if the model is valid, decisions made using the model would be similar to those that would be made if it were possible to physically experiment with the system. There are at least three important steps in model validation (Law and Kelton 2000; Naylor and Finger 1967; Schechter and Lucas 1978). First, the model should be checked for face validity. That is, it should work in ways that seem reasonable to those who know how the system should operate. Second, the operating assumptions of the model should be empirically tested. Sensitivity analyses can be used to make certain that outputs change in predicted ways when important model variables are changed. Finally, it is important to assess how closely model output data resemble those that might be obtained from field data.

Schechter and Lucas (1978) discuss various ways they assessed the validity of the Wilderness Use Simulation Model. A common validation technique involves comparing model output to field observations. Simulation models are normally developed initially to describe current or “baseline” conditions in a park or wilderness area. For example, input variables on visitor use levels and patterns for a trail and campsite network might be used to develop a model designed to estimate trail and campsite encounters. Field observations of trail and campsite encounters might be collected through direct observation or self-reports of visitors, and these data compared to model estimates to test the degree to which model estimates are accurate or “valid.”

In the case studies reported in Chapter 4, face validity has generally been assessed and sensitivity analyses have been conducted. However, comparisons of model output to field data have either not been conducted or have been based on limited field data. Therefore, our confidence in the validity of models is limited, as is our knowledge of the precision of results. Where limited field data were collected, it is not possible to conduct a more rigorous validation than to simply compare observations with outputs and conclude whether they seem similar enough to have confidence in the model. With a sufficient sample of field observations it is possible to rigorously estimate the accuracy of the model. Freese (1960) shows how standard chi-square tests can be used to estimate the accuracy of the model.

Using the Simulator

As noted above, the simulator can be used to describe the existing spatio-temporal distribution of use. Output from the simulation can be valuable to management, given the difficulty of obtaining such information in any other way. The simulator can also be used to monitor crowding-related indicators, such as number of encounters, persons-at-one-time or persons-per-viewscape, either to describe the current situation or to determine whether standards for such indicators are being violated. The simulator provides a much more cost-efficient way to gather such data than monitoring these indicators directly.

The simulator can also be used for predictive purposes. For example, it can be used to predict the maximum amount of use that can be sustained without exceeding some crowding-related standard, such as trail encounters per day, by running scenarios with various use levels until the use level that barely complies with the standard is identified. A wide variety of alternative management scenarios can be simulated to predict the outcome of such actions as changes in the timing and distribution of use, changes in the travel network, and changes in facility type, location, or capacity. Alternatives are evaluated by running the simulator after making changes in visitor data or travel network data. Outputs from several different scenarios can be compared to identify those most closely aligned with desired future conditions. Many of these uses of simulation are illustrated in the case studies in Chapter 4.

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Chapter 4:
Case Studies of Simulation Models of Recreation Use

David N. Cole

Computer simulation models can be usefully applied to many different outdoor recreation situations. Model outputs can also be used for a wide variety of planning and management purposes. The intent of this chapter is to use a collection of 12 case studies to illustrate how simulation models have been used in a wide range of recreation situations and for diverse planning and management applications.

The types of recreation situations included in these case studies vary in the size and remoteness of the area being modeled, as well as in the type of recreation. Case studies include:

- large backcountry areas: Bighorn Crags in the Frank Church River of No Return Wilderness, Misty Fjords National Monument, Colorado River through Grand Canyon National Park, Humphrey's Basin in the John Muir Wilderness, and Isle Royale National Park;
- smaller frontcountry areas: Yosemite Valley in Yosemite National Park, Alcatraz Island in Golden Gate National Recreation Area, Arches National Park, Acadia National Park, Paradise Meadows in Mount Rainier National Park, and the Twelve Apostles in Port Campbell National Park, Australia;
- overnight hikers: Bighorn Crags, Humphrey's Basin, and Isle Royale;
- day hikers on trails: Yosemite, Arches, Acadia, and Mount Rainier;
- visitors to facilities: Alcatraz Island and the Twelve Apostles;
- bicyclers: Acadia National Park;
- whitewater rafters: Grand Canyon National Park;
- visitors on cruise ships and ocean kayakers: Misty Fjords;
- visitors in automobiles: Acadia.

Perhaps the most basic use of computer simulation modeling is as a tool for describing current use patterns. The purpose of the first four case studies (Bighorn Crags, Misty Fjords, Grand Canyon, and John Muir) is to illustrate this use. Simulation can also be used to monitor crowding-related indicators, such as number of encounters, persons-at-one-time or persons-per-viewscape, either to describe the current situation or to determine whether standards for such indicators are being violated. The Bighorn Crags and John Muir case studies illustrate the estimation of encounter rates, while persons-at-one-time or persons-per-viewscape measures are estimated in the Yosemite, Alcatraz Island, Arches and Acadia case studies.

Computer models can also be used for predictive purposes. In the Isle Royale case study, simulation was used to help planners identify alternative management actions that would be effective in reducing campsite sharing. This was accomplished by predicting the effects on campsite sharing of reductions in amount of use, changes in the spatial and temporal distribution of use and increases in behavioral restrictions and number of facilities. At Yosemite, Alcatraz Island, and Arches, simulation was used to predict the maximum amount of use that can be sustained without violating crowding-related standards. At Alcatraz and Arches, the effect of alternative public transportation systems on maximum allowable use was also predicted.

Simulation can also be used to prepare for the future. In the Acadia and Twelve Apostles case studies, use is steadily increasing, and future use levels are forecast to be much higher than they are presently. In these case studies, simulation models are used to predict the effect of increased use on crowding-related variables. In the Twelve Apostles case study, the effects of changes in park infrastructure are also predicted. Finally, the Mt. Rainier case study shows an innovative way to collect data on visitors in a challenging situation.

The case studies included in this chapter suggest that there is reason to be enthusiastic about the potential of computer simulation modeling as a visitor management tool. However, this enthusiasm must be tempered with appropriate realism and caution. The application of simulation to outdoor recreation issues is still in its infancy, and there is much need for more learning and development. As with so many things, the more we learn, the more we recognize the need to know even more. The models presented in the case studies have only been partially validated. Simulation outputs have not been statistically compared to real-world observations. Numerical estimates and predictions are presented without numerical estimates of how much confidence one should have in these metrics. More work is needed to ensure that the models developed are as valid as possible, simulation runs are conducted correctly and outputs are appropriately interpreted. However, these case studies demonstrate the useful outputs that valid models can produce.

Recreation Visitation and Impacts in the Bighorn Crags Portion of the Frank Church—River of No Return Wilderness

Randy Gimblett
Suzanne Cable
David N. Cole
Robert M. Itami

Purpose

This case study demonstrates the use of agent-based modeling and simulation to describe recreation use patterns in a popular portion of the Frank Church—River of No Return Wilderness in central Idaho. The case study will demonstrate the data collection methods, modeling, and simulation of backpackers and recreational stock users on multiple day trips. Particular attention is given to estimating encounter rates in the interior of this wilderness because encounter rates can affect the experience of wilderness visitors. Consequently, wilderness managers commonly want to monitor encounter rates and frequently develop standards for maximum acceptable number of encounters.

Study Area

The Frank Church—River of No Return Wilderness Area is the largest contiguous wilderness area in the United States, outside of Alaska. The most popular portion of this wilderness for backpackers is an area known as the Bighorn Crags. The area also receives substantial use by groups traveling with pack and saddle stock. Rugged and remote, this country offers adventure, solitude, and breathtaking scenery. Like other popular wilderness areas, physical impacts from dispersed visitor use are evident throughout the area, and social impacts to visitor experiences are likely, but currently not well documented. To develop the information needed to better manage recreation in the Bighorn Crags, we conducted inventories of all recreation impacts in the Crags (official trails, user-built trails, and campsites), and collected the data needed to build a computer simulation of the distribution of recreation use.

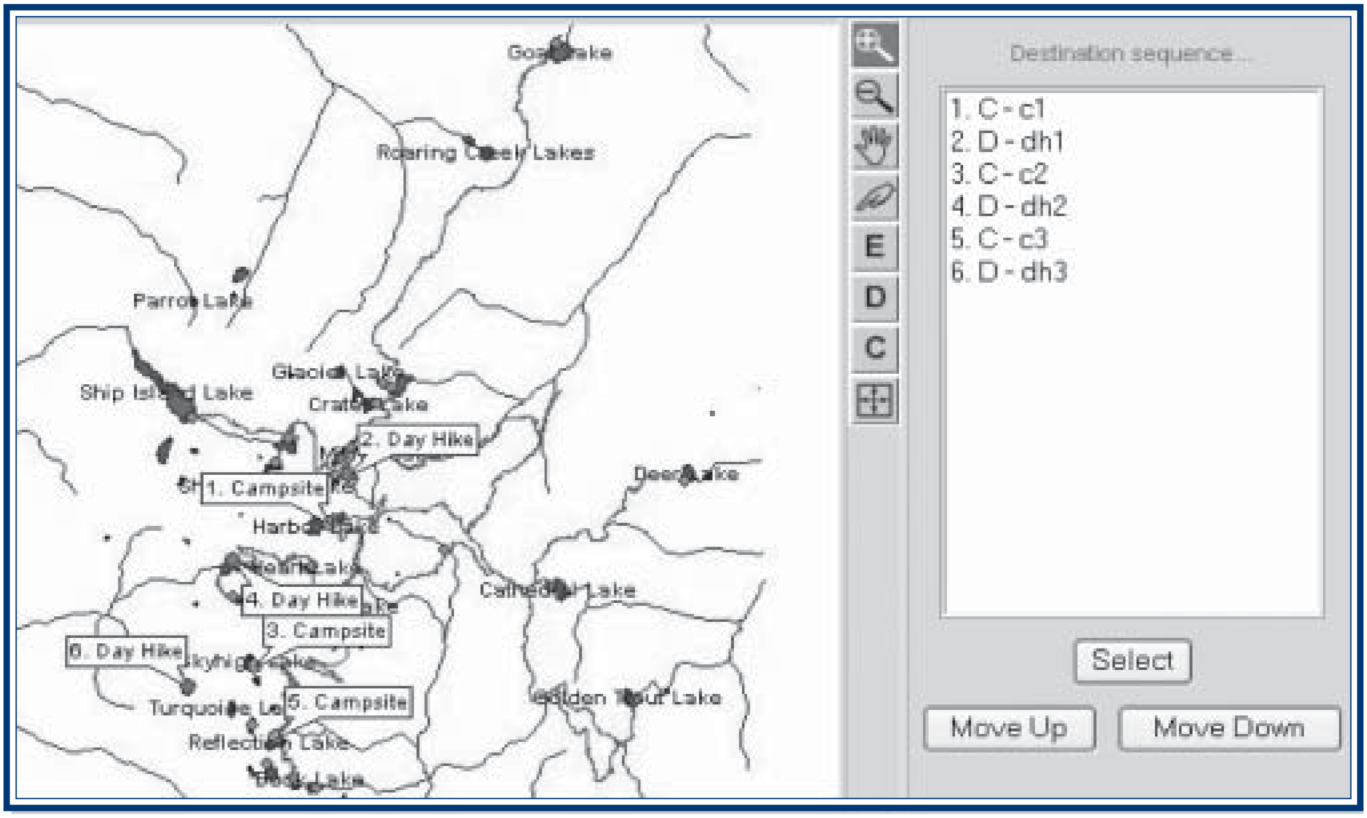
Data Collection Procedures

To build the computer simulation, data were collected on both visitor demographics and site characteristics. Site characteristics include a map of travel networks and popular destinations.

Visitor Characteristics—Trip diaries were used to collect the data on visitor itineraries needed to construct the simulation. Visitors were asked to take a diary with them and record on one side of the diary their group size, mode of travel, and date and time of entry and exit. They were also asked a series of attitudinal questions about trail, campsite, and management conditions. On the other side of the diary, a map was provided so a group could record route information. Specific instructions for the map were as follows:

> Please indicate on the map where you camp, the number and type of encounter(s) you have and a notation at the edge of the map anytime you leave and re-enter the wilderness area. Please locate each of the campsites you visit as accurately as possible on the map. Place a ‘C’ beside the campsite and a number that indicates the night of the trip that you camped at that location (Example C2 denotes the place where you camped on the 2nd night of trip). In addition to camp locations we would like you to indicate the number and type of encounters you have with other parties throughout your trip. Place an ‘E’ to mark any encounters you have along the trail as they occur or while at camp at the end of the day. Associated with the ‘E’, provide one or more of the following notations to denote the type of encounter(s) you had, ‘O’ (Other Party Camping), ‘P’ (Packstock) or ‘B’ (Other Backpacker) followed by a number which indicates the number of people in the group encountered. (Example EP10 means encounter with a packstock group of 10 people).

To create trip itineraries in the format required by RBSim, all spatial and relational data from the diary were entered into an Access database via a Web-based interface developed specifically to enter both types of data. Figure 1 provides an example of this interface and one of the trips that was entered into the database. This was a 4-day trip into the area. C1, C2, and C3 were the three locations where the group camped, and DH represents day hikes taken from each of the campsites. To represent this trip in RBSim, data were transformed into a sequence of travel routes and destinations (generically referred to as links and nodes). The sequence was determined by the number on the left side of the destination notation. For example, the trip in figure 1 camped the first night at Harbor Lake. The next day began with a day hike to Bird Bill Lake, followed by a backpack to and camping at Sky High Lake. The next day began with a day hike to Terrace Lakes, followed by a backpack to and camping the third night at Reflection Lake. The fourth day began with a day hike to Lost Lake



Destination sequence...

1. C - c1
2. D - dh1
3. C - c2
4. D - dh2
5. C - c3
6. D - dh3

Figure 1—Interface for capturing spatial data about the trip.

and then a return to the trail head. No other visitors were encountered on the trip. This sequence of links, nodes, and durations at campsites are conformed into a data sequence that RBSim reads and uses to replicate this trip in the trace simulation.

Site Characteristics—Global Positioning System (GPS) tracks were used to inventory trails and campsites to create a travel route and destination network. All trails in the study area were inventoried during the summer of 2003. Link data were then converted into ArcView format, and then converted into a format that conforms to standards established for RBSim. In some cases, it was clear that recreationists traveled offtrail between destinations. These informal routes were digitized and represented as part of the trail network.

Campsite inventory data were also collected in the field. This consisted of creating a photographic record of the sites, using a GPS to locate recreation sites, and taking quantitative measures of variables such as soil erosion, vegetative cover, and amount and type of disturbance (Cole 1989). Similar to the trail data, campsite and trailhead nodes were inserted into the ArcView map. Since most of these campsites were situated beside lakes, a single node was established for each lake, and all campsites at the lake were associated with that node. Consequently, campsite statistics are provided for lakes rather than individual campsites. We were not confident that visitors could identify the exact campsite they used at a lake.

Modeling Characteristics

RBSim, a recreation behavior simulator (Gimblett and others 2001) was used to describe patterns of visitor use across the landscape. The modeling approach used in this study is a trace simulation using baseline fixed itineraries derived from the trip diaries. A typical trip for the Bighorn Crags simulation is described by an entry node, an exit node to the network, an arrival curve, a probability distribution of agent types, a list of destinations, and trip duration. On execution, the simulator reads all the trip itineraries, schedules all trips, and then an agent representing the type of trip moves from one destination to the next across the travel network using the shortest travel time between the two points. A large set of information for each agent is collected and stored in an Access database for later processing.

Simulation Outputs

Simulation output can be used to describe use levels on trails and at lakes as well as encounter levels on trails and at camping areas around lakes. There is considerable interest in the estimation of encounter levels because they are a common indicator and are difficult to measure in the field. To derive encounters along trails and at campsite destinations, a simulation was constructed. The simulation was run for a total of 89 days, from July 3 through September 29, 2003. A total of 75 trips through the Bighorn Crags were simulated. Average trip length was 3.6 days. Visitors typically arrived on Friday or Saturday and departed the wilderness on Sunday or Monday. Peak use occurred in late July and early August. Average group size was 2.8. Model outputs were visitor use levels and encounters by trail segment and camping area (lake). Statistics are the mean of 10 replications of the simulation. Trail encounters varied substantially between replications, while trail use, camp area use, and campsite encounters did not.

Trail Use—Table 1 shows simulation output for three different trail segments. Total use is indicated by the total number of groups that traversed the trail segment during the simulated sampling period. The most heavily used trail segments are from the trailhead at Bighorn Crags campground to the trail intersection that branches off to Welcome and Wilson Lakes. Encounters are recorded when one group overtakes another group in the simulation or where two groups pass each other in opposite directions. Table 1 shows the total number of encounters that occurred during the 89 day season, the mean number of encounters per day, as well as the number of days on which encounters occurred.

There is not a simple linear relationship between use levels and encounter levels. Nor is there a linear relationship between the average number of encounters and the days on which encounters occur. This illustrates the value of the computer simulations. Segments 64 and 66 have similar encounter levels, but both use levels and the number of days with encounters are much higher for segment 64. Trail segment 64 is much shorter than segment 66. Apparently, as the length of trail segments decreases, so does the ratio between number of encounters and amount of use. Figure 2 displays the distribution of trail encounters across the Bighorn Crags. The maximum mean daily encounter level was just 0.51 encounter per day, and on many of the trail segments, no encounters occurred. This suggests that crowding on trails is not a serious issue in the Bighorn Crags.

Table 1—Simulation output on use and encounter levels for selected trail segments.

Trail segment	Total groups	Total encounters	Encounters per day	Days with encounters
61	2	0	0	0
64	104	7	0.08	5.5
66	26	6	0.07	1.4

Campsite Use

Table 2 provides information about use levels and encounters between groups at the more popular camping areas in the Bighorn Crags. Camping areas are entire lakes or other destinations. Ship Island and Wilson Lakes are the most popular camping destinations in the Bighorn Crags (figure 3). Someone was camping at these lakes about 30 nights during the 89-day season. By dividing nights occupied by 89, one can derive the likelihood of camping with at least one other group at each camping area.

The simulation also generates output on the total number of groups that camped in each area over the season. Dividing total number of groups by 89 generates an estimate of mean groups per night (table 2). If more than one group is camped in a camping area on the same night, campsite encounters occur. All groups camped in the same area were assumed to encounter all other groups in that area. Encounters are derived from simulation output as the difference between the total number of groups that camp in the area and the number of nights that anyone camps in the area. When divided by 89, an estimate of mean campsite encounters per night is generated (table 2).

Conclusion

This case study illustrates how a computer simulation model can be used to describe the distribution of use across a large complex of backcountry trails and campsites. It can generate estimates of encounter levels, useful indicators of potential crowding problems that are costly to monitor directly. Simulation output suggests that crowding in the Bighorn Crags is typically not a serious problem at present.

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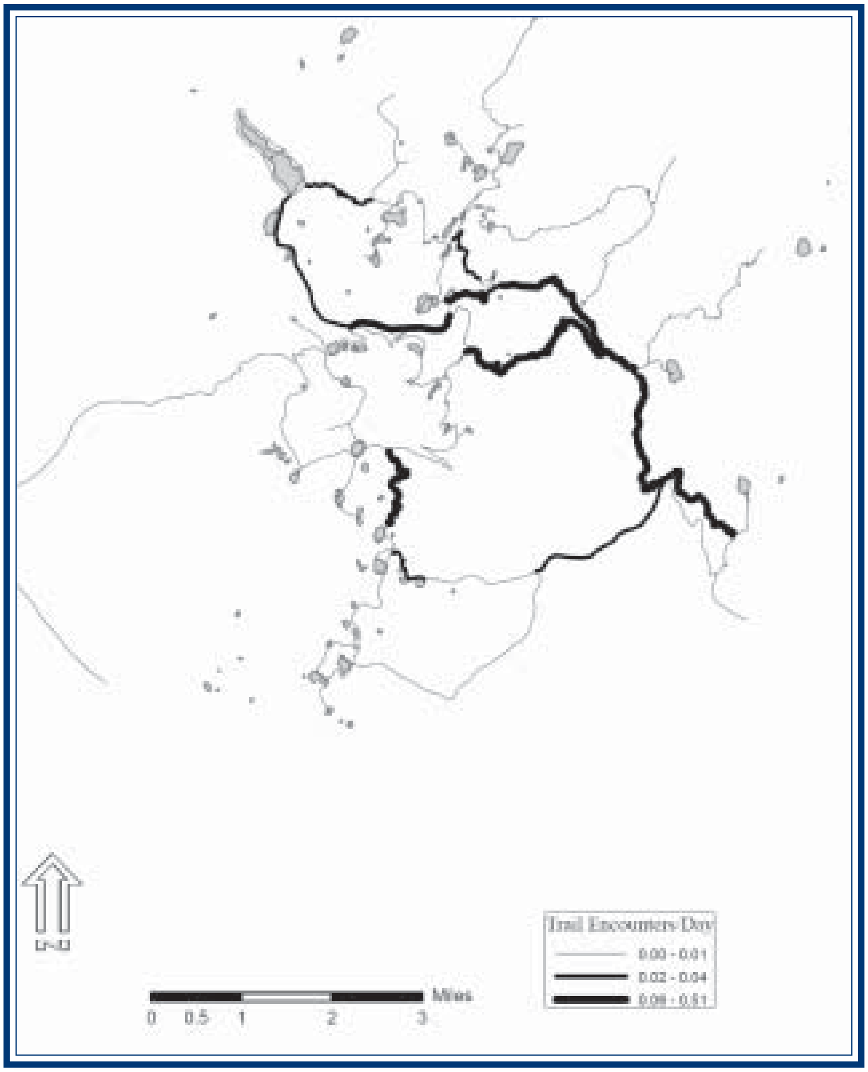

Figure 2—Mean trail encounters per day in the Bighorn Crags over an 89-day season.

Table 2—Simulation output on use and encounters at camping areas.

Camp area	Nights occupied	Likelihood of a camp encounter	Mean groups per night	Mean encounters per night
Ship Island Lake	31	0.35	0.54	0.19
Wilson Lake	29	0.33	0.39	0.07
Airplane Lake	27	0.30	0.30	0
Welcome Lake	24	0.27	0.33	0.05
Reflection Lake	23	0.26	0.33	0.07
Cathedral Lake	18	0.20	0.28	0.08
Birdbill Lake	13	0.15	0.18	0.03
Terrace Lakes	11	0.12	0.15	0.02
Barking Fox Lake	9	0.10	0.11	0.01
Sky High Lake	9	0.10	0.12	0.02
Heart Lake	8	0.09	0.09	0
Wilson Creek—offtrail	6	0.07	0.07	0
South of Cathedral Rock	3	0.03	0.03	0
Cathedral Rock	3	0.03	0.03	0
Gentian Lake	3	0.03	0.03	0
Buck Lake	3	0.03	0.03	0
Ramshorn Lake	2	0.02	0.02	0
Wilson Creek west of Buck Lake	2	0.02	0.02	0

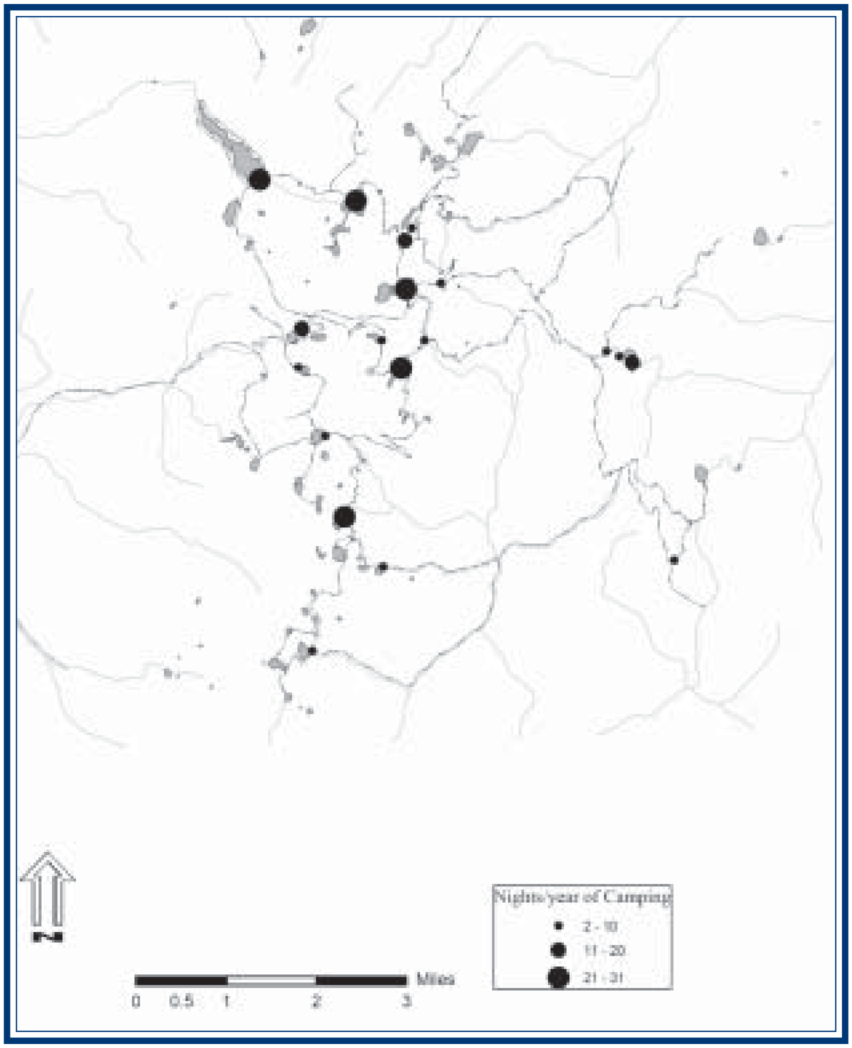

Figure 3—Nights per year of camping at lakes in the Bighorn Crags, over an 89-day season.

Recreation Visitation in Misty Fjords National Monument in the Tongass National Forest

Randy Gimblett
Robert M. Itami
Suzanne Cable

Purpose

This case study illustrates the utility of agent-based modeling and simulation in describing recreational use patterns at Misty Fjords National Monument in the Tongass National Forest. The case study demonstrates data collection, modeling, and simulation of multiple travel modes including arrivals and departure of helicopters, floatplanes, and cruise ships on multiday trips. Particular attention was given to assessing potential impacts on wildlife at certain critical locations along the coastline.

Study Area

Located in southeast Alaska, Misty Fjords National Monument is 35 km east of Ketchikan and about 1,100 air km from Seattle. Created in 1978, by Presidential Proclamation, the Monument encompasses about 920,000 ha within the Tongass National Forest. In 1980, Congress passed the Alaska National Interest Lands Conservation Act (ANILCA) and designated all but 60,000 ha as Wilderness. Monument status protects ecological, cultural, geological, historical, prehistorical, scientific, and wilderness values. Remote and wild, the Monument is a primarily mountainous, nearly untouched coastline, characterized by deep saltwater fjords, and is home to mountain goats, brown and black bears, and a host of fish and marine mammals.

The Behm Canal, a deep, long waterway of the northeastern Pacific Ocean, leads to the heart of the Monument. Places such as Walker Cove and Rudyerd Bay, characterized by rock walls jutting 1,000 m above the ocean, provide flightseers, cruise ship passengers, boaters, and hikers with photographic opportunities. Commercial services are allowed, under permit, to provide basic public services in keeping with Monument designations. The Forest Service and the State of Alaska manage fish and wildlife habitat cooperatively. Very little recreation use actually occurs on the land due to the steep, inaccessible terrain, but since there is limited regulation of air or water, encroachment of tourists from anchored ships and commercial flights on wildlife is of serious concern.

Data Collection Procedures

Data were collected on both visitor demographics and site characteristics. Site characteristics include a map of travel networks and popular destinations, as well as those areas wildlife biologists understand to be rich estuaries that provide needed forage and protection during particular times of the year for wildlife populations.

Visitor Characteristics

Trip itineraries for the simulation were constructed from visitor data acquired from a number of sources for the 2000 tourist season. These included records from cruise ship tours, commercial fishing and hunting records, harbor master records of water-based travel of large cruise ships entering the harbor, and in particular, privately owned recreational luxury boats and sailboats. In addition, records were obtained for floatplane tours and a range of administrative trips regularly taken by the Forest Service. Information collected included the type of activity, size of watercraft, name of company, number of visitors on tour, duration of visit, time of departure from origin of trip, and time of arrival at selected destinations. Typical boat, helicopter, and floatplane speeds and common flying altitudes were also collected. This information provided enough background to characterize the type and frequency of trips as well as common destinations.

While trip logs are an excellent source of data to characterize the trip, many routes can be taken to any destination. So in addition to trip itinerary data, travel companies and commercial floatplane operators were asked to map their preferred and typical travel routes, stopovers at lakes, and any other information that could be used to accurately describe the pattern of travel. Anecdotal information was also collected on events that might cause variations in typical travel routes. For example, travel patterns in Alaska are frequently dependent on weather.

Site Characteristics

All the mapped travel route data were entered into a Geographic Information System (GIS) and used to construct a network of all possible travel routes. A network was created for water travel (including cruise ships, privately owned recreational fishing and luxury boats, sailboats, administrative water craft), floatplanes (commercial and administrative; fig. 4), and helicopters (commercial and administrative). These networks included all major destinations identified in the trip logs and in interviews with tour operators.

Modeling Characteristics

RBSim, a recreation behavior simulator (Gimblett and others 2001) was used to examine the seasonal patterns of visitation that occur in Misty Fjords National Monument. The modeling approach used in this study is a trace simulation using baseline fixed itineraries. Central to the trip planning behavior of a recreation agent is the typical trip. The concept of a typical trip is based on the premise that visitors have common patterns of use. For example, day use visitors arriving during weekdays will have a different arrival pattern, a different duration of stay, and perhaps a different pattern of destinations than a traveler arriving on a weekend or an overnight visitor.

A typical simulated trip has a global trip plan, which specifies an intended list of destinations the agent wishes to visit. A global trip plan consists of total trip duration, an entry node, an arrival time, an exit node and a sequence of intermediate nodes (destinations) between the entry and exit nodes. Each destination node has a visit duration.

The simulator reads all the trip itineraries and schedules all trips, then moves each agent from one destination to the next across the travel network using shortest travel time between the two points. Information for each agent is collected and stored in a database for processing.

Simulation Outputs and Management Recommendations

A total of 2,149 trips were entered into the simulation for the 2000 visitor use season for Misty Fjords National Monument. The simulator produced output on encounter levels for all destinations on the network. Encounters are the number of other agents visible within a specified radius of the destination categorized by craft type. Figure 5 shows total number of encounters at the 12 most frequently visited destinations. A number of destinations received very little use, while others would be considered to be high use destinations. Rudyerd Bay and associated docking facilities (1,301 combined encounters) are the most popular destinations in the Monument. Visitation peaks in August, generating the greatest potential for conflict between different modes of travel (fig. 6).

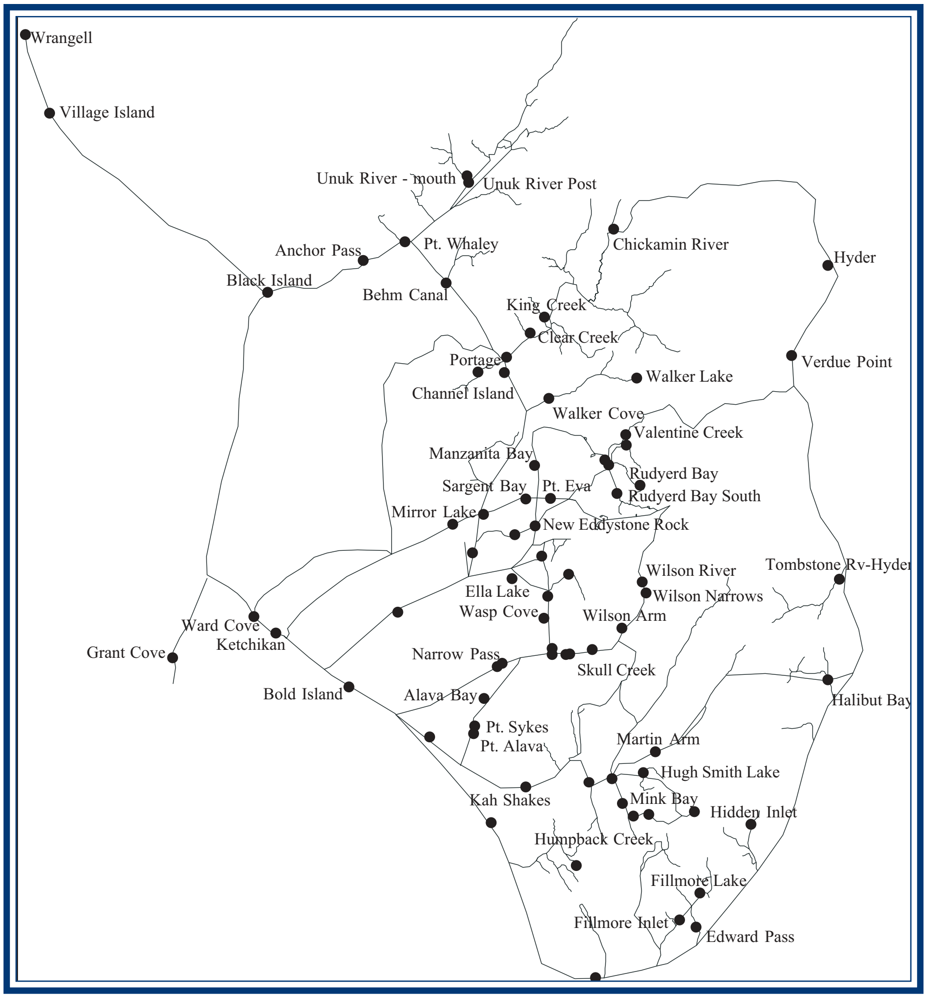

Figure 4—Floatplane network, including destinations for Misty Fjords.

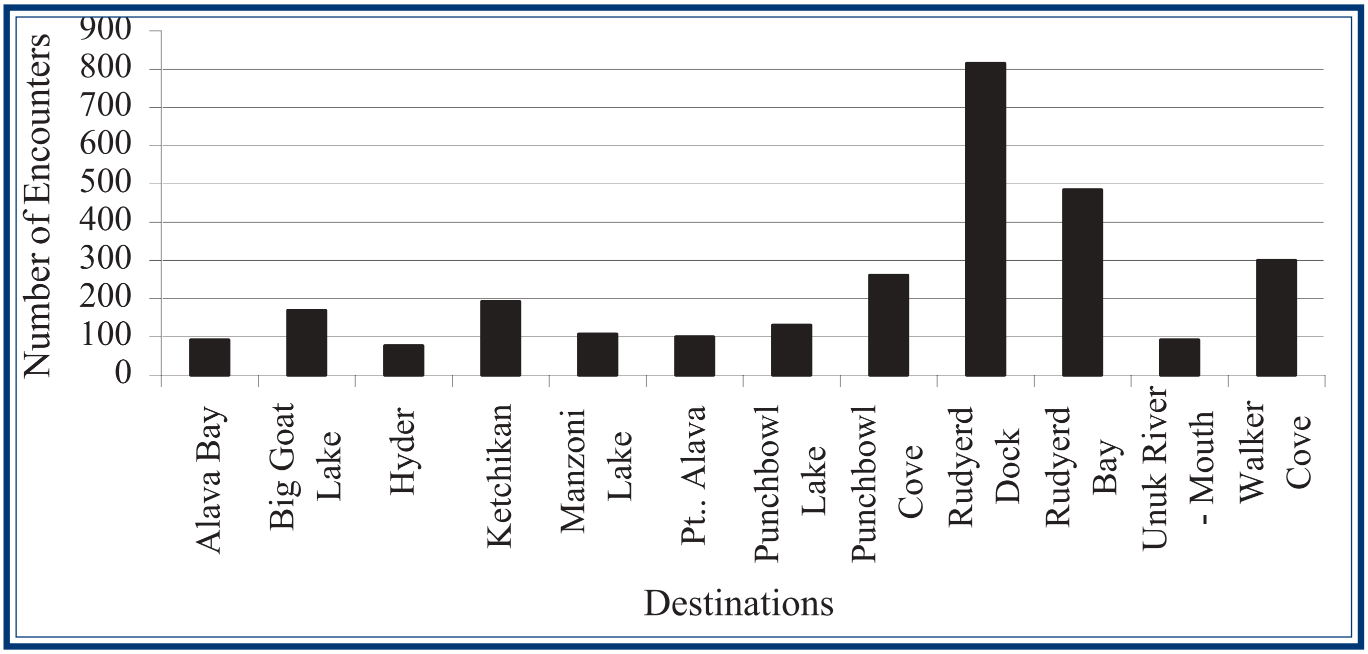

Figure 5—Number of encounters at 12 frequently visited destinations.

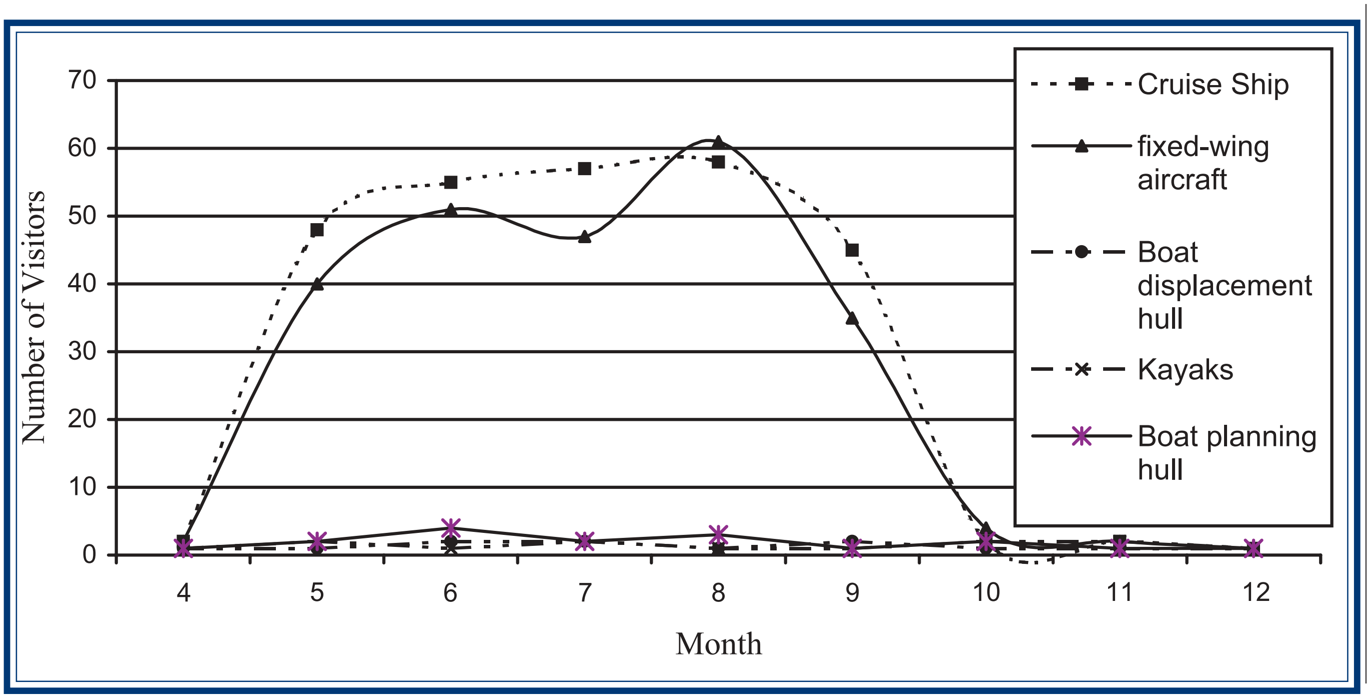

Figure 6—Monthly use levels for different user types.

To gain insight into potential conflict between recreation and wildlife, a more detailed analysis was performed at both Walker Cove and Rudyerd Bay. Monitoring agents were placed at both areas and the simulations rerun for the month of August (peak period of visitation) to determine the temporal distribution of use. Wildlife disturbance can be responsive to temporal use distributions. We were interested in peak use days in August, as well as the hours during those days that visitors are within sight of wildlife.

At Rudyerd Bay, visitation varied from day to day, increasing slightly as the month progressed (fig. 7). The number of fixed-wing aircraft frequenting the area was lower than expected. The hourly assessment revealed a cyclical pattern of visitation over the period of a day (fig. 8) with the number of ships increasing during the evening hours. Many of these cruise ships anchor in the cove at night and then leave early in the morning (between 4:00 and 10:00 a.m.).

These daily and hourly patterns of visitation reveal that there is very little time during the month of August when there is not a cruise ship or commercial floatplane in Rudyerd Bay.

Conclusion

This case study illustrates the application of computer simulation modeling in a marine environment used by many different types of users. The spatial and temporal explicitness of outputs is helpful in assessing management concerns about the potential for impacts on known concentrations of waterfowl, shorebirds, and harbor seals. Such impacts are highly space and time dependent.

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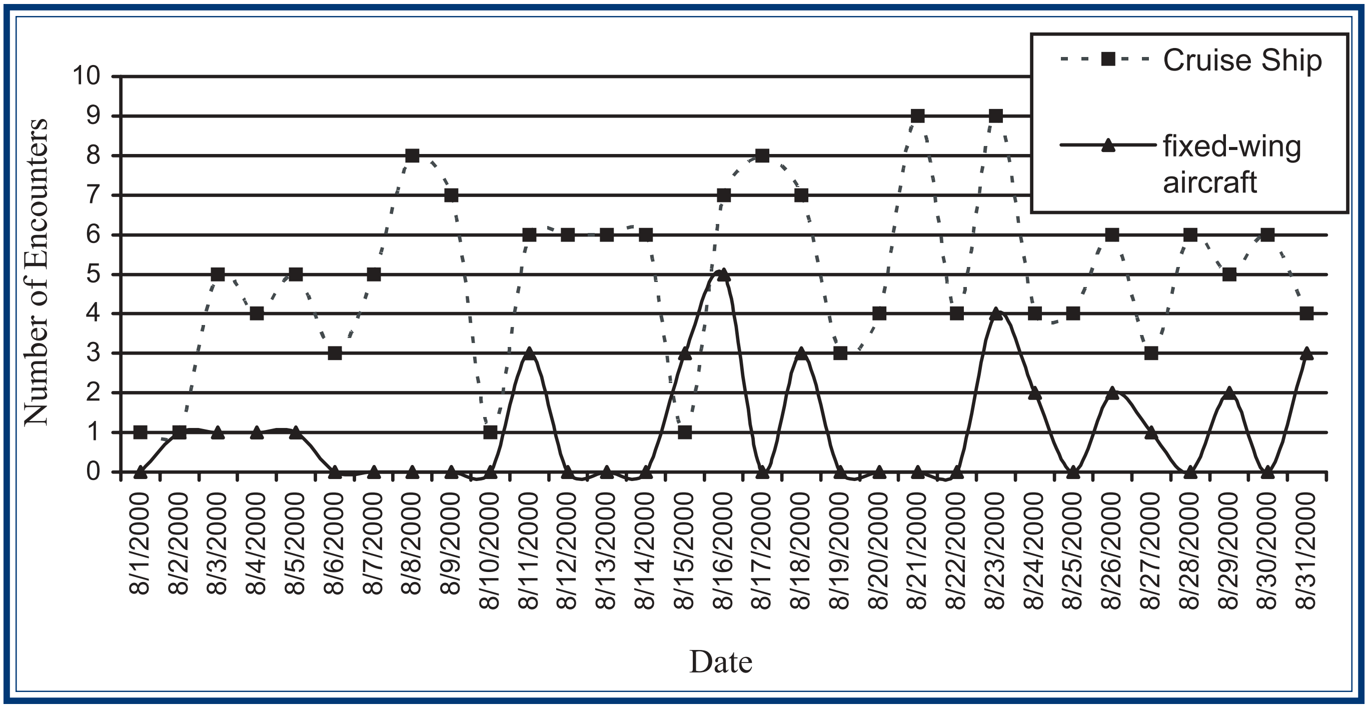


Figure 7—Daily encounters, for cruise ships and fixed-wing aircraft, at North Arm of Rudyerd Bay, August 2000.

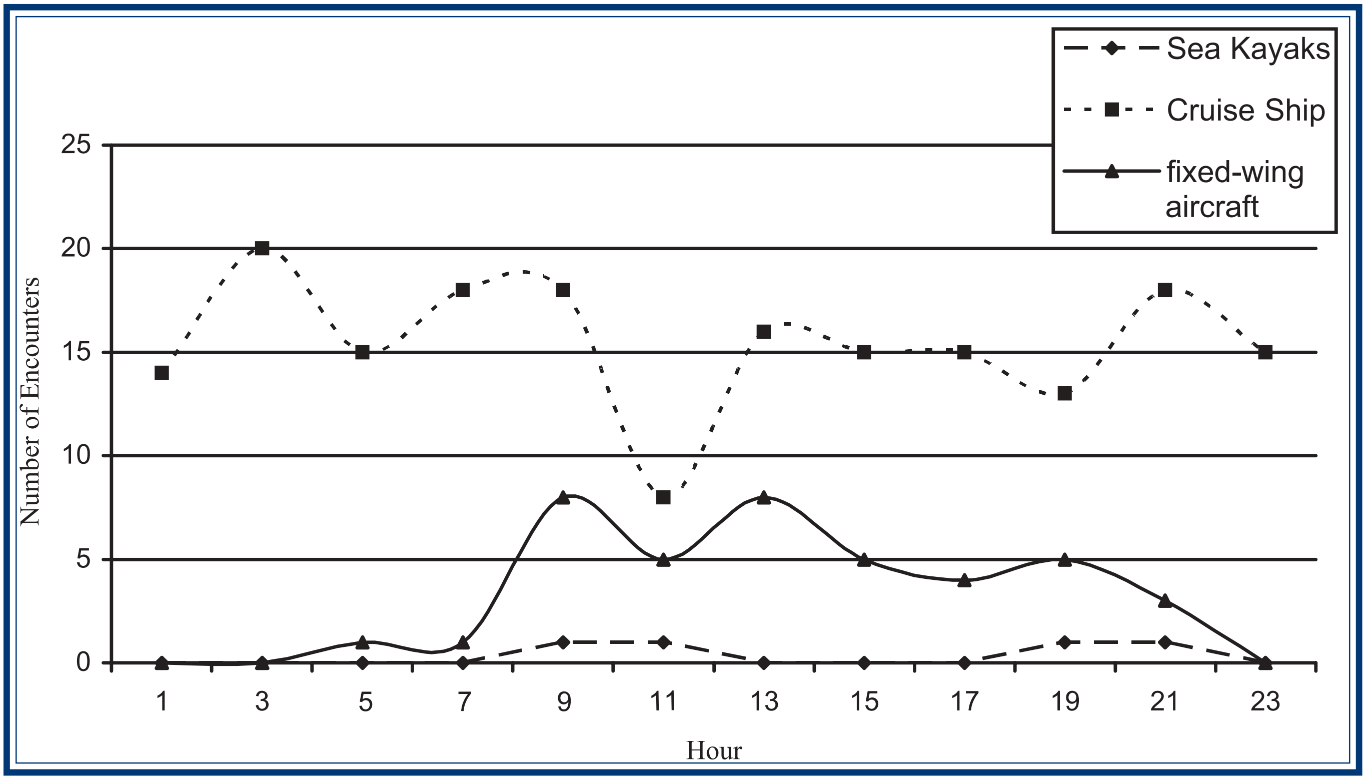


Figure 8—Hourly encounters, for sea kayaks, cruise ships, and fixed-wing aircraft, at North Arm of Rudyerd Bay, August 2000.

Simulation of Recreation Use Along the Colorado River in Grand Canyon National Park

Randy Gimblett

Purpose

The purpose of this case study is to demonstrate the use of agent-based modeling and simulation of multiday river trips along the Colorado River, trips that are in high demand and for which crowding is a major concern. Model outputs not only illustrate use patterns along the river, but also predict how modifications of trip scheduling can affect use distribution and crowding.

Study Area

The increasing popularity of whitewater trips on the Colorado River through Grand Canyon National Park threaten to impact sensitive, dynamic ecosystems and degrade the quality of experience of human visitors. Over 23,000 individuals and another 3,700 guides, researchers, and park staff travel through the Grand Canyon each year. Visitors travel on over 600 commercial or privately organized river trips on a variety of watercraft powered by oars, paddles, or motors. Trips range from 6 to 18 days (to Diamond Creek) in the primary use season, and up to 30 days at other times. Because of fluctuating water levels imposed on the river from Glen Canyon dam, trip speed can vary substantially through particular reaches of the river. When water levels are low, progress is slower (especially for oar-powered trips), and lost time is usually made up by skipping or reducing the time allocated to attraction sites and/or by spending more time rowing down the river. High water results in faster progress, which usually translates to more stops and longer times at both attractions and campsites, resulting in more crowding and greater environmental impacts.

Many of the major drainages and side canyons along the 450-km river corridor in Grand Canyon National Park provide opportunities for hiking and swimming. Well-known attractions and destinations are regular stops for nearly every river trip that passes through the canyon. Crowding and encounter levels along the river at attraction sites are often extreme and have been shown to affect the character and quality of the visitor experience (Shelby and Nielsen 1976). Simulation modeling was proposed as a means of better describing existing use patterns along the river, as well as to predict whether changes in launch schedules could be used to decrease crowding on the river.

Data Collection Procedures

Data were collected on both visitor characteristics and site characteristics. Site characteristics include river travel networks and popular destinations.

Visitor Characteristics

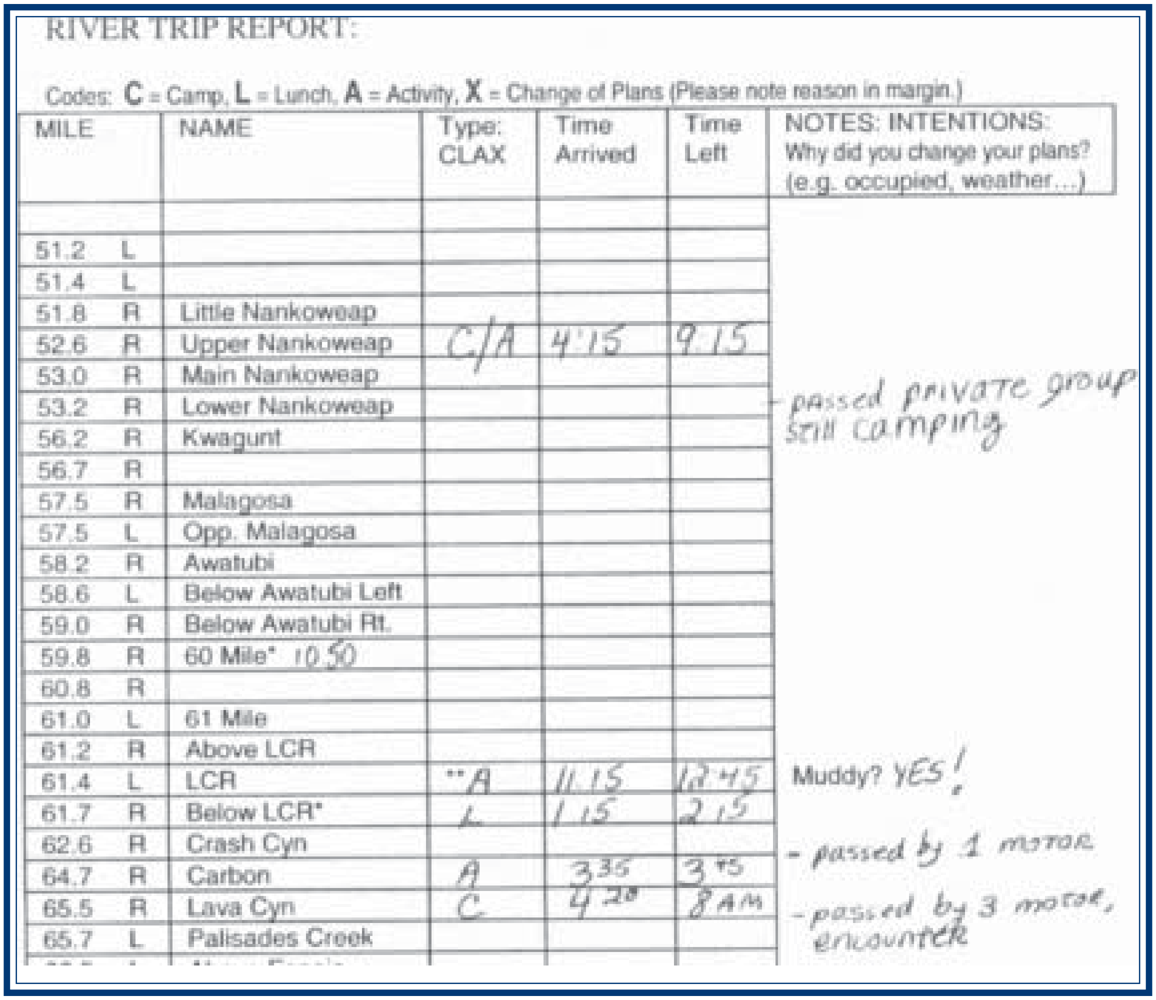
In 1998 and 1999, hundreds of trip leaders from private and commercial trips were asked to complete trip reports (fig. 9). These trip reports asked the trip leader to record the time in and time out for every reasonable day or overnight stop for some 250 designated sites between the launching spot at Lees Ferry and Diamond Creek. Other information collected to characterize the trips included: (1) river flow rates during the trip, (2) type and size of craft, and whether oar or motor power, (3) number of passengers on the craft, (4) experience of the guide, (5) number of encounters with other parties, and (6) planned or actual time allocated to specific sightseeing, rest, and camping stops during the trip.

Approximately 500 trip diaries were collected, representing about a 50 percent return rate for the commercial trips and a 30 percent return rate for the private trips. The trip diaries represent trips of all lengths and propulsion types (motorized, non-motorized). Itineraries were created from each of the diaries returned. The trip itineraries were subsequently used to simulate individual trips moving down the river, stopping at and starting from designated sites.

In addition, 15 river guides were interviewed. These guides collectively represented many years of experience running the Colorado River either non-commercially (privately) or as guides for commercial outfitters. They had experience at various river flows and with all types of watercraft (oars, paddle boats, dories, and motor boats). The intent of the interviews was to learn as much as possible about the logic employed by a river guide when taking a trip down the Colorado River. Questions were open-ended. For example, to understand how a guide might choose a campsite we asked questions such as, “when do you start thinking about camping for the evening?”, “what campsites do you like and why?”, “which campsites do you try to avoid and why?”, and “what factors go into the process of choosing a campsite, and explain why each factor is important?” These insights were used to create a list of possible reasons regarding whether or not a campsite was likely to be selected.

Site Characteristics

Data for the Colorado River were entered into a Geographic Information System (GIS) and used to construct a network for water travel on the river. The network included launch and take out sites, major



RIVER TRIP REPORT:

Codes: **C** = Camp, **L** = Lunch, **A** = Activity, **X** = Change of Plans (Please note reason in margin.)

MILE		NAME	Type: CLAX	Time Arrived	Time Left	NOTES: INTENTIONS: Why did you change your plans? (e.g. occupied, weather…)
51.2	L					
51.4	L					
51.8	R	Little Nankoweap				
52.6	R	Upper Nankoweap	C/A	4:15	9:15	
53.0	R	Main Nankoweap				
53.2	R	Lower Nankoweap				- passed private group still camping
56.2	R	Kwagunt				
56.7	R					
57.5	R	Malagosa				
57.5	L	Opp. Malagosa				
58.2	R	Awatubi				
58.6	L	Below Awatubi Left				
59.0	R	Below Awatubi Rt.				
59.8	R	60 Mile* 10:50				
60.8	R					
61.0	L	61 Mile				
61.2	R	Above LCR				
61.4	L	LCR	**A	11:15	12:45	Muddy? YES!
61.7	R	Below LCR*	L	1:15	2:15	
62.6	R	Crash Cyn				- passed by 1 motor
64.7	R	Carbon	A	3:35	3:45	
65.5	R	Lava Cyn	C	4:20	8 AM	- passed by 3 motor, encounter
65.7	L	Palisades Creek				

Figure 9—A portion of the trip diary used to collect spatial and temporal trip information.

rapids, and attraction sites. In addition, data on over 200 beach sites, obtained from the Grand Canyon National Park, were included. Beach site data included information on beach size at high water, estimated campsite capacity, and location by river mile and right or left side of the river.

Modeling Characteristics

The Grand Canyon River Trip Simulator (GCRTS) used a trace and terminating simulation approach (Daniel and Gimblett 2000) (refer to chapter 3 for more detail). Central to the trip planning behavior of a recreation agent is the typical trip. The concept of a typical trip is based on the premise that visitors have common patterns of use. A typical trip has a global trip plan, which specifies an intended list of destinations the agent wishes to visit in a given sequence, and durations. A global trip plan consists of a total trip duration, an entry node, an arrival time, an exit node, and a sequence of intermediate nodes (destinations) between the entry and exit nodes. Each destination node has a visit duration.

While this is a trace simulation, there is minimal decisionmaking the agents must do when confronted with certain situations on the river. While their trip plan specifies that they are to travel to a specific campsite, that campsite might be full that night. In this case, the agent might choose to move to the next unoccupied site. The simulation uses elements of fuzzy logic in the decision structure to weigh factors or variables to provide the agent with some autonomy in adaptive decisionmaking. For example, when the agent is choosing a campsite, the current conditions of the river and the individual trip play a role, as does the historical popularity of a campsite under consideration. This fuzzy logic approach takes into account all these factors and weighs them appropriately so that each agent's campsite decision represents a reasonable outcome for that given, particular set of circumstances.

On execution, the simulation engine reads in a launch schedule (either the current launch schedule or a prospective calendar created by the user), then it creates and launches the trips from Lees Ferry. These simulated trips execute their days on the river by choosing attraction sites for hikes or other activities, by stopping for lunch, and by selecting an appropriate campsite each night. Certain trips must be at given locations on certain times (for example, some trips exchange passengers at Phantom Ranch). The trips are managed by the simulator to meet these fixed points as scheduled. Moreover, a planning algorithm helps each simulated trip plan out an optimal schedule that will, for example, include stops at the key attraction sites and ensure that campsite selections are appropriate. A record is kept for each simulated trip—where and when it encounters other trips, where it chooses to engage in an activity or to stop to camp, how long it stays, and so on. A large set of information for each trip is collected and stored in a database for processing.

Simulation Outputs

Figure 10 shows the popularity of selected attraction sites along the river with commercial groups. Similar outputs can be produced for noncommercial groups, as well as for campsites along the river. None of the sites along the river are used more than 60 nights during the primary use season.

To explore how different management options might affect crowding levels, a scenario was developed to test how changes in the launch schedule would affect the distribution of visitors and number of contacts along the Colorado River. Current management policy directive states that during the primary use season there should be an 80 percent probability that a party will make contact with seven parties or less per day. There should be an 80 percent probability that contacts will not exceed 90 minutes per day and 125 people per day. A baseline simulation was run using the data collected on river trips launching between July 1, 1998, and August 31, 1998 (peak season), and tested against a second simulation where launch restrictions were imposed on the trips. All original trips that launched before noon were randomly assigned a time before 10:00 a.m. and all trips that previously had launched after 12:00 were randomly assigned a launch time after 2:00 p.m. We wanted to test whether this fixed launch schedule would more evenly disperse trips along the river, leading to an increase in the percentage of trips that met management objectives for contacts.

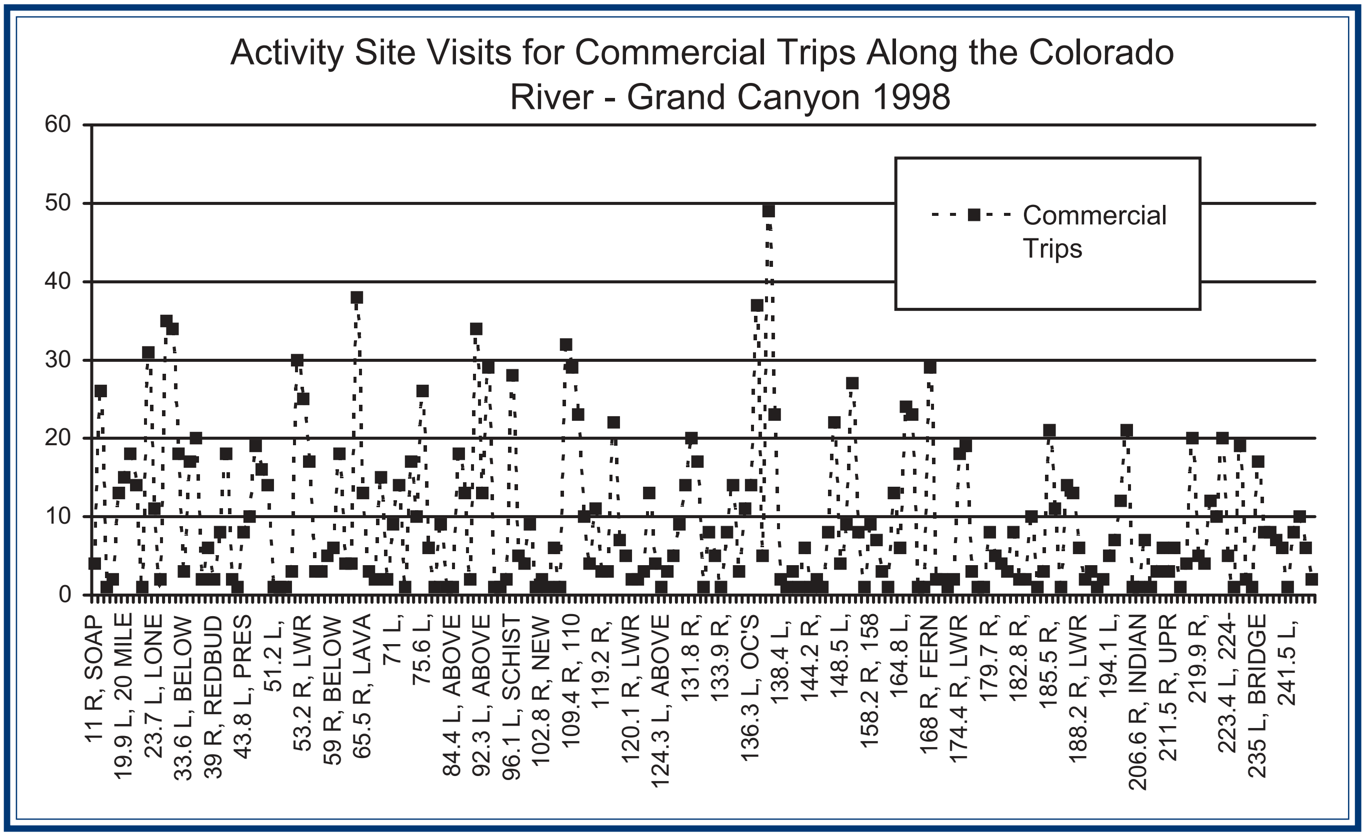


Figure 10—Number of commercial trips per year that stop at selected sites along the Colorado River.

Of the trips launched between July 1, 1998, and August 31, 1998, only 9 percent actually met the management objective of coming into contact with seven or fewer parties, and 14 percent of those trips exceeded the maximum duration of contact. Altering the launch schedule to impose restrictions after early morning and not allowing departures until early afternoon on a daily basis during the same time period did improve the situation: 24 percent of trips met the management objective of coming into contact with seven or fewer parties, with only 8 percent of those trips exceeding the maximum duration of contact. Comparing the two simulations illustrates that, by imposing restrictions on launch times, managers can increase the number of trips that meet management objectives.

Figure 11 shows the total number of river contacts by river mile for both simulation runs for the period July 1, 1998, through August 31, 1998. This provides the manager with an estimate of the total number of the contacts and where those contacts occur. Imposing launch restrictions reduces the total number of contacts along the river. At miles 34, 58.6, and 160, imposing launch restrictions reduces the number of river contacts by nearly half. Imposing launch restrictions has a surprising effect on river contacts in the middle section of the river, but has little effect towards the end of the trip.

More work still needs to be done to calibrate and validate the model. However, as this case study suggests, trace, fixed itinerary, terminating simulations as described in this paper, can provide useful information for park managers on the spatial and dynamic distribution of river trips. Simulating baseline conditions and comparing them to simulated scenarios can provide ways to test and derive more meaningful management objectives and standards for visitor contacts and capacity. Altering launch schedules, discontinuing exchanges, and limiting use at camp and activity sites are all conscious management actions, one of which has been shown here to significantly reduce numbers of contacts.

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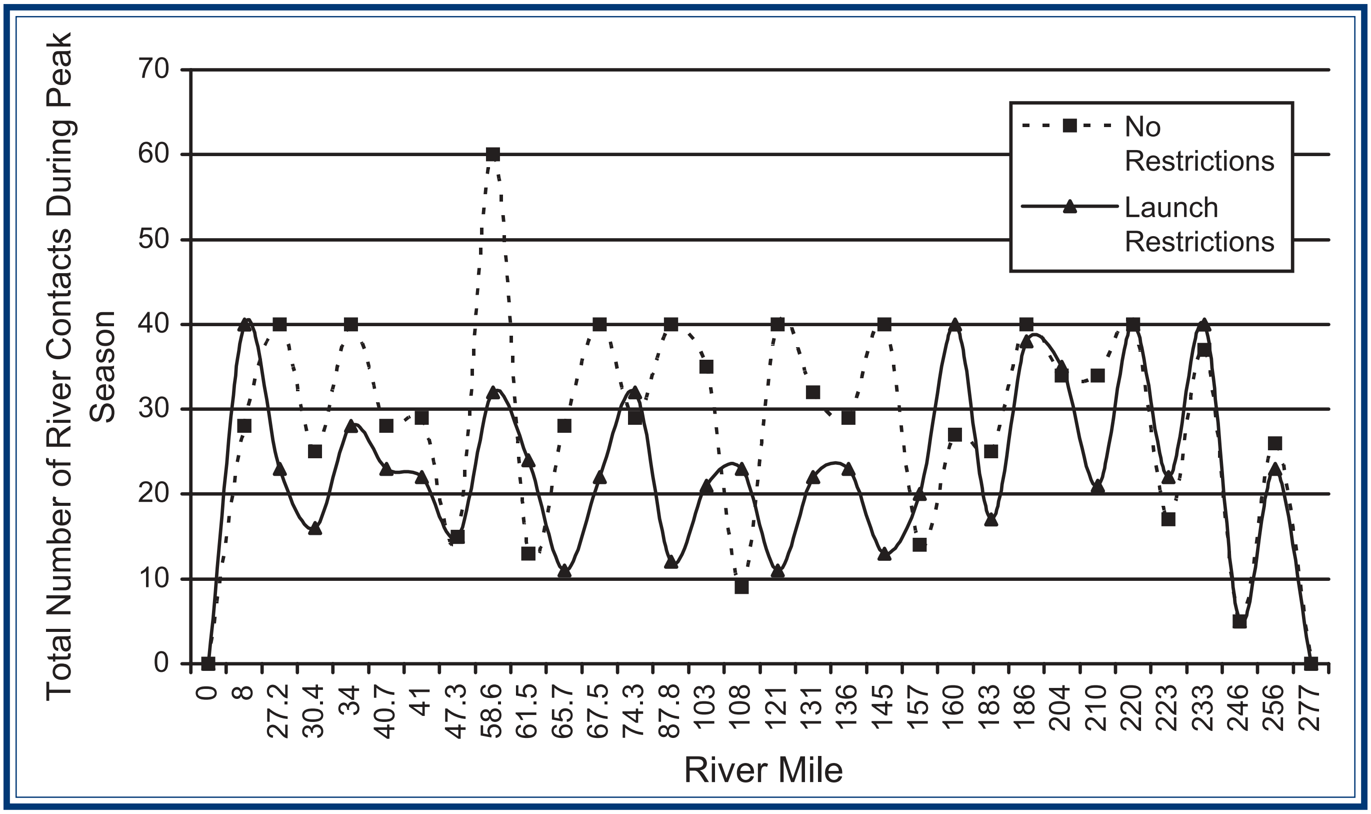

Figure 11—Number of contacts per river mile for scenarios with and without launch restrictions.

John Muir Wilderness: Describing the Spatial Distribution of Backpacking Use on a System of Trails and Campsites

Steven R. Lawson
Robert M. Itami
Randy Gimblett
Robert E. Manning

Purpose

This case study demonstrates the utility of a computer simulation model in describing the spatial distribution of visitor use and encounters between groups in a dispersed recreation setting. A simulation model of backcountry hiking and camping use was developed for a portion of the John Muir Wilderness in the Inyo National Forest, California (Lawson and others 2004). The John Muir Wilderness covers 235,000 ha in the Sierra Nevada Mountains. The area is characterized by snowcapped mountains with hundreds of lakes and streams and lush meadows. The simulation model estimated hiking and camping use and encounters by trail segment and camping location. Outputs from the simulation model were imported into a Geographic Information System (GIS) database and mapped. This case study should be considered exploratory and illustrative. There were weaknesses in the data collection phase that suggest results do not accurately represent current use distribution in the study area. For example, response rate to the visitor survey was low, and respondents were not necessarily representative of all visitors to the area. However, since these weaknesses can be easily corrected, the study illustrates the potential value of this tool.

Data Collection

Visitor Characteristics—During the 1999 visitor use season, diary-like questionnaires were distributed to backcountry visitors in a portion of the John Muir Wilderness. Questionnaires were distributed at trailhead self-registration stations and at ranger stations when visitors picked up their agency-issued permit. Randomly selected self-registration stations were periodically attended by data collectors who distributed diaries to visitor groups and collected completed questionnaires from groups as they finished their trips. In addition, questionnaires were distributed by commercial packstock outfitters, following instructions given by the research team.

The diary-like questionnaire included a series of questions concerning group and trip characteristics and a map of trails and natural features. Respondents were instructed to record their route of travel during their visit, including the trailhead(s) where they started and ended their trip, and their camping location on each night. Respondents were also asked to report the duration of their visit, the number of people in their party, and their mode of travel. The response rate was 32 percent, resulting in a total of 324 competed diaries. The low response rate is a primary reason we question the validity of model outputs for other than illustrative purposes.

Site Characteristics—Data on the trail network within the study area were provided by the Inyo National Forest as a GIS overlay. The data included all trail segments and intersections within the study area. These data were supplemented with information from a campground inventory completed in the summers of 1999 and 2000. Campsite “clusters” were created from the visitor surveys by grouping camping locations based on proximity and common access. A single campsite cluster was comprised of all reported camping locations that were within a subjectively determined reasonable distance of each other. The campsite clusters were used to determine camping encounters within the travel simulation model. Specifically, groups camping at locations within the same campsite cluster were considered to be within close enough proximity to be within sight and/or sound of each other.

Travel Simulation Model Design and Analysis

The travel simulation model was developed using the commercially available general-purpose simulation software, Extend, developed by Imagine That, Inc., and is a probabilistic, steady-state simulation (see Chapter 3 for information about probabilistic and steady-state simulations). Two simplifying assumptions worth noting were built into the model. First, only data for overnight hikers were included in the model; packstock trips and day trips were excluded. Second, the travel simulation model was only applied to a small portion of the larger study area. The section of the study area for which the model was developed is referred to as the Desolation Lake Locale (fig. 12).

The majority of visitor use occurs during the summer months. Therefore, the computer simulation model was designed to focus on the “peak” period of the visitor use season, July 1 through September 30, 1999. The simplifying assumptions described in the previous paragraph, coupled with the decision to focus on the summer months of the visitor use season, resulted in a total of 190 usable trip itineraries included as inputs into the travel simulation model.

Outputs—The simulation model was designed to generate four outputs concerning visitor use densities

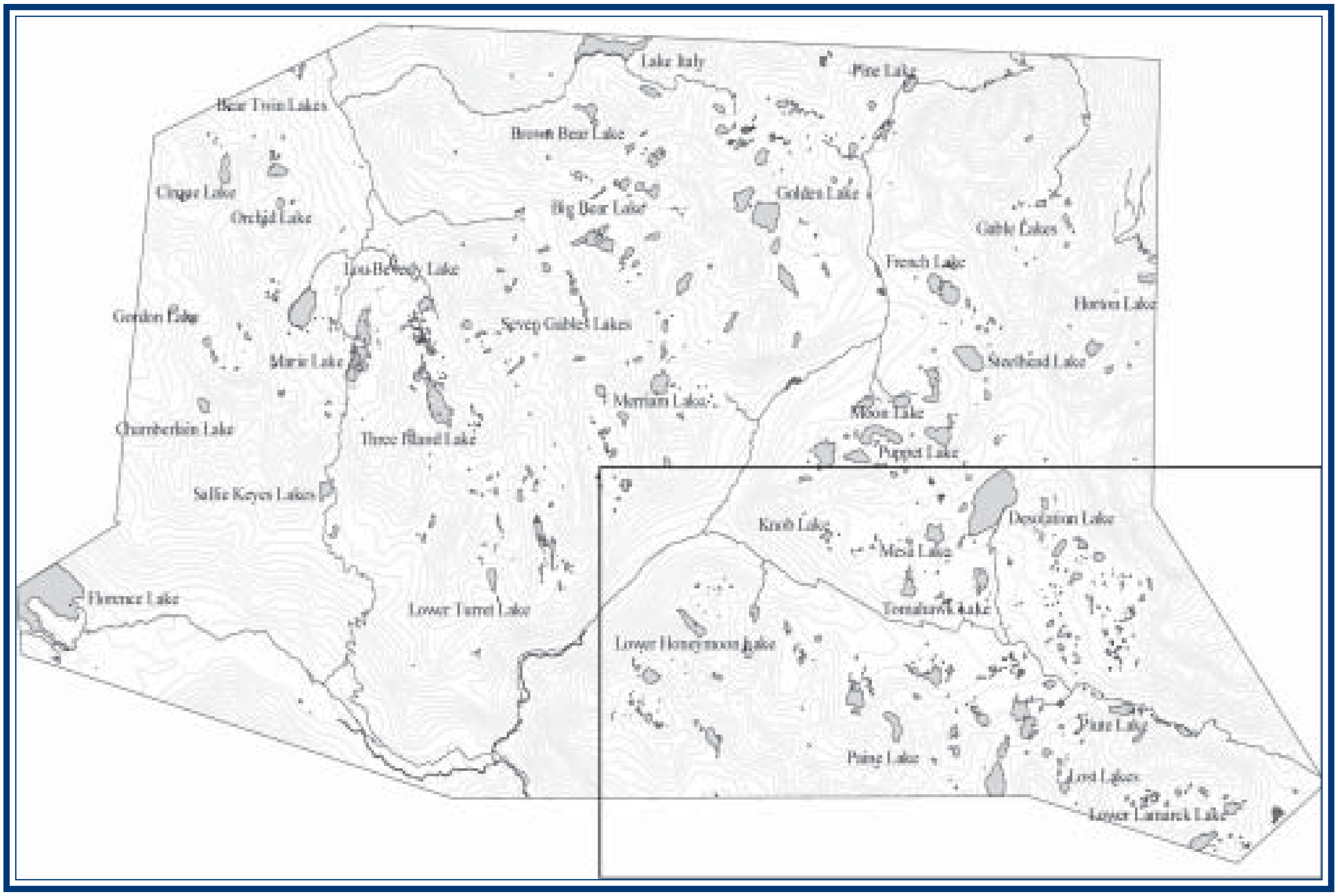

Figure 12—Larger study area, with the Desolation Lake locale inside the box.

and hiking and camping encounters. First, average hiking use per day is calculated for each trail segment by summing the number of groups that pass through each trail segment during the course of the simulation and dividing by the total number of days simulated.

Second, average hiking encounters per group per day are calculated for each trail segment on each day that at least one group passes along the trail segment. Two types of hiking encounters were calculated (Schechter and Lucas 1978). "Overtaking encounters" are defined as one group passing another group while traveling in the same direction along the trail while "Meeting encounters" are defined as two groups passing each other while traveling in opposite directions. The average number of hiking encounters per group per day is calculated for each trail segment by summing the total number of hiking encounters along the trail segment throughout the simulation and dividing by the total number of groups that hiked the trail segment during the simulation.

Third, average camping use per night is calculated for each campsite cluster by summing the number of groups that camp at the campsite cluster during the course of the simulation and dividing by the total number of nights simulated. Fourth, average camping encounters per group per night are calculated for each night that a campsite cluster is occupied by one or more parties. The number of camping encounters a group has on a given night is equal to the number of other groups camping in the same campsite cluster on the same simulated night. The average number of camping encounters per group per night is calculated for each campsite cluster by summing the total number of campsite encounters throughout the simulation and dividing by the total number of groups that camped at the campsite cluster during the simulation.

Baseline Simulation—The simulation reported here was designed to generate the outputs described above for baseline visitor use levels and existing management practices, where the baseline level of visitor use is assumed to be equal to the number of groups that completed the diary questionnaire during the sampling period. The reader is cautioned that only about one-third of the groups completed the questionnaires. Therefore, the outputs reported underestimate use substantially—perhaps by a factor of about three.

Model Verification—Several model verification techniques were conducted to ensure that the simulation model was implemented correctly. First, individual components of the simulation model were developed and debugged to ensure that they functioned properly. Modules for the campsite clusters, trail segments, trail junctions, and trailheads were developed and tested individually before being combined in the full model. Second, the authors conducted a structured "walk-through" of the simulation model to review the logic and operation of the simulation model. Third, Extend's built-in debugging functions were used to detect and correct data coding errors in the full model that resulted in incorrect routing of simulated trips. Fourth, Extend's animation function was used to visually verify that the model did not contain errors. Fifth, the trip itinerary data reported by respondents to the diary questionnaire were used as the basis for a quantitative verification technique. Specifically, the proportion of camping use for each campsite cluster was calculated for the diary trip itinerary data and compared to the proportion of camping use for each campsite cluster. This technique provided a method for comparing the output of the model with known analytical results (Schecter and Lucas 1978).

The most powerful technique for validating a computer simulation model is to compare model output data to data from the actual system the model is designed to replicate (Law and Kelton 2000). Due to a lack of data from the actual system (for example, hiking encounters per group and hiking use per trailhead in the area), this quantitative technique could not be used to assess the validity of the computer simulation model. However, validation techniques based on intuitive judgement were used to assess the content and face validity of the simulation model by examining the reasonableness of the inputs and outputs. Furthermore, sensitivity analyses were conducted to test whether the model outputs change in the expected direction in response to changes in selected input parameters (for example, total use).

Results

Table 3 reports mean camping use per night and mean camping encounters per group per night for each campsite cluster. The map in figure 13 portrays the spatial distribution of camping use within the study area. Table 4 reports mean hiking use per day and mean hiking encounters per group per day, by trail segment. The map in figure 14 portrays the spatial distribution of hiking use within the study area.

The results reported in table 5 suggest that the computer simulation model has been constructed correctly and that operating errors have been eliminated through the debugging and verification techniques described earlier in this paper. Specifically, as indicated in table 5, there is no substantive difference between the distribution of campsite cluster use reported in the diary survey and the simulated trips.

Table 3—Mean camping use and encounters, by campsite cluster.

Campsite clusters	Mean number of camping groups per night	Mean camping encounters per group per night
7	0.86	0.90
36	0.12	0.14
37	0.74	0.75
38	0.05	0.06
39	0.15	0.12
40	0.05	0.03
41	0.26	0.22
42	0.32	0.33
44	0.44	0.43
45	0.13	0.12
46	0.48	0.51
47	0.31	0.25
48	0.14	0.14
49	0.04	0.00
50	0.12	0.15
51	0.07	0.04
52	0.02	0.00
53	0.04	0.10
56	0.10	0.09
57	0.14	0.13
80	0.11	0.09
81	0.07	0.02

Due to the low response rate to the questionnaire, the content validity of the model, which is concerned with the reasonableness of the model inputs, is low. Furthermore, statistical comparisons of model outputs to actual system data are not possible due to a lack of "ground-truthing" data. However, results of a series of simulations conducted with the model support the internal and face validity of the model. Specifically, as the total simulated use of the study area is "ramped up," estimates of hiking and camping use and encounters increase or remain unchanged for all trail segments and campsite clusters, respectively.

Conclusions

This study illustrates the potential usefulness of computer-based simulation modeling in describing the spatial distribution of recreational use in backcountry and wilderness landscapes. Dispersed recreation in such areas is inherently difficult to observe directly. However, the study findings suggest that by collecting representative data by means of trailhead counts and a diary survey of a sample of visitor groups, it is possible to estimate levels and patterns of visitor use. The model can also estimate encounters between

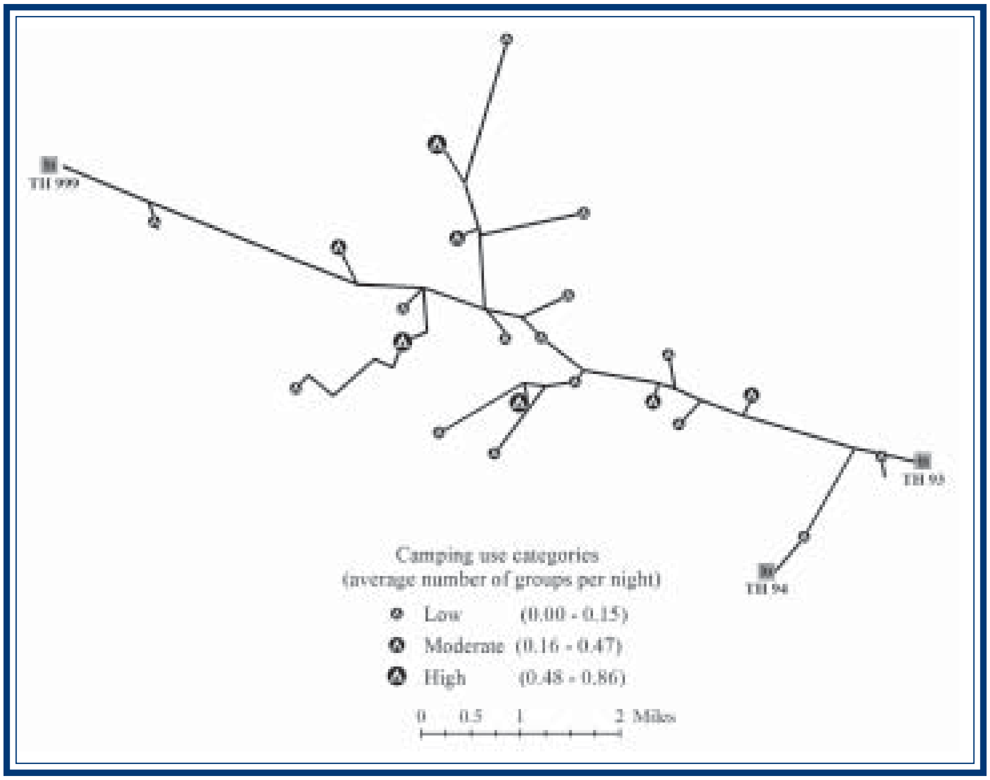

Figure 13—Use levels of campsite clusters in the Desolation Lake locale.

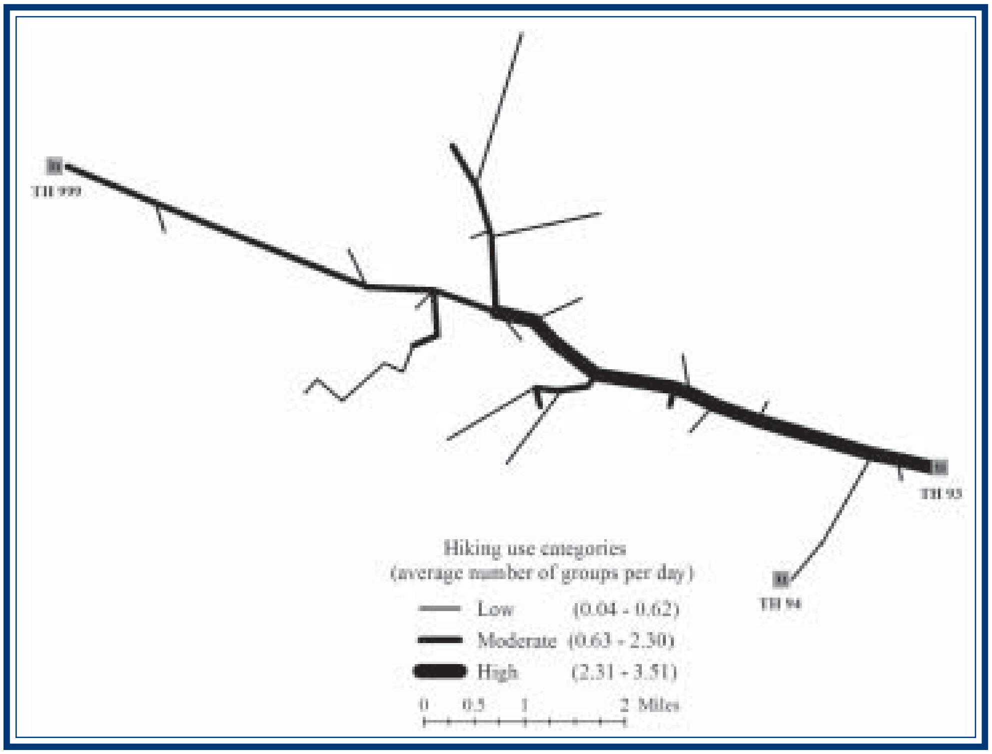

Figure 14—Use levels of trail segments in the Desolation Lake locale.

Table 4—Mean hiking use and encounters, by trail segment.

Campsite clusters	Mean number of hiking groups per day	Mean hiking encounters per group per day
2	3.51	0.20
3	0.08	0.00
4	3.51	0.11
5	3.43	0.34
6	0.58	0.03
7	0.14	0.03
8	0.04	0.00
9	3.35	0.11
10	3.28	0.10
11	3.20	0.05
12	0.12	0.00
13	0.20	0.01
14	0.80	0.04
15	2.95	0.20
16	1.10	0.02
17	2.47	0.11
18	2.41	0.05
19	0.15	0.01
20	0.99	0.01
21	0.90	0.03
22	0.77	0.06
23	0.09	0.00
24	0.13	0.01
25	2.31	0.07
26	0.15	0.02
27	1.08	0.06
28	0.15	0.01
29	0.45	0.02
30	1.29	0.01
31	0.68	0.03
32	0.63	0.05
33	0.04	0.00
34	1.87	0.09
35	0.07	0.00
36	1.43	0.08
37	0.29	0.02
38	0.88	0.06
39	1.29	0.21
40	0.22	0.01
41	1.25	0.07
132	0.06	0.00

Table 5—Percentage of total camping use in each cluster based on survey data and model output.

Campsite cluster	Survey data	Model output
7	0.18	0.18
36	0.02	0.02
37	0.16	0.16
38	0.01	0.01
39	0.03	0.03
40	0.01	0.01
41	0.05	0.05
42	0.07	0.08
44	0.09	0.10
45	0.04	0.03
46	0.10	0.10
47	0.06	0.06
48	0.03	0.03
49	0.01	0.01
50	0.03	0.02
51	0.01	0.01
52	0.00	0.00
53	0.01	0.01
56	0.02	0.02
57	0.03	0.03
80	0.02	0.02
81	0.01	0.01

groups, which is particularly difficult to monitor directly. This information can be used for several purposes, including monitoring indicator variables to ensure that standards are not violated, identifying potential bottlenecks or congested sites, scheduling maintenance and patrol activities, and educating visitors about the conditions they are likely to experience.

Finally, the results of this study demonstrate that, by integrating computer simulation and GIS technologies, it is possible to map existing recreational use patterns. This capability provides managers with a tool to communicate more effectively with the public regarding existing visitor use management issues. By importing computer simulation results into a GIS database, it is possible to conduct overlay analyses with resource data to examine relationships between natural resource characteristics (for example, resource fragility, resource impacts, and so forth) and existing visitor use patterns. Furthermore, integrating GIS and computer simulation technologies provides managers with a means to illustrate with maps the potential effect of alternative visitor use policy decisions and management practices on visitor use patterns and natural resources within a dispersed, backcountry setting.

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Frontcountry Trails and Attraction Sites in Yosemite National Park: Estimating the Maximum Use That Can Be Accommodated Without Violating Standards of Quality

Robert E. Manning
William A. Valliere
Benjamin Wang
Steven R. Lawson
Peter Newman

Purpose

Many park managers are concerned about overuse of trails and attraction sites resulting in low quality visitor experiences. Using contemporary planning frameworks, such as Limits of Acceptable Change and Visitor Experience and Resource Protection, they often formulate indicators and standards of quality. Indicators of quality are measurable, manageable variables that reflect the quality of the visitor experience. Standards of quality define the minimum acceptable conditions of indicator variables. Once indicators and standards of quality have been formulated, management actions can be implemented to ensure that standards of quality are maintained. Computer simulation modeling can be used to estimate the maximum level of visitor use that can be accommodated along trails and at attraction sites without violating crowding-related standards of quality. This case study provides an illustration of the utility of computer simulation modeling for this purpose at heavily used frontcountry trails and attraction sites in Yosemite National Park (Manning and others 2003).

Description of Study Area

Yosemite Valley is the scenic heart of Yosemite National Park, arguably the first National Park in the United States, and certainly one of America's best known and most popular National Parks. Yosemite Valley is a glacially carved area of approximately 20 km^2 and features sheer granite walls of up to 5,000 feet and several of the world's highest waterfalls. Yosemite National Park draws over 4 million visits annually, and carrying capacity has been a long-standing and controversial issue. Several specific visitor attraction sites were chosen for this study: the trail to Vernal Fall, Yosemite Falls (including the base of the falls and the trail leading to it), Bridalveil Fall (including the base of the fall and the trail leading to it), Glacier Point, and the trail to Mirror Lake.

Potential Standards

The Yosemite Valley project involved two phases. The first used a visitor survey to generate a range of potential standards for maximum people-at-one-time (PAOT) at attraction sites and persons-per-viewscape (PPV) along trails. Using computer-edited photographs illustrating a range of PAOT and PPV at study sites, respondents were asked about the level of use they (1) prefer, (2) consider acceptable, (3) consider so unacceptable they would no longer visit, and (4) think the National Park Service should allow (fig. 15). Mean responses for each of these four evaluative domains (denoted as preference, acceptability, tolerance, and management action, respectively) provide a range of potential standards from the perspective of current visitors. Reponses were compiled for visitors on four trail segments and at three popular viewpoints (table 6).

Computer Simulation Modeling

The second phase, the primary subject of this case study, involved using computer simulation to predict maximum use levels that could be sustained without violating these potential standards. For this purpose, detailed counts and observations of visitor use were collected at each of the seven study sites. Variables included length of trails, length of typical trail viewscapes (how far along the trail a hiker can typically see), number of visitors arriving per hour, visitor group size, length of time visitors stop at attractions, and the speed at which visitors hike trails.

Using the input data described above, simulation models were developed for each of the study sites. The models were built using the commercial simulation package, Extend, by Imagine That, Inc. Extend is an object-oriented, dynamic simulation package that has

Figure 15—Study photograph of the trail to Yosemite Falls, representative of moderate use levels.

Table 6—Alternative crowding-related standards of quality for all study sites.

Normative standard of quality	Trail to Vernal Fall (PPV)	Trail to Yosemite Falls (PPV)	Base of Yosemite Falls (PAOT)	Trail to Bridalveil Fall (PPV)	Base of Bridalveil Fall (PAOT)	Glacier Point (PAOT)	Trail to Mirror Lake (PPV)
Preference	11	18	43	7	8	19	10
Acceptability	26	40	92	18	20	42	24
Management action	30	46	100	20	19	49	26
Tolerance	39	60	126	26	25	61	34

been used extensively in business, manufacturing, and electronics applications to improve quality and efficiency. The object orientation makes code-writing unnecessary, and the programming algorithm can easily be expressed by the graphic display of objects and connections. For example, figure 16 shows the top layer of the simulation model developed for Glacier Point. The model was built with a series of "blocks" to represent components of this study site. The block labeled "Hiker Generator" in the top left section of the model is where simulated visitors are generated. Connected to it are groups of blocks that provide data concerning empirical visitor arrival rates and group sizes. (These data are derived from field observation.) The block "Total Use" allows the researcher to specify the daily total visit use level to be simulated. The simulated visitors then spend a randomly assigned length of time (based on field observations) at the "Viewing Area" block that represents the Glacier Point visitor attraction. The associated blocks (those underneath the Viewing area block) measure the number of people-at-one-time (PAOT) at the Glacier Point viewing area. The simulation models developed in this project were probabilistic (based on probabilities of simulated visitors selecting available travel itineraries) and were terminating (they modeled an entire day).

Model output could be generated in several graphic and numerical forms. For example, figure 17 traces minute-by-minute PPV levels along the trail to Bridalveil Fall over the duration of a day. This particular model run was generated using an average summer day total use level of 1,415 visitors (derived from the counts of visitor use taken to help construct the model). To predict the maximum total daily use level that could be accommodated at each study site and each evaluative domain (preference, acceptability,

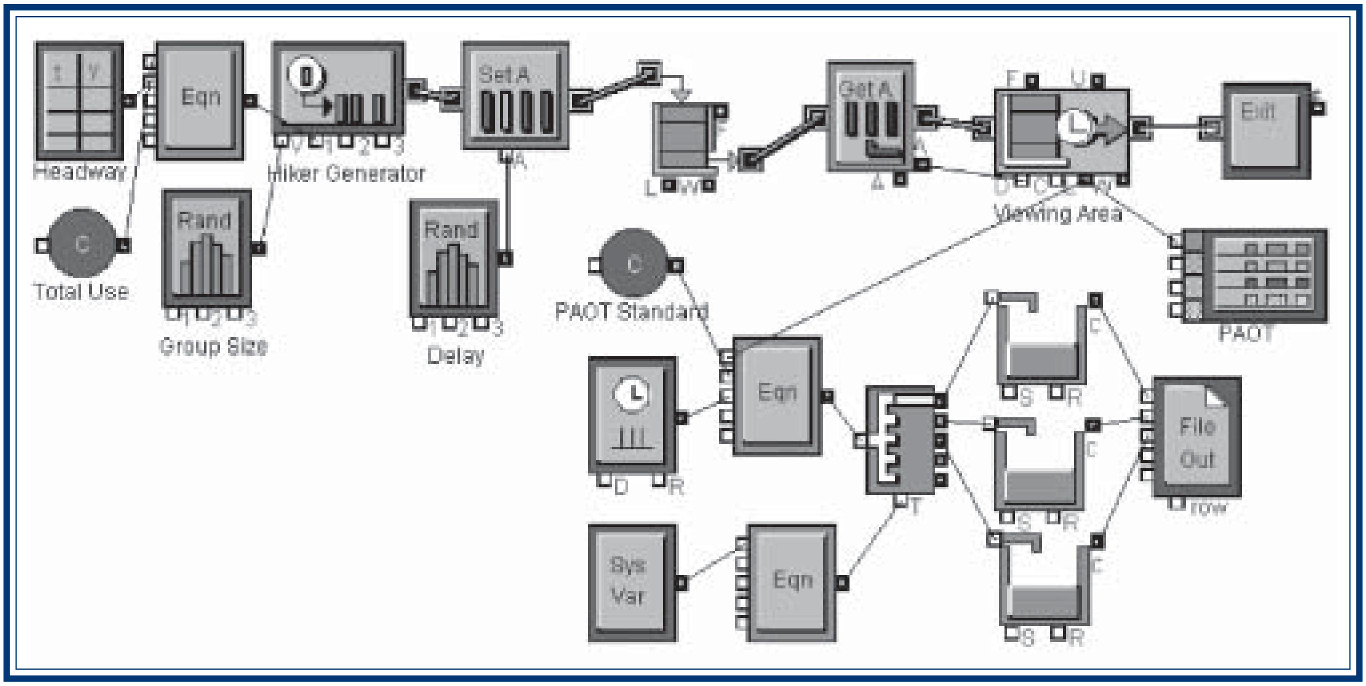

Figure 16—Schematic diagram of computer simulation model of Glacier Point.

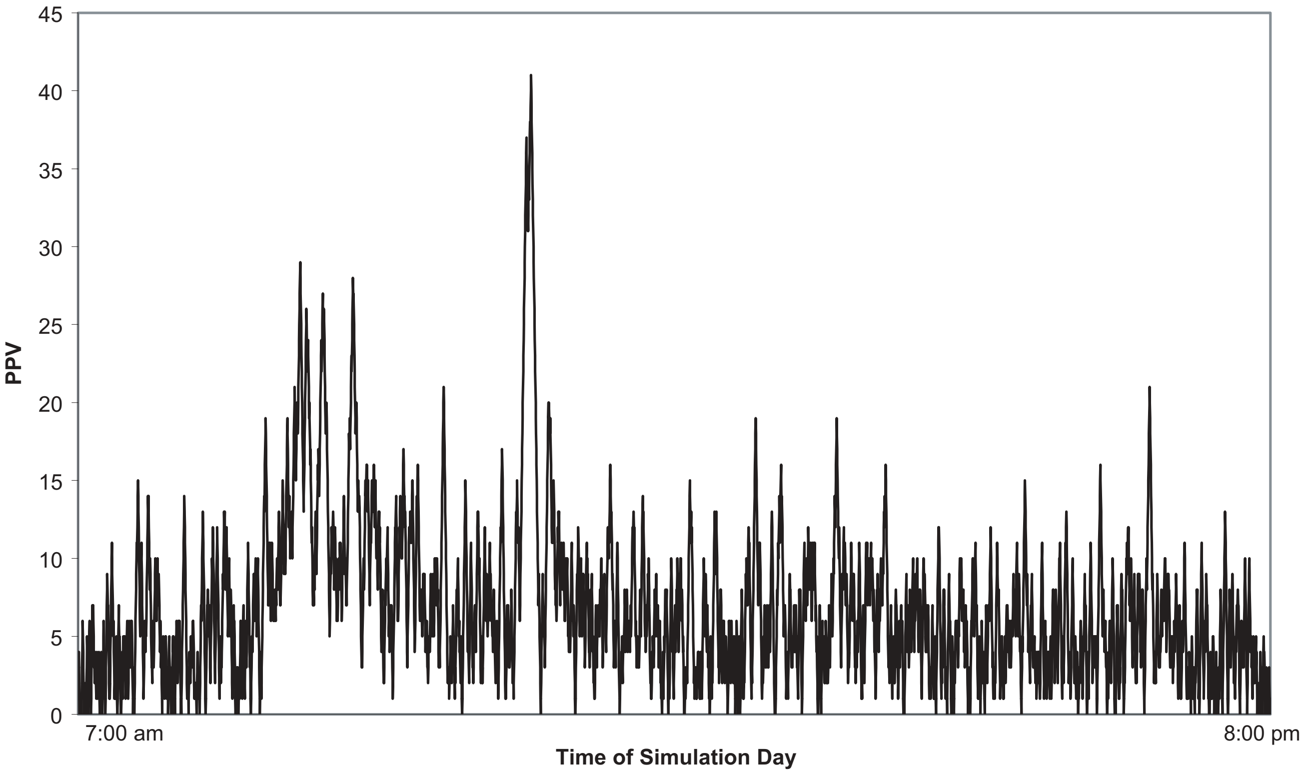

Figure 17—Person-per-viewscape (PPV) along the trail to Bridalveil Fall.

management action, and tolerance), models were run multiple times. If standards were violated, models were rerun at successively lower use levels until standards were no longer violated. In addition, all models were run multiple times to "average out" the randomness associated with each individual model run. The range of estimated daily maximum use levels for each study site and evaluative domain is shown in Table 7.

Conclusion

This project illustrates the utility of computer simulation modeling related to planning and management of trails and attraction sites in the front country of parks. Specifically, it illustrates an important application of modeling for estimating the maximum use levels that can be sustained without violating standards related to crowding. Planners can use this information to evaluate the consequences of deciding among alternative standards. Such predictions can also be linked to transportation planning. For example, once standards are selected, a visitor transit system could be designed for Yosemite Valley to deliver the "right" number of visitors to the "right" places at the "right" intervals.

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Table 7—Range of daily maximum use levels at all study sites[a].

Normative standard	Trail to Vernal Fall	Trail to Yosemite Falls	Base of Yosemite Falls	Trail to Bridalveil Fall	Base of Bridalveil Fall	Glacier Point	Trail to Mirror Lake
Preference	2,100	4,500	3,000	1,200	700	1,500	1,800
Acceptability	6,000	9,500	5,500	3,200	1,700	4,000	5,000
Management action	7,000	11,000	5,900	3,500	1,700	4,800	5,500
Tolerance	9,300	13,000	7,300	4,800	2,300	6,300	7,700

[a] Daily maximum use levels were calculated to allow standards to be exceeded a maximum of 10 percent of the time.

Alcatraz Island: Estimating the Maximum Use That Can Be Accommodated Without Violating Standards of Quality

William A. Valliere
Robert E. Manning
Benjamin Wang

Purpose

The purpose of this case study is to illustrate how a computer simulation model can be used to estimate the maximum number of people that can visit Alcatraz Island without violating crowding-related standards of quality for the cellhouse on the Island (Manning and others 2002). The model acts as a translator that takes simple inputs (such as the number of visitors per ferry boat servicing the island and the frequency of boat arrivals) and estimates the persons-at-one-time (PAOT) on Michigan Avenue (as representative of the whole cellhouse). This approach provides an efficient and economical way of monitoring an indicator of quality to measure against standards of quality.

Description of Study Area

Alcatraz Island is an historic site within Golden Gate National Recreation Area, a unit of the USDI National Park System, and is a heavily visited tourist attraction. The island, located in San Francisco Bay, is widely known for its history as a Federal prison for incorrigible criminals. This history has been romanticized and popularized in several books and movies; consequently, the demand to visit Alcatraz is high. Visitation now exceeds several hundred thousand annually, and continues to grow rapidly.

Data Collection Procedures

Data collection consisted of two phases. During the first phase, visitors were asked questions regarding the acceptability of different levels of use in the cell house (fig. 18). Using computer-edited photographs, respondents were asked about the level of use they (1) prefer, (2) consider acceptable, and (3) think the National Park Service should allow. Mean responses for each of these three evaluative domains (denoted as preference, acceptability, and management action, respectively) were 25, 44, and 44 persons-at-one-time (POT). These values provide a range of potential standards from the perspective of current visitors.

Data collection for the second component of the research consisted of gathering the information necessary to construct the computer simulation model. Inputs gathered to build the basic model included current numbers of visitors per ferry boat, current boat schedule, the lengths of time between debarkation and arrival into the cellhouse audio tour ticket line, and the length of time that visitors take to go through the audio tour. Boat schedules and the number of visitors per boat were easily obtained from Park records. The time between debarking and arrival at the audio tour and the time it takes visitors to finish the audio tour were determined by research staff over a 3-day period in October 1998. On October 27 through 29, three researchers stationed at the dock and various points in the cellhouse handed time assessment cards to randomly selected visitors. The researchers recorded on the cards the times of the day when the visitors arrived and departed from selected places. A total of 179 time assessment cards were collected during the 3-day period.

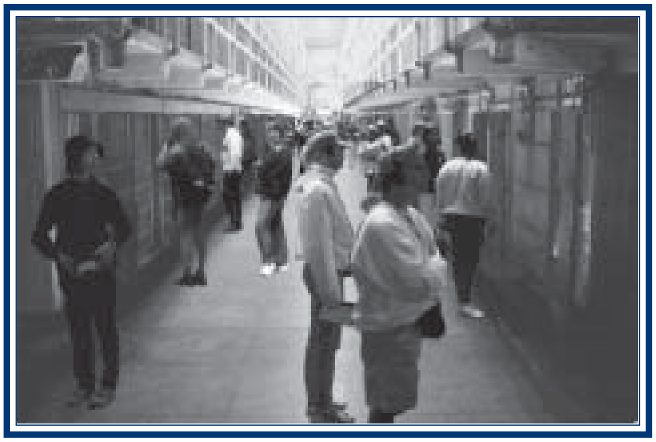

Figure 18—Study photograph of Michigan Avenue in the prison cellhouse, representative of a moderate use level.

Model Characteristics

The software package selected for the simulation was Extend by Imagine That, Inc. Figure 19 is the top layer of the model, and is what a researcher or manager would encounter after opening the model. The prison cellhouse model was built with “blocks” that represented specific components of the Alcatraz Island visitor system. The block labeled “Dock” in the top-left section of the model is where debarking simulated visitors are created. Double clicking on it would reveal an interface that allows the researcher or manager to specify the boat schedules and boat loads to be simulated. The block labeled “Up the Hill” represents the areas where the visitors are between the time they debark and the time that they line up for the audio tour. The amount of time that the simulated visitors are delayed here was determined by the 3 days of

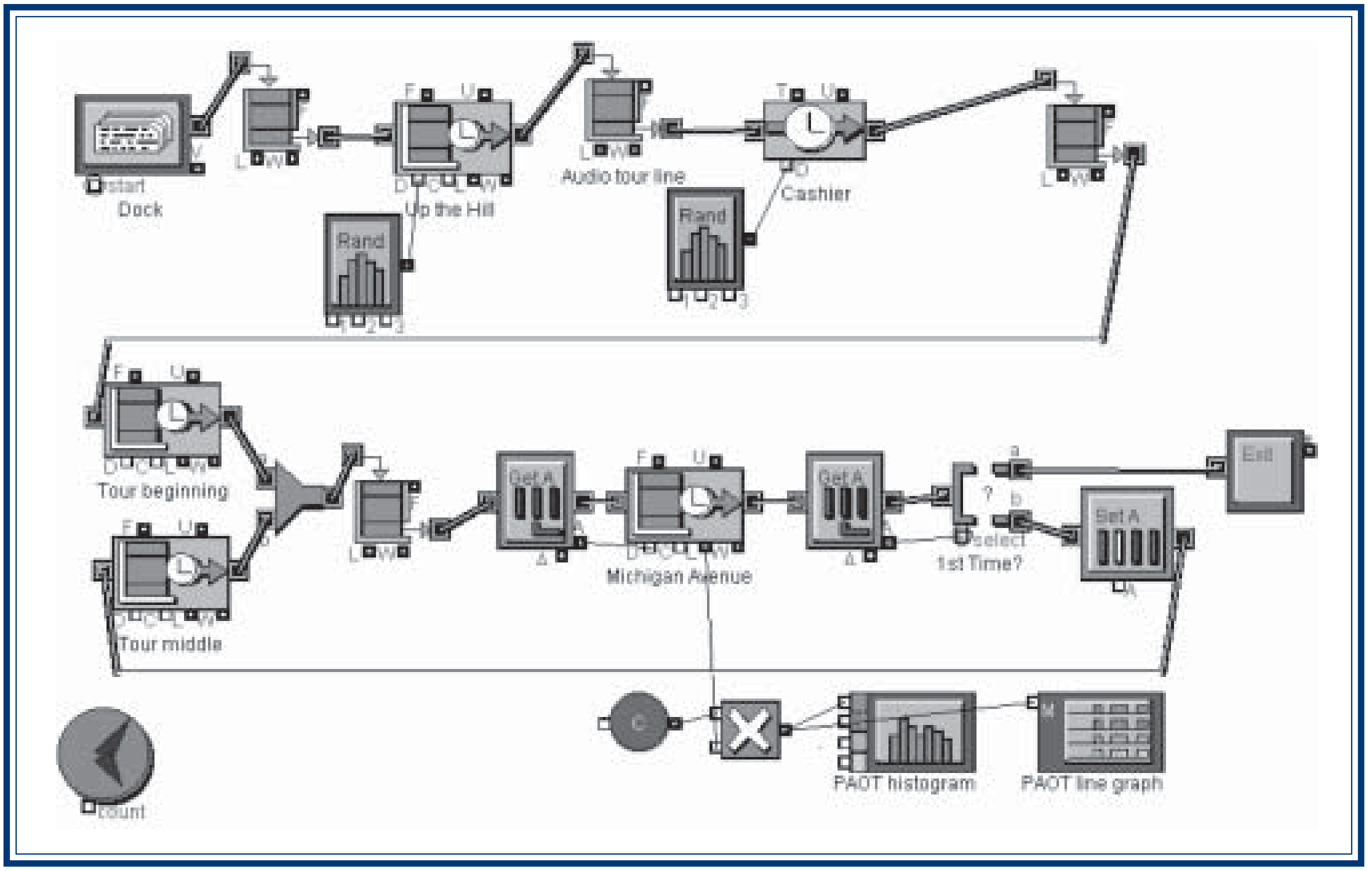

Figure 19—The Alcatraz cell house visitor research model.

empirical time assessment exercises described above. The average time taken was 32 minutes, with a standard deviation of 19 minutes. The blocks labeled “Audio tour line” and “Cashier” simulate the queue that visitors wait in to pay for their audio tours.

The next series of blocks simulate portions of the audio tour in the cell house. Each simulated visitor travels through the blocks labeled “Tour beginning,” “Tour middle,” and “Michigan Ave.” Both the audio tour program and the estimated time that visitors paused the cassette during their tour determine the amount of time visitors take to move through the system. The length of time that visitors took to travel through the entire system was measured during the 3 days of time assessments. The average time taken was 44 minutes with 13 minutes standard deviation. When compared with the cassette running time of approximately 35 minutes, these results indicate that visitors frequently pause their cassette players during the tour. The ratio between these times was used to estimate that the total time each visitor spent out in the open on Michigan Avenue was about 5.4 minutes.

Model Outputs

A typical simulation model run with current summer boatloads and schedule yields a line graph showing the numbers of simulated visitors on Michigan Avenue through an entire simulated day (fig. 20). Figure 20 shows that PAOT on Michigan Avenue at any one time can fluctuate substantially, anywhere from about 50 people to about 90 people. Figure 21 provides a different look at this fluctuation in the form of a histogram. Each bar represents a range of PAOT conditions on Michigan Avenue through the same simulated day.

The average condition on Michigan Avenue during 10 computer runs was about 70 PAOT. The model estimates that visitors encounter more than 70 PAOT for about 44 percent of their tour time. They encountered more than 80 PAOT for about 15 percent of the time and more than 90 PAOT for about 3 percent of the time.

The model was run multiple times (to “average out” the randomness associated with each individual model run) to estimate the maximum total daily use levels that could be accommodated on the Island without violating each of the potential crowding-related standards more than 10 percent of the time (table 8). For

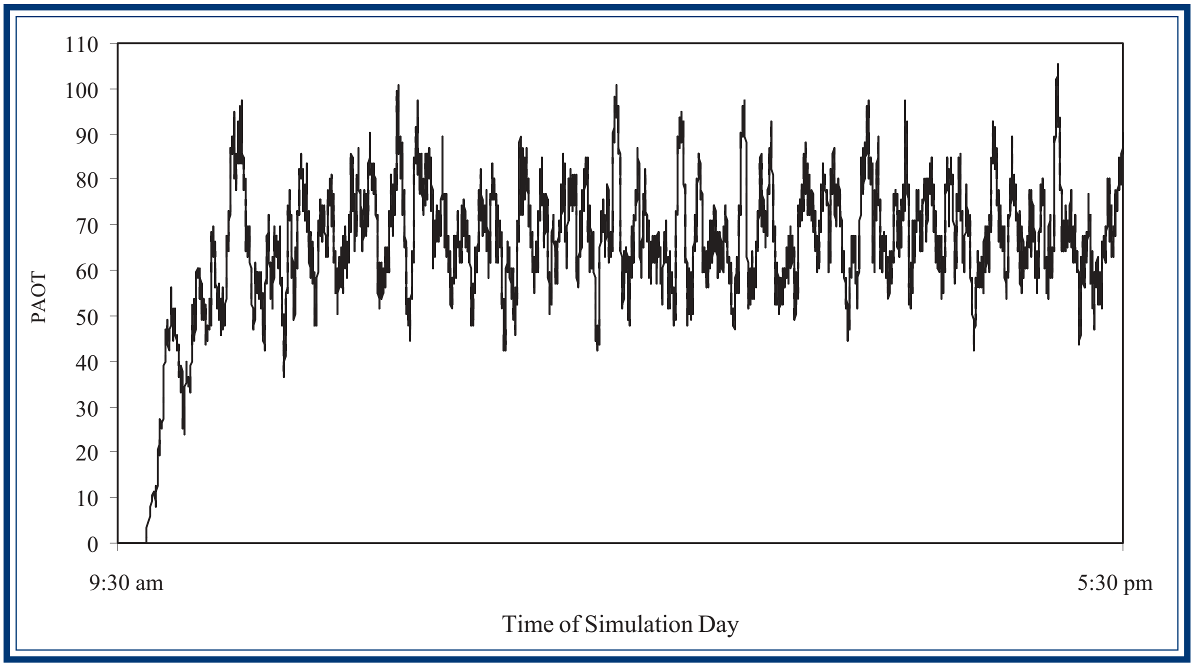

Figure 20—People-at-one-time (PAOT) in Michigan Avenue over the minutes of a simulated day.

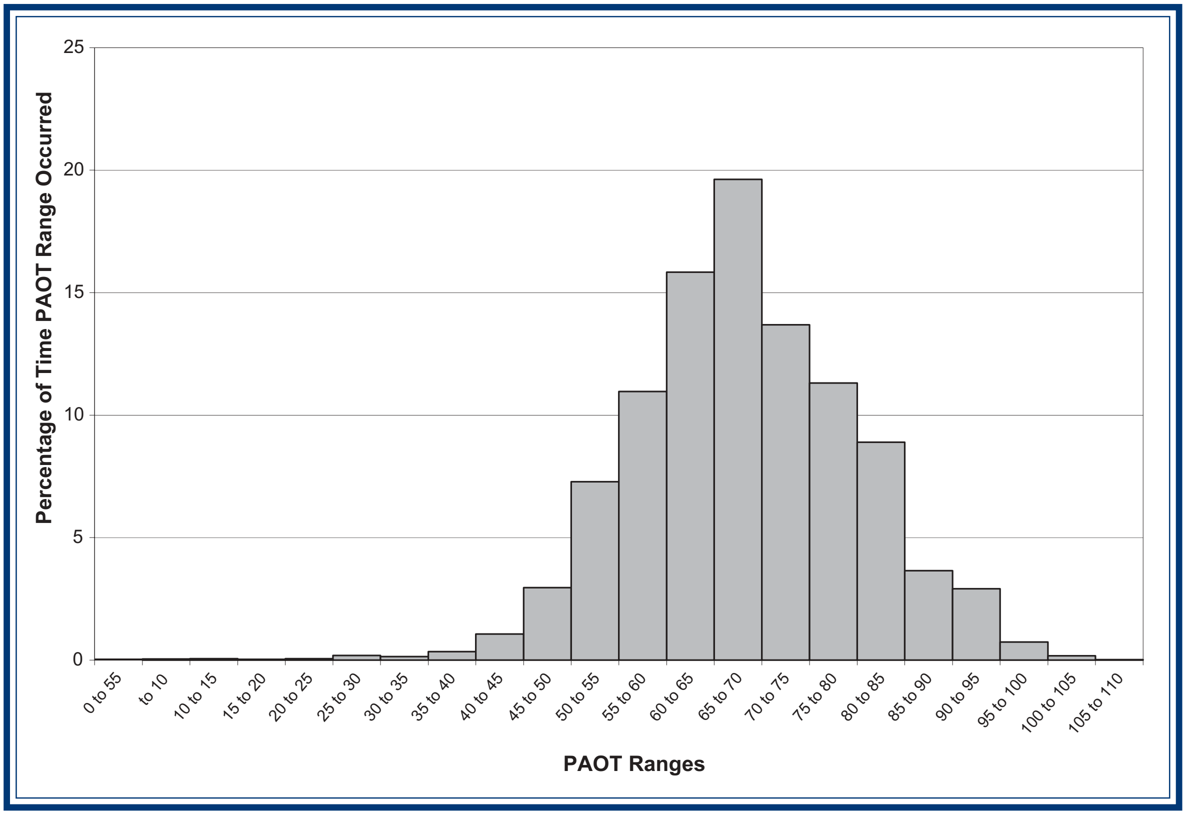

Figure 21—Simulated people-at-one-time (PAOT) conditions on Michigan Avenue.

Table 8—Alternative daily maximum use levels at Alcatraz Island.

Standards of quality	Maximum daily use level
Preference (25 PAOT)	2,560
Acceptability (44 PAOT)	4,800
Management action (44 PAOT)	4,800

this range of potential standards, maximum allowable use on Alcatraz Island could range between approximately 2,500 and 4,800 visitors per day. A daily use limit for Alcatraz Island could be implemented relatively easily through management of the ferry system serving the Island.

A final analytical approach used in this study employed the computer simulation model of visitor use to explore the effect of alternative ferry schedules. Currently, ferries depart San Francisco for Alcatraz Island every half hour from 9:30 a.m. to 5:30 p.m. If ferry departures were reduced to every hour, maximum allowable use would also be substantially reduced. Relatively large numbers of visitors arriving at the same time, however, would result in many visitors seeing relatively large PAOT in Michigan Avenue.

For example, with the current ferry schedule, approximately 4,800 visitors per day can be accommodated on Alcatraz Island without exceeding 44 PAOT more than 10 percent of the time (table 8). However, if ferries were to depart only every hour, the computer simulation model estimates that only 3,200 visitors per day could be accommodated without exceeding 44 PAOT more than 10 percent of the time. Increasing the frequency of ferry service would not increase maximum allowable use levels substantially. For example, increasing the frequency of departures to every 15 minutes would increase the maximum use level that would not exceed 44 PAOT more than 10 percent of the time from approximately 4,800 visitors per day (under existing ferry service) to approximately 4,900 visitors per day.

Conclusions

This case study illustrated the utility of a computer simulation model in dealing with crowding-related issues in an urban park. Specifically, it provided a means of predicting maximum use levels that could be accommodated without violating specified standards. In addition, it provided insight into how varying public transportation schedules might influence maximum use levels.

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Arches National Park: Describing Visitor Use Patterns and Predicting the Effects of Alternative Transportation Systems

Steven R. Lawson
Robert E. Manning
William A. Valliere
Benjamin Wang

Purpose

The purpose of this case study is to illustrate how a computer simulation model can describe daily visitor use patterns and levels throughout Arches National Park’s road and trail network and at selected attraction sites. The simulation model provides managers with estimates of “minute-by-minute” vehicle traffic levels along all road segments and at all parking areas within the park on a “typical” peak season day, as well as the number of visitors along selected trail segments and at significant park attractions (for example, Delicate Arch). Further, the model is used to predict the likely effects of alternative transportation systems on crowding and congestion. Specifically, simulation was used to predict the effect of a mandatory shuttle bus system on the number of visitors that can be accommodated at Delicate Arch.

Arches National Park

Arches National Park is located in southeastern Utah, 8 km north of the town of Moab. The park is approximately 30,000 ha in size and is known for its unique sandstone features, including Delicate Arch, The Windows, and Devil's Garden. The predominant recreation uses of the park include hiking, photography, and scenic driving, and the majority of recreation use is concentrated along trails and at attraction sites adjacent to or near the park’s road network. Most visitors enter the park through an entrance gate at the southern end and access the interior via the park’s road system. Currently, there are no restrictions on the number of vehicles allowed to enter the park, and there is no required alternative transportation system. The park is undergoing an alternative transportation planning process, however, and a shuttle bus system is among the ideas being discussed by park staff and the public.

Data Collection Procedures

A variety of methods were employed to gather the data used to build the simulation model of visitor use. A traffic counter at the entrance to the park recorded the number of vehicles entering and the time each vehicle entered. These traffic data were collected during the 7-day period August 19 to 25, 1997. Total daily entries for these 7 days averaged 1,346 vehicles.

Data on visitor characteristics and travel patterns within Arches National Park were collected through a series of onsite surveys administered to 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. Respondents were 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 at least 5 minutes). 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 August 14 to 30, 1997, and to tour bus drivers on 42 days between July 9 and October 22, 1998. For safety concerns, 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 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 and at the Arch, and where and how long they paused during the hike (for at least of 5 minutes). These questionnaires were administered on 3 days during the period August 15 to 24, starting at 7:00 a.m. and ending at 10:00 p.m.

Hiking questionnaires were also 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, 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 July 18 to August 3, and 320 questionnaires were administered to hikers returning from their hikes in the Devil's Garden on 5 days during the period July 5 to August 6. Surveys in both locations started at 7:00 a.m. and ended 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 were sampled. For example, a greater number of sampling days was 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 2-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 4 days during the period from August 19 to 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.

Model Characteristics

Using the data inputs described above, a probabilistic, terminating simulation model of park use was developed (refer to Chapter 3 for more information about terminating and probabilistic simulation modeling). A terminating simulation has a known initial state (usually zero) and a known ending state, which is well suited for replicating a system's behavior over a discrete period of time, such as a single day. Since the primary use of the simulation model developed in this project was to describe recreation use patterns and levels on a "typical" peak-season day, terminating simulation was adopted.

Simulation Model Runs

Use Levels and Patterns—To estimate existing recreation use levels and patterns (vehicle and pedestrian), a series of runs was conducted to simulate current average "peak" daily use. Twelve replications of the current daily use simulation were conducted to account for stochastic variation of model inputs and outputs. As noted earlier, safety concerns prevented vehicle and tour bus travel route surveys from being administered after dark. Therefore, each run simulated a single day of park use from 5:00 a.m. to 4:00 p.m.

Effect of Alternative Transportation—Previous research has led to establishment of selected indicators and standards of quality for major attractions within Arches National Park (Manning and others 1995, 1996a,b; National Park Service 1995). 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. An initial set of simulations was conducted with the Arches computer simulation model to estimate the maximum number of visitors that can be allowed to hike to Delicate Arch before this standard of quality as violated (referred to in the remainder of this paper is maximum allowable use at Delicate Arch). Next, a series of simulations were conducted to predict whether implementing a mandatory shuttle bus system would increase the maximum allowable use of Delicate Arch and, if so, by how much.

To estimate maximum allowable use for Delicate Arch without a shuttle bus system, 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 (in other words, 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 percent 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 percent 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 percent of the time, the next set of 12 simulations was run at a higher level of visitor use.

A series of model runs was conducted to simulate the operation of a shuttle bus system designed to deliver visitors to the Delicate Arch parking lot 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 minutes. 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 allowable use of Delicate 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. Although 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 to believe that this would be more valid than assuming no change. Because the delivery schedule was fixed for each shuttle bus system considered, the simulations were deterministic (in other words, the results of multiple simulations of a given shuttle bus delivery schedule would always be the same).

Model Validation—A series of 48 model runs was conducted to validate the simulation model output. The number of vehicles entering the park was varied to match the number of vehicles entering the park on the 4 days that parking lot counts were conducted. The model runs were repeated 12 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.

Model Output

Use Levels and Patterns—Estimates of the number of people at one time (PAOT) at Delicate Arch throughout the hours of a “typical” peak season day are presented in figure 22. Estimates of the number of vehicles along a selected road segment and in the Delicate Arch parking lot throughout the hours of a “typical” peak season day are presented in Figures 23 and 24, respectively.

Alternative Transportation System—Without a mandatory shuttle bus system, 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 percent of the time. Results of simulation runs conducted to test the effect of implementing a mandatory shuttle bus system are reported in table 9. The data in the third and fourth columns suggest that the maximum allowable use of the Arch could be increased by 29 to 68 percent if visitors were required to ride shuttle buses to the Delicate Arch parking lot. For example, the model estimates that a shuttle bus system designed to deliver visitors to Delicate Arch every 60 minutes would increase the maximum allowable use 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 maximum allowable use of Delicate Arch to an even greater extent.

Model Validation—Table 10 presents validation results based on comparisons between actual parking lot counts and model estimates for three parking lots and parkwide. The fact that cars were only counted for 4 days precludes statistical comparison of observed and predicted counts. It is also not possible to assess the accuracy of model outputs, such as those in table 9. However, the relatively small difference in means for observed and predicted counts suggests that the model performed as expected.

Conclusion

This case study demonstrates how computer simulation modeling can be used to describe visitor use patterns and levels throughout a dispersed recreation area. The findings also illustrate the capability of simulation modeling to conduct a more comprehensive monitoring program than may be feasible by relying solely on on-the-ground monitoring techniques. Monitoring indicators such as PAOT by means of on-the-ground counts can be very time consuming and expensive. However, once a computer simulation model of visitor use has been developed, PAOT can be estimated relatively easily.

Figure 22—Model estimates of people at one time at Delicate Arch.

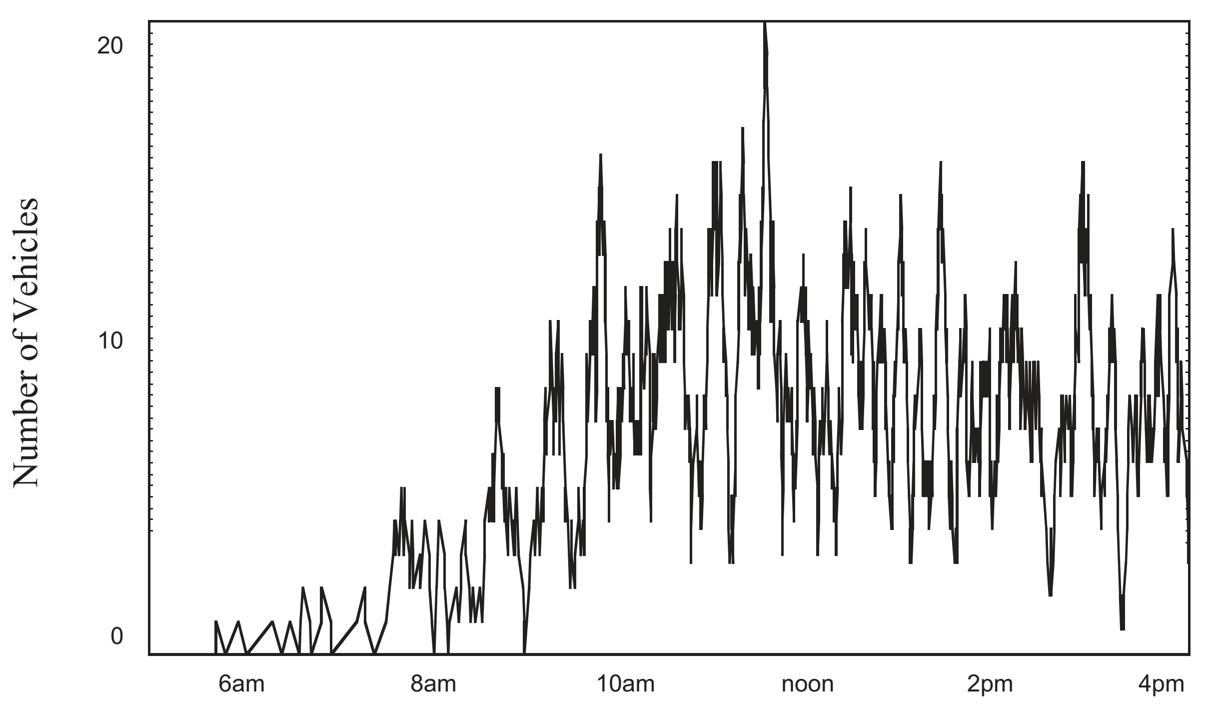

Figure 23—Model estimates of vehicles at one time on a 2.4 km segment of road.

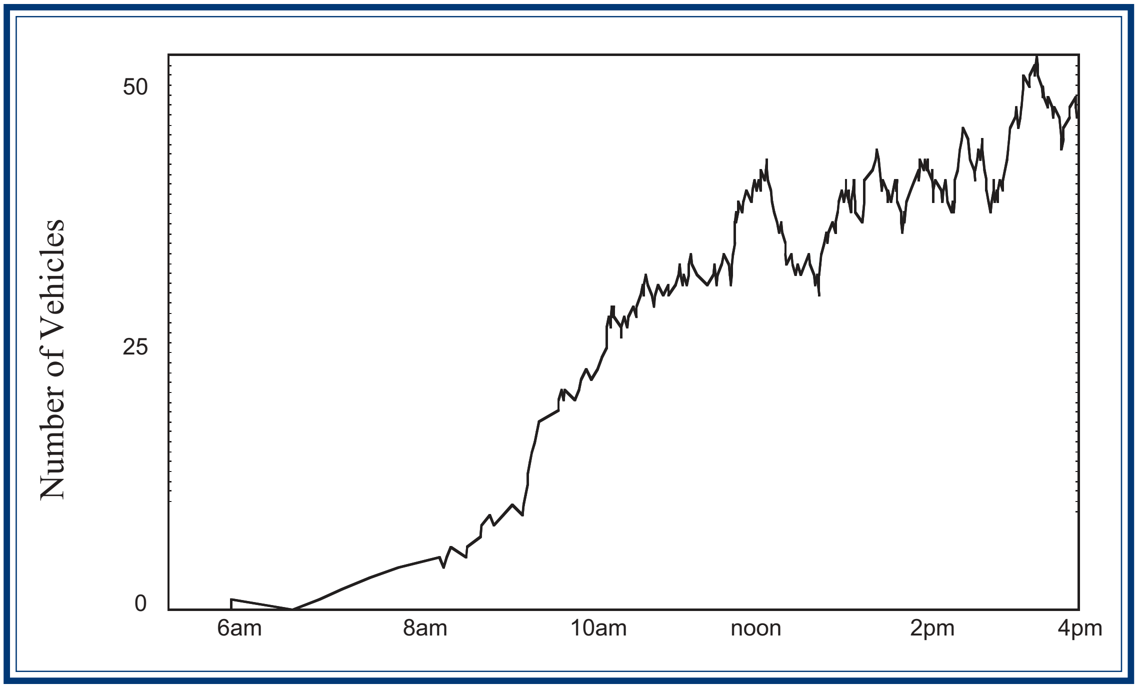

Figure 24—Vehicles at one time in the Delicate Arch parking lot.

Table 9—Estimated maximum allowable use of Delicate Arch with mandatory shuttle system.

Arrival interval (minutes)	Passengers	Estimated maximum daily use	Percent increase in allowable use
60	37	407	29
30	21	462	47
15	12	528	68

Table 10—Parking lot car counts—number observed and number predicted by the model.

	Observed	Model
Delicate Arch	29	25
The Windows	25	30
Devil's Garden	67	69
All parking lots	40	41

The findings from this project suggest that requiring visitors to ride a regularly scheduled shuttle bus to the Delicate Arch parking lot would increase the maximum allowable use of the Arch. More generally, this project demonstrates the capacity for computer simulation modeling to assist managers in assessing the effectiveness of alternative transportation systems in a manner that is more cost effective and less politically risky than on-the-ground trial-and-error approaches.

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Isle Royale National Park: Estimating the Effectiveness of Alternatives for Managing Crowding at Wilderness Campsites

Steven R. Lawson
Robert E. Manning
Ann Mayo Kiely

Purpose

The purpose of this case study is to demonstrate how a computer simulation model can be used to identify management actions that are effective in bringing conditions into compliance with standards. The study was conducted at Isle Royale National Park, located in the northwest corner of Lake Superior, approximately 120 km from Houghton, Michigan, and 30 km from Grand Portage, Minnesota (Lawson and Manning 2003a; Lawson and others 2003). Approximately 99 percent of the park's land base is designated wilderness. The park has a system of 36 campgrounds, with a total of 244 designated tent and shelter sites dispersed along lakeshores, and a network of 260 km of trails. Primary recreation activities at the park, which is open to visitors from mid-April until the end of October, include hiking, camping, and boating.

In recent years, recreation use of Isle Royale National Park has increased steadily. The park is particularly popular for backpacking and backcountry camping, and as a result, overnight backcountry use densities are among the highest in the National Park System (Farrell and Marion 1998). Isle Royale National Park's approach to backcountry camping management is designed to maximize public access and maintain visitors' sense of spontaneity and freedom. Visitors interested in backcountry camping at Isle Royale National Park are required to obtain a permit, but there is no limit on the number of permits, and visitors are not required to follow fixed itineraries. While visitors do have the option to obtain special permits for offtrail hiking and camping, the vast majority choose to camp at the designated campground sites (Farrell and Marion 1998). Consequently, backcountry campground capacities are commonly exceeded during peak periods, causing visitors to have to "double-up" at campsites with other groups. Because previous research at the park suggests that for some visitors, having to "double-up" detracts from the quality of their experience (Pierskalla and others 1996, 1997), the park has considered establishing standards for the maximum proportion of backpackers who would have to "double-up" at campsites. Managers needed insight into what actions might have to be taken to achieve these standards.

The simulation model was designed to achieve three related objectives: (1) to describe the current spatial and temporal extent of campsite sharing in the park; (2) to assist park managers in identifying management actions capable of reducing or eliminating campsite sharing; and (3) to enhance the effectiveness of public involvement processes by providing managers with precise, quantitative estimates of the effectiveness of management alternatives.

Data Collection

Backcountry camping permits issued by park staff during the 2001 season provided the primary source of data needed to construct the computer simulation model. Data needed to test whether the simulation model outputs are valid estimates of on-the-ground conditions were gathered through a series of campground occupancy observations conducted throughout the park's 2001 visitor use season. Specifically, backcountry rangers and campground hosts recorded the number of groups camping in selected campgrounds on several nights throughout the visitor use season.

Constructing Model Inputs From Permit Data

Information from the permits concerning each backcountry camping group's starting date, camping itinerary, and group size were used as inputs to construct the simulation model. Starting dates reported on the backcountry camping permits were used to determine the total number of trips starting on each day of the 2001 visitor use season. From these data, the average number of trips starting on weekdays and weekend days from Rock Harbor, Windigo, and all other locations was computed. Within the model, for each of the three simulated entry points, an exponential distribution with a mean equal to the mean number of trip starts for the corresponding location and day of the week was used to generate simulated backcountry camping trips.

Information about group sizes reported on the backcountry camping permits was used to compute the percentage of small (six or fewer people) and large (more than six people) visitor groups during the 2001 season. Within the simulation model, this information was used to assign visitors a group size (small or large).

Trip itineraries recorded on the permits were segmented by trip starting location and group size to construct a set of six probability distributions of simulated backcountry camping trips (small and large group itineraries for each of the three simulated entry points). After being assigned a group size within the model, simulated visitor groups were assigned a camping itinerary from the distribution itineraries that corresponded to their starting location and group size.

Computer Simulation Model Characteristics

Using the data inputs described above, a probabilistic, steady-state simulation model of backcountry camping use was developed (refer to Chapter 3 for more information about steady-state and probabilistic simulation modeling). The commercial simulation software package, Extend, developed by Imagine That, Inc., was used to develop the simulation model. The primary use of the simulation model developed was to replicate backcountry camping use at the peak of the visitor use season in order to address the objectives outlined earlier. Consequently, steady-state simulation was adopted for this study because it is designed to replicate system behavior over the long run at a given level of production or capacity.

Simulation Model Runs

Simulation runs were conducted to estimate the extent of campsite sharing in the park under status quo conditions, and to estimate the effectiveness of management actions at reducing or eliminating campsite sharing. Management alternatives evaluated with the simulation model include reducing use through quotas on permits, requiring visitors to follow prescribed fixed itineraries, and building additional campsites within existing backcountry campgrounds.

A series of simulations was also conducted to validate the simulation model outputs. Data concerning the average number of groups per night camping in selected campgrounds were gathered from 20 model runs. These data were compared with campground occupancy count data collected by park staff for the same campgrounds during the 2001 visitor use season. In addition, a workshop was conducted to instruct park staff how to use and modify the simulation model to continue meeting their planning needs. The park staff's use of the simulation model is ongoing, allowing them to evaluate management strategies as new ideas emerge throughout the park's backcountry and wilderness planning process.

Model Output

Table 11 summarizes the results of simulation runs conducted to estimate the current extent of campsite sharing, and to estimate the effectiveness of alternative strategies for reducing or eliminating campsite sharing. The alternatives outlined in table 11 were selected for analysis with the simulation model because they reflect a range of management approaches that emphasize campsite solitude, visitor freedom, public access, and facility development to varying degrees.

Park managers have the option of managing backcountry camping to maintain status quo conditions. Under this alternative, an average of about 39 permits would be issued per day, there would be no new campsite construction, and visitors would not be required to follow prescribed itineraries. Park planners were interested in a standard of no more than 5 percent campsite sharing. Simulation results for the "Status Quo" alternative suggest that under the park's current management approach, an average of about

Table 11—Management alternatives quantified, based on simulation model output.

Wilderness values	Status quo	Permit quota	Fixed itineraries	Campsite construction	Temporal redistribution
Public access	Current use	22% reduction in July/August use	30% increase in July/August use	Current use	Current use (shift 22% of peak)
Facility development	No new campsites	No new campsites	No new campsites	13 new campsites	No new campsites
Visitor freedom	No fixed itineraries	No fixed itineraries	Fixed itineraries	No fixed itineraries	No fixed itineraries
Camping solitude—July and August	9% of groups share sites/night	5% of groups share sites/night	<1% of groups share sites/night	7% of groups share sites/night	5% of groups share sites/night
Camping solitude—low-use period	0.4% of groups share sites/night	0.4% of groups share sites/night	<1% of groups share sites/night	<1% of groups share sites/night	1.4% of groups share sites/night

9 percent of groups are required to share campsites per night during July and August, with 24 percent sharing during the busiest 2 weeks of this period. Less than 1 percent of groups are estimated to share sites during the low-use period of the season.

Simulation runs were conducted to assess the effectiveness of a permit quota at reducing or eliminating campsite sharing. Under the "Permit Quota" alternative, there would be no new campsite construction and visitors would not be required to follow prescribed itineraries. However, the average number of permits issued per day during July and August would be reduced to ensure that an average of no more than 5 percent of groups share campsites per night (a standard for campsite sharing that the park is considering). Such an approach would continue to emphasize visitor freedom and limit facility development in wilderness, while allowing for greater camping solitude than the status quo for those groups able to obtain a permit. However, fewer individuals who want to take a backcountry camping trip during July or August would be able to. The simulated "Permit Quota" alternative suggests that the park would need to reduce visitor use during July and August by nearly 25 percent to ensure that an average of no more than 5 percent of groups share campsites per night.

Decisions to limit public use of public lands are inherently controversial. To avoid this controversy, park managers could institute a fixed itinerary system, rather than a permit quota, to reduce or eliminate campsite sharing. Under this approach, visitors would be assigned to campgrounds that had open campsites, and no new campsites would be constructed. However, visitors would have fewer choices of itineraries and would lose the freedom to spontaneously alter their camping itinerary during the course of their trip. The results of the simulated "Fixed Itineraries" alternative suggest that, by requiring visitors to follow prescribed camping itineraries, the park could issue approximately 30 percent more permits than they did during the 2001 visitor use season, and at the same time virtually eliminate campsite sharing.

Rather than institute a permit quota or require visitors to follow prescribed itineraries, managers could try to reduce or eliminate campsite sharing by building new campsites. The park's recently adopted General Management Plan allows for construction of up to 13 additional campsites in specific campgrounds. If this "Campsite Construction" alternative were to be adopted, the simulation results suggest that, without instituting any limits on use, the park could reduce campsite sharing by about 2 percent, resulting in an average of approximately 7 percent of groups sharing campsites per night.

As the results of the simulated "Status Quo" alternative indicate, campsite sharing is a problem primarily during the months of July and August, while there is virtually no campsite sharing during the low use period of the season. Further, results of the "Permit Quota" alternative suggested that park managers would need to reduce the number of permits issued during July and August by about 25 percent to ensure that an average of no more than 5 percent of groups share sites per night. However, rather than turning those visitors away completely, park managers could shift "surplus" peak season use to the low-use period. This "Temporal Redistribution" approach would allow managers to maintain season-wide visitor use levels, reduce campsite sharing during July and August, avoid building new campsites, and maintain visitor freedom with respect to camping itineraries. Results of the simulated "Temporal Redistribution" alternative suggest that campsite sharing would increase from an average of approximately 0.4 percent of groups per night during the low use period of the season, to just over 1 percent of groups per night.

Another option is to redistribute use spatially. Simulations conducted to estimate the effect of redistributing visitor use evenly across the two primary starting locations for backcountry camping trips (Windigo and Rock Harbor) would not reduce campsite sharing. Finally, redistributing use evenly across the days of the week also would have no effect on campsite sharing. The results of these simulations are not included in table 11.

Results of simulation runs conducted to test the validity of the model outputs are summarized in table 12. There were no substantive differences between the observed campground occupancies and the corresponding model output. This suggests that the computer simulation model accurately represented backcountry camping conditions at the park during the 2001 season.

Park staff's use of the simulation model is ongoing. For example, park staff have used the model to estimate the effect of shifting some use to secondary entry points, differentially altering the visitation levels of hikers, paddlers, and powerboaters, and setting alternative standards for campsite sharing at different times of the season. In addition, park staff have used the model to estimate where and how

Table 12—Mean campground occupancy rates, with number of observations in parentheses, as observed and predicted by the model.

Campground	Observed	Model
Daisy Farm—weekend	15.0 (15)	15.8 (16)
Daisy Farm—weekday	15.1 (14)	13.3 (40)
Belle Isle —weekend	3.1 (12)	3.8 (16)
Belle Isle—weekday	3.1 (19)	3.1 (40)

many new campsites would need to be added to eliminate campsite sharing during peak season demand. Using simulation results as a guide, park staff conducted site visits to determine the feasibility and desirability of campground development needed to meet peak camping demand, based on considerations of physical constraints of wetlands, fragile habitats and topography as well as appropriate size of campgrounds in different areas of the park. The number of new sites that would be needed to accommodate peak demand, according to model estimates, is greater than the number of sites that could be added, given the constraints listed above. However, the number of feasible new sites would mitigate campsite sharing during the peak period of the season to some extent.

Conclusions

Findings from this project demonstrate how simulation modeling can be used to identify effective management actions and avoid those that are less effective. Furthermore, by providing park managers with precise, quantitative estimates describing the effectiveness of management alternatives, the computer simulation model serves as a communication tool. Park planners have used simulation model data to better inform the public of the costs and benefits of different management options, resulting in more effective public involvement processes. An additional use of the model data is its incorporation in further research. For example, the model data generated in this study served as the basis in designing a visitor survey in which respondents were asked to evaluate a range of management alternatives (Lawson and Manning 2003b). The model data provided an important element of realism to the choices presented to respondents.

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Acadia National Park Carriage Roads: Estimating the Effect of Increasing Use on Crowding-Related Variables

Robert E. Manning
Benjamin Wang

Purpose

The purpose of this project was to create and apply a computer simulation model to estimate use patterns along the carriage roads in Acadia National Park in a way that was meaningful in understanding and managing the quality of the visitor experience. Recreation use of the park's carriage road system has increased dramatically in recent years, and this has caused concern among both park users and managers. Dominant uses have evolved from horses and carriages (for which the nearly 80 km of roads were originally constructed in the early part of the twentieth century) to hiking and, more recently, mountain biking.

Because of the complex, intersecting nature of the carriage road system and its inherently dispersed use, direct, systematic observation of recreation use is difficult. Thus, it is challenging to quantify recreation use levels and patterns. How many visitors are using the carriage roads? How often do visitors encounter one another along the carriage roads? How many visitors can be accommodated on the carriage roads before the quality of the recreation experience is diminished to an unacceptable degree? The simulation model of the carriage road system was designed and used to help answer these and related questions.

Description of the Study Area

The carriage roads of Acadia National Park, on Maine's Atlantic Coast 65 km southeast of Bangor, are a unique system of more than 80 km of beautifully designed and highly engineered gravel roads built under the direction of John D. Rockefeller, Jr., in the early 1900s. Although the roads were built for horse-drawn carriages, they are now used mainly by bicyclists and walkers, providing a welcome escape from automobile traffic and access to many undeveloped areas of the park. Equestrian use is now low and declining. Longtime observers agree that carriage road use increased greatly with the rise in popularity of the mountain bike in the 1980s, although no data on carriage road use were collected during that time period. However, the park fielded an increasing number of complaints from visitors and area residents during that time about "crowding" and "conflict" on the carriage roads.

Data Collection Procedures

Surveys of carriage road users indicated that the number of other visitors seen while hiking and biking was important in defining the quality of the recreation experience (Jacobi and Manning 1999; Manning and others 1998). Since use of the carriage roads is relatively high, the concept of persons-per-viewscape (PPV) was developed as an appropriate measure of carriage road use. PPV was defined as the number of carriage road visitors per 100 m of the trail system, the average distance that can be seen along the generally winding carriage road system. Thus, the simulation model was developed to estimate PPV levels across the carriage road system.

A variety of methods were employed to gather the baseline data necessary for building the simulation model (Wang and Manning 1999). These were visitor census counts, onsite visitor surveys, Geographic Information System (GIS) analysis, a field visit, examination of engineering maps, and computer timing of visitor arrival patterns. These are described in more detail below.

Data on where, when, and how many visitors entered the carriage roads system were gathered using five 1-day visitor censuses. From 9:00 a.m. to 5:00 p.m. on each of the 5 days, observers stationed at all eight main entrance points recorded the number of visitors that entered per hour. Census data suggest that about 3,000 visitors per day use the carriage roads on an average summer day.

Information on visitor characteristics and travel patterns were gathered with an onsite survey. A total of 514 questionnaires were administered at the eight main exit points. The number of surveys gathered at each site was proportional to that site's share of total exits from the entire system as determined by a census of visitor use conducted the previous summer. One visitor from each group was asked about their group size, their mode of travel (hiking versus biking), the total amount of time they had spent on the carriage roads that day, and where and how long they paused during the visit. Equestrian-related cases were not included in the study since these uses constitute such a small percentage of all carriage road use. Finally, with the aid of a map, respondents were asked to list, in order, all of the carriage road intersections they passed during their trip. This produced a total of 381 unique travel routes along the carriage road system.

The lengths of carriage road sections between intersections were calculated from a digital coverage using GIS analysis. The lengths of each unique route that respondents traveled were then calculated with a short ARC Macro Language program.

A field visit to the carriage roads and an examination of engineering maps determined that the length of a typical viewscape—the length of carriage road that can be seen at one time—was approximately 100 meters.

The precise timing of visitor arrival patterns was measured using a Pascal computer program. Data were gathered over four half-hour periods with similar use levels near one entrance point on the carriage roads. Each time a visitor group arrived, a key was hit on the computer to record the time of arrival (down to a second) and travel mode (hiking or biking). Sixty-five data points were recorded. These data were gathered to verify the use of a decaying exponential distribution to simulate arrival patterns. The use of an exponential distribution assumes that visitor groups arrive independently.

Model Characteristics

The simulation model was built using Extend, a commercial, general simulation software package developed by Imagine That, Inc. The structure of the model was built with hierarchical blocks that represented specific parts of the carriage road system. The three main types of hierarchical blocks that comprised the model were entrance/exit blocks, intersection blocks, and road 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 census counts. The parties were then randomly assigned travel modes (hiking or biking) and group size, both according to probability distributions derived from the visitor survey. Simulated visitor parties were then randomly assigned travel speeds according to a lognormal distribution. The mean and standard deviation of the distribution were calculated from the travel times reported by survey respondents and the lengths of their travel routes. Lastly, 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 proper direction when they arrive at carriage road 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 serve two functions. The first was 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 second function was to gather PPV data. Within each road section block, a simulated 100-m road segment was built. The number of visitors traveling on that 100-m segment was counted and recorded once every simulated minute.

The simulation model developed in this project was probabilistic (based on probabilities of simulated visitors selecting available travel itineraries) and was terminating (an entire day was modeled).

Model Runs

The model was run 135 times to generate information on average PPV. Each run simulated carriage road use from 9:00 a.m. to 5:00 p.m. (the hours of peak use), but only recorded output from 10:00 a.m. to 5:00 p.m. Output from the first hour was considered unreliable because people who would have entered the carriage roads before 9:00 a.m. were not included in the simulation. The completed model was run for six levels of total daily use of the carriage roads (multiples of the current use level of 3,000 visitors): 375, 750, 1,500, 3,000, 6,000, and 12,000 visitors per day. The model runs were repeated five times at each use level to capture stochastic variation and generate statistical confidence intervals. PPV conditions were recorded for four use zones: the entire carriage road system, road sections designated as high-use zones, road sections designated as low-use zones, and the road section between intersections 6 and 9 (a particularly heavily traveled section).

The model was also run for validation purposes. Data on how many simulated visitor parties exited at each exit point each hour were gathered for 20 model runs. Data on how many parties passed by the west side of Eagle Lake (the site of a permanent infrared trail counter) were gathered for 16 runs.

Model Outputs

Results are presented first on PPV conditions, and then on the results of model verification and validation. Figure 25 summarizes results estimating PPV conditions across all carriage road sections in the system for different total use levels. The results of the simulated days are expressed in the number of minutes out of an hour that a typical visitor will see certain selected numbers of PPV. For example, in figure 25, when 1,500 visitors use the roads in a day, a typical visitor would see no one else (0 PPV) for 48 minutes out of an hour, one to five other visitors for 11 minutes out of an hour, and six or more other visitors for 1 minute out of an hour. Each data point shown represents the mean values, rounded to the nearest minute, from five model runs. Standard deviations calculated for these mean values range from 1.10 minutes (total use 6,000, 0 PPV) to 0.03 minutes (total use 12,000, 21 to 30 PPV).

Figure 26 provides a comparison of PPV results among the different use zones when 3,000 visitors use the system in a day (the approximate current use level on the average day). The use zones are (1) low-use road sections, (2) all of the road sections in the system, (3) high-use road sections, and (4) the road section between intersections 6 and 9, the most heavily used road section in the system. Each data point shown represents the mean values, rounded to the nearest minute, from five model runs. Standard deviations calculated for these mean values range from 1.58 minutes (highest-use road section, 0 PPV) to 0.10 minutes (all road sections, 11 to 15 PPV).

Figure 27 compares observed data with theoretical distributions used in the model. Figure 27A shows the empirical distribution of interarrival times (amount of time between arrivals of visitor parties) gathered with the laptop computer at entrance points alongside a theoretical exponential (M = 103.94) distribution. Figure 27B shows the distribution of average biker travel speeds calculated from visitor surveys alongside a theoretical lognormal (M = 0.799 min/100 m, SD = 0.431) distribution. Figure 27C shows the distribution of hiker travel speeds gathered with visitor surveys and calculated with a GIS program alongside a theoretical lognormal (M = 1.615 sec/100 m, SD = 0.879) distribution. Visual comparison of these distributions suggests there is little reason to conclude that the data are poorly fitted by the theoretical distributions used in the simulations.

Figure 28 summarizes output validation results. Results are shown for three comparisons between observed data and model outputs: (A) the distribution of visitors across exit points, (B) the distribution of visitor exits across time, and (C) the distribution of visitors who passed by the Eagle Lake infrared trail counter site through the hours of the day. Visual comparison of the distributions suggests there is no reason to conclude that the observed data are poorly fitted by the model output.

Conclusions

This case study illustrates the utility of computer simulation as a tool for estimating how hiking and biking use are spatially and temporally distributed and how these use patterns vary with a range of use levels. PPV outputs for different total use level conditions and use zones provide a sophisticated view of carriage road use that would be difficult to observe directly, but that is strongly related to the quality of the visitor experience. A second phase of this project involved a survey of carriage road visitors to help determine PPV-related standards of quality (Jacobi and Manning 1999; Manning and others 1999, 2000). The computer simulation was then used to estimate the maximum number of visitors that can be accommodated on the carriage roads without violating PPV-related standards (Manning and others 1998).

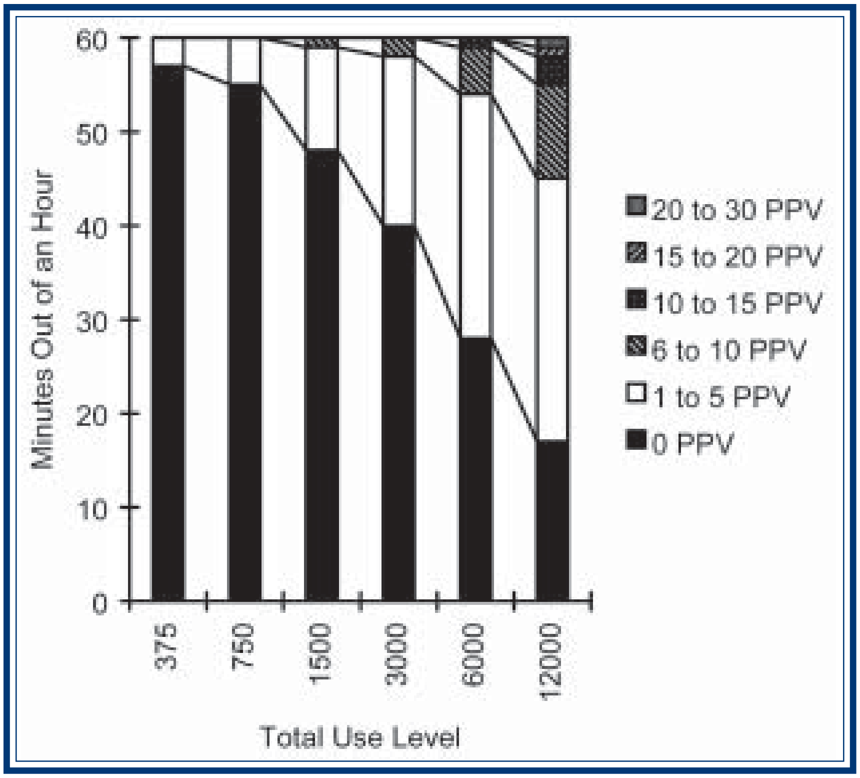

Figure 25—Persons-per-viewscape (PPV) distributions for six total use levels, for all road sections in the system.

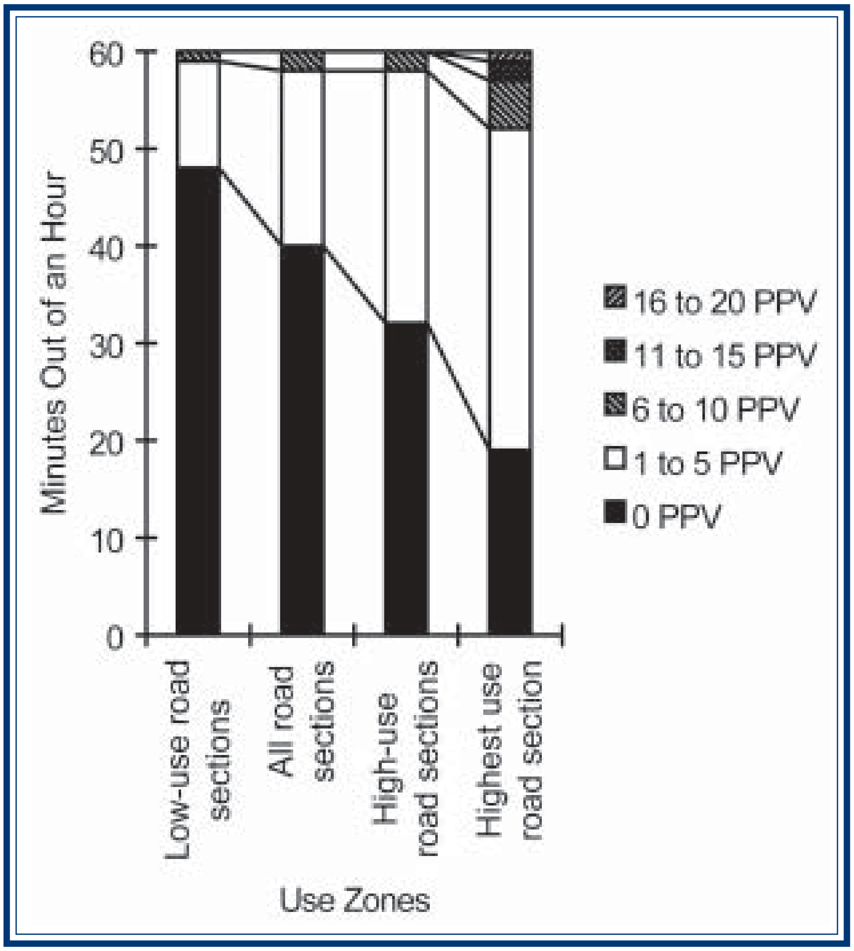

Figure 26—Comparison of persons-per-viewscape (PPV) distributions among different use zones with 3,000 total system use.

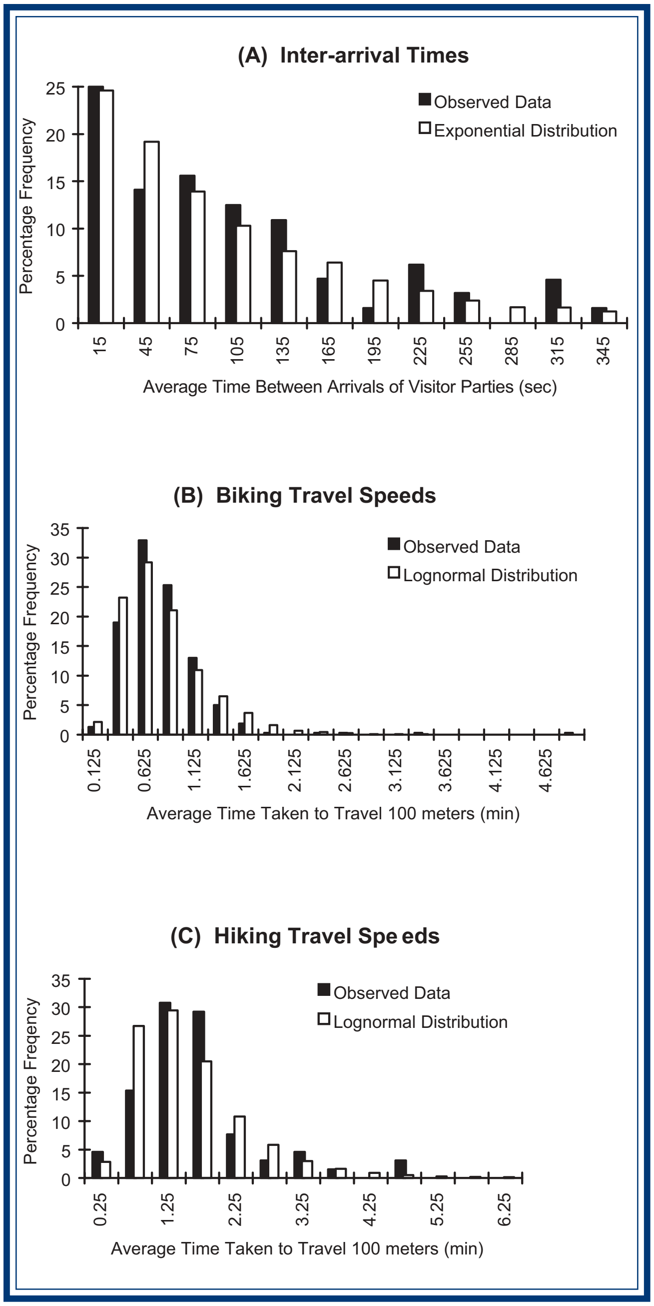

Figure 27—Frequency comparisons for the verification of input distributions.

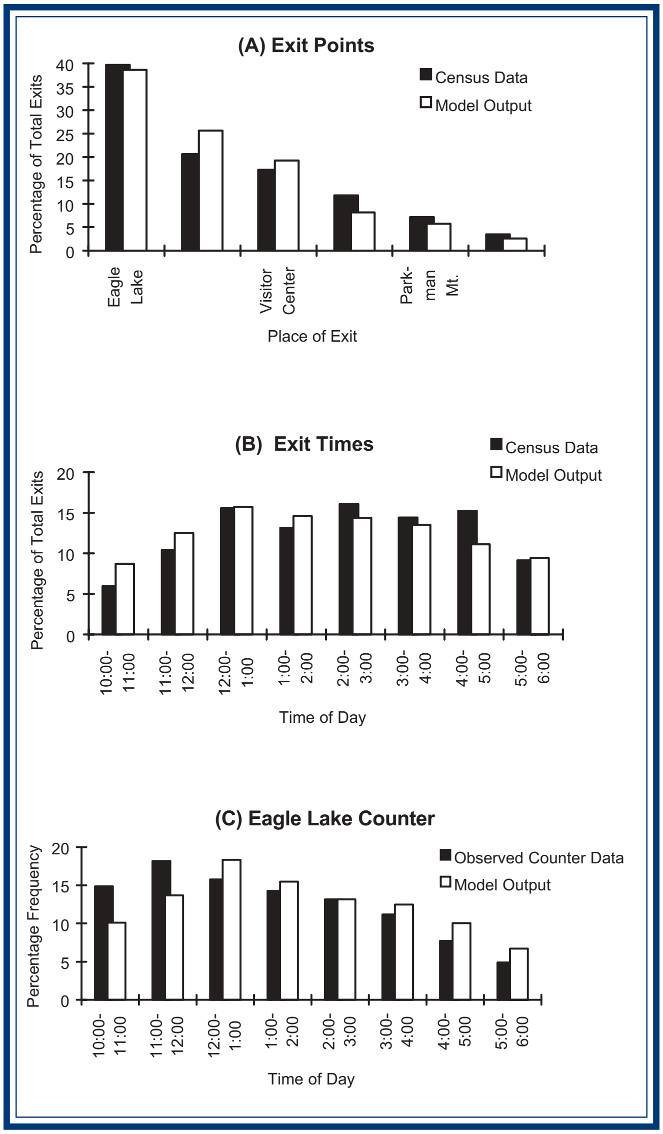

Figure 28—Frequency comparisons for validation of model outputs.

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Acadia National Park Scenic Roads: Estimating the Relationship Between Increasing Use and Potential Standards of Quality

Jeffrey C. Hallo
Robert E. Manning
William A. Valliere

Purpose

Automobile use is the primary means of transportation to and through most National Parks, and for many visitors it is also the predominant means by which the park is experienced. Some National Park units, such as the Blue Ridge National Parkway, are designed primarily for automobile use. Others, such as Acadia National Park on the Maine coast, rely on scenic roadways interspersed with pull-offs or side roads to vistas to provide “the national park experience” to a majority of users. Despite the importance of automobile use in the National Parks, little research has been conducted to examine crowding, automobile congestion, and social carrying capacities on park roads. This case study illustrates how a computer simulation model of automobile traffic in Acadia National Park can be used to help estimate the maximum number of vehicles that can be accommodated on the park road system.

Description of Study Area

Established as the first eastern National Park, Acadia currently receives more than 3 million visits annually. The Schoodic Peninsula is one of three geographically separate areas of Acadia, located approximately an hour’s drive from the main Mount Desert Island portion of the park. Frazer and Schoodic Points are the most frequently visited areas of this 900 ha portion of the park.

A scenic road is the sole travel route through Schoodic Peninsula. The road enters the park near Frazer Point and follows the shoreline of the peninsula, reaching Schoodic Point prior to leaving the park. The road permits only one-way vehicle travel, except on access roads to both scenic points. A segment of road between Frazer and Schoodic Points was modeled in this study. This segment was selected because it represented a generalized section of the park scenic road.

Data Collection Procedures

Data collection consisted of two phases. During the first phase, visitors were asked questions regarding the acceptability of different levels of road traffic. Using computer-edited photographs, respondents were asked about the level of use they (1) prefer, (2) consider acceptable, (3) consider so unacceptable they would no longer visit, and (4) think the National Park Service should allow. Mean responses for each of these four evaluative domains (denoted as preference, acceptability, tolerance, and management action, respectively) provide a range of potential standards from the perspective of current visitors.

Phase 2 of the study involved the collection of travel route information using commercially available, hand-held Global Positioning System (GPS) units. Route data were collected during 9 days in July, 2003. Occupants of the first 10 cars to enter Schoodic Peninsula at the start of the daily data collection period (9 a.m.) were asked to participate in the study by carrying a GPS unit in their car. Participants were instructed not to leave the GPS units on their automobile dashboards since preliminary trials had determined that units were susceptible to overheating and malfunction in this circumstance. The GPS units were collected from participants at the Schoodic Peninsula exit, and the route data were downloaded to a computer. The GPS units were then returned to the park entrance for collection of additional route data throughout the sampling day.

The GPS units (GARMIN eTrex Legend) were set to automatically record route points. Numerous points were collected for every route, with each point containing a latitude, longitude, and time. Specifications for the GPS unit state that location information is accurate to within 3 m. An Arc Macro Language (AML) script was then used to extract data points of interest from the many recorded. The script did this by first setting circular zones around each intersection or point of interest. The earliest and latest recorded data falling within these zones were then extracted from the data set.

The final aspect of data collection, during phase two, involved counting the number of cars arriving during half-hour intervals between 9 a.m. and 7 p.m. These headway counts were used to determine mean interarrival times for each half-hour interval.

Model Characteristics

A simulation model of the Schoodic Peninsula was built using Extend, a commercial, generalized simulation software package produced by Imagine That, Inc. Car travel through the Schoodic Peninsula was set up as a terminating, discrete event simulation model. In other words, the simulation model was designed to release individual cars over a 10-day peak period into the system, each with its own unique set of information (in other words, attributes). The model, built from Extend’s libraries of standard blocks, was organized into hierarchical blocks and overlaid on a map of the

Schoodic Peninsula to provide a more accurate visual representation.

Cars are generated, released into the model, and assigned the necessary attributes in the entrance block. The entry of cars follows a decaying exponential distribution, based on mean interarrival times for the half-hour intervals corresponding to the time of day in the simulation. Once in the system, one of 193 unique routes collected using GPS units are randomly selected and that route's attributes are assigned to a simulated vehicle. The route attributes specify whether a simulated vehicle visits or bypasses Frazer and Schoodic Points, the amount of time spent at each of the two points, and the time required to travel on the park road between Frazer and Schoodic Points. The selection of a travel path based on its frequency of occurrence in the data set of empirically derived routes is characteristic of a probabilistic model. However, the model was also set up with an option to route cars to the next location specified in the route if the physical capacity of either of the points' parking lots was exceeded. In this way the model represents a hybrid of both probabilistic and rule-based models.

Model Outputs

The simulation model was run five times (50 days) at the automobile density-related standards of quality for preference, acceptability, management action, and displacement (table 13). None of the standards for the road segment were violated at the sampled use level (M = 415 cars/day). At increased multiples of the sampled use level, standards of quality were progressively violated, as measured by the percentage of time out of standard (table 14).

Table 13—Standards of quality for the scenic park road collected during Phase 1.

Type of standard	Standards of quality (No. cars/quarter mile)
Preference	2.5
Acceptability	7.5
Management Action	8.5
Displacement	12.7

These outputs can be used in many different ways. For example, additional runs of the simulation between two and three times the sampled use level showed that at approximately 2.1 times the sampled use level, the preference standard is violated 10 percent of the time. When multiplied by the sampled use level this indicates that 871 cars per day could be allowed into the Schoodic Peninsula without violating visitors' preference for crowding on the park road more than 10 percent of the time. Similar outputs were not generated for acceptability, management action, and tolerance standards because the multiples of current use at which the 10 percent threshold would be crossed were beyond that deemed likely to occur, at least in the near future.

The effect of the Frazer Point parking lot size on crowding along the park roadway was also an output of the simulation model. By tripping (virtual) digital switches located on the bottom right of the model, a physical capacity could be imposed at both Frazer and Schoodic Point parking lots. When the parking lots reached their designated capacity, cars were prohibited from entering and were forced to continue on the park road to their next destination. However, because the Schoodic Point parking lot is located beyond the segment of park road modeled for this study, it does not affect the crowding results. Restricting the number of cars at Frazer Point to 24 (the current number of spaces in the parking lot) had no statistically significant effect on roadway crowding at any multiple of the sampled use level ($p > 0.05$).

Table 14—Percentage of time each standard of quality was violated on the park road.

Multiple of current use	Preference	Acceptability	Management action	Displacement
1	0.0	0.0	0.0	0.0
2	7.6	0.0	0.0	0.0
3	45.1	0.0	0.0	0.0
4	69.4	0.0	0.0	0.0
5	80.1	0.1	0.0	0.0
6	86.3	3.4	0.3	0.0
7	91.3	19.0	5.4	0.0
8	93.4	40.4	20.8	0.0
9	95.2	52.6	39.9	0.1
10	97.3	60.3	50.7	1.5

Conclusion

This case study illustrates how computer simulation models can estimate baseline use levels on park roads and estimate how much use can be accommodated before potential standards are violated. Results suggest that crowding on the road is not a problem at existing use levels, even when cars are forced to bypass their visit to Frazer Point. However, if use doubled, managers may need to limit use if managing for a preference-based standard of quality.

Port Campbell National Park, Australia: Predicting the Effects of Changes in Park Infrastructure and Increasing Use

Robert M. Itami

Purpose

The purpose of this case study is to demonstrate the use of agent-based modeling and simulation to predict the outcomes of increasing use and different management scenarios at a popular day-use site at Port Campbell National Park in Victoria, Australia. The case study demonstrates the modeling and simulation of multiple travel modes, including arrivals by bus and private automobile, and onsite pedestrian behavior. It illustrates how to construct agent-based visitor models using RBSim for existing conditions and for a new master plan with new parking facilities, pedestrian walkways, visitor center, and toilet facilities. Finally, simulation modeling is used to examine the performance of a new master plan over a 10-year time period and compare the results with a “do nothing” alternative which maintains the existing site management regime. In this case study, the “do nothing” alternative is referred to as “Scenario 1”and the new master plan is referred to as “Scenario 2.” This case study is described in detail as an example of rule-based simulations.

Description of Study Area

Port Campbell National Park and the associated Bay of Islands Coastal Park are located on the Great Ocean Road, approximately 250 km west of Melbourne. Comprising 65 km of rugged and spectacular coastal scenery, the two parks are protected in a strip ranging in width from a few meters in the Bay of Islands Park to 2 km within the Port Campbell National Park. The parks have World Conservation Union (IUCN) ratings of Category II (National Parks) and Category III (National Monuments) and are designated for ecosystem conservation and appropriate recreation and protection of outstanding natural features, education, research, and recreation respectively. The Port Campbell National Park attracts large and steadily increasing numbers of visitors. The park’s popularity is enhanced by its proximity to Melbourne and the large number of tour buses that visit the site daily.

Modeling Two Scenarios at Twelve Apostles

RBSim was used to examine the impact of changes in park infrastructure and increasing visitor rates over a 10-year period on the Twelve Apostles site. Some 701,000 people visited the site in 2001/2002, and by 2006/2007 the number is expected to be 864,000. Figure 29 shows the layout plans for the two scenarios. Scenario 1 shows the conditions before development of facilities in the new master plan. Car and bus traffic entered the site from the Great Ocean Road and traveled southwest onto a loop road, which was configured with car and bus parking around the perimeter of the road. Pedestrians then entered the viewing platforms from the loop road. They proceeded along wooden walkways and viewing platforms located at the top of the cliffs overlooking the view of the Twelve Apostles. On busy days the loop parking filled quickly, causing drivers to park along the entry driveway and along Great Ocean Road with resultant safety hazards.

Scenario 2 shows the layout anticipated in the new master plan. In this scenario the viewing platforms and walkways in the viewing areas remain the same, but vehicular parking is located to the north of the Great Ocean Road. A pedestrian underpass allows pedestrians to pass safely under the Great Ocean Road to the viewing platforms. Major facilities provided in the new master plan include a new parking area for buses, cars and trailers, a new visitor center with public toilets, and a new walkway extending from the visitor center to the viewing platforms.

Model Inputs

Data inputs for RBSim models fall into two categories: site characteristics and visitor characteristics. Site characteristics include a GIS map of the road and trail network, a Digital Elevation Model (DEM), an inventory of visitor facilities (including location, capacity, and typical visit durations), and the rate of arrival of visitors in cars, buses, or other travel modes. Visitor characteristics include arrival curves, rules of behavior, and typical trips.

Site Characteristics

Road and trail network—The existing road and trail network for Scenario 1 was imported from Park Victoria’s corporate GIS database. RBSim has utilities for importing GIS data from either MapInfo tab

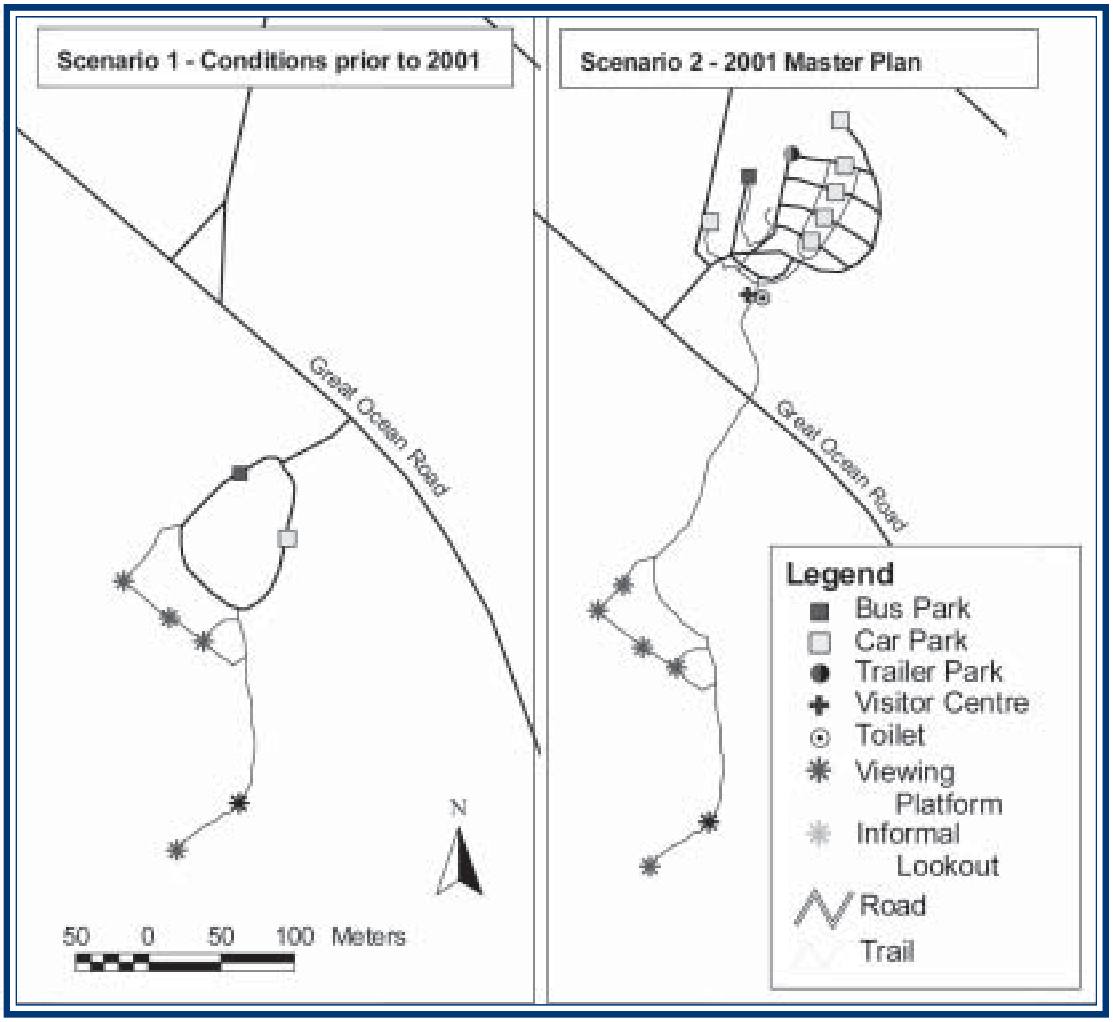


Figure 29—Network layout and facilities for Scenario 1 and Scenario 2.

files or ESRI Shape files. The new road and trail network for Scenario 2 was provided in the form of an AutoCAD drawing file. The network for car and bus parking, pedestrian walkways, and visitor facilities was simplified and generalized (while maintaining positional accuracy) and hand digitized with RBSim's digitizing functions. RBSim uses network algorithms for calculating travel time, travel distances, and shortest path from one destination to the next. This requires that the travel network is structured in such a way that the endpoints of all links connect to nodes, and that there is a node at the intersection of three or more links. The RBSim network import utility attempts to construct this topology by breaking links at intersections and inserting nodes, joining the endpoints of links according to user-specified tolerances, and building a tabular database that describes the topology of the network in the form of a forward star database. RBSim provides network editing functions for correcting network topology and adding or deleting links and nodes while maintaining network topology. Once the network topology is corrected, the network links are attributed for the maximum travel speed. In the case of the main highway (Great Ocean Road) the maximum speed is 90 km/hr. For entry roads the maximum speed is 15 km/hr, 10 km/hr for parking areas, and 4 km/hr for trails.

Digital elevation model (DEM)—The DEM represents the elevation of the land surface and is stored as a grid matrix of elevations. The digital elevation model for Port Campbell National Park was generated in ESRI ArcInfo from contour elevations and spot heights derived from 1:25,000 topographic maps with 10-m contour intervals. Elevations were interpolated on a 20-m floating point grid and imported into RBSim in ESRI grid export format. The DEM is used by RBSim to calculate uphill and downhill slopes to determine walking speeds for pedestrians and to calculate line-of-site across terrain for intervisibility calculations. If a DEM is not specified, RBSim assumes a flat surface with an elevation of zero.

Facilities inventory—Results of an onsite facilities inventory to determine the type and capacity of visitor facilities were entered into the Scenario 1 network as node attributes. For Scenario 2, parking spaces for cars, buses and trailers were counted from the drawings provided by Parks Victoria. The number of toilets and the capacity of the visitor center were determined from design documentation for the 2001 master plan. The facilities for both scenarios are enumerated in table 15.

Locales—A locale is a collection of one or more nodes with associated facilities that have a shared identity and can be grouped based on proximity or common access. The Twelve Apostles visitor site, including viewing platforms, boardwalks, parking lots, and trails is an example of a locale. Locales are defined in the travel network by selecting all nodes to be included in the locale using the RBSim network editing functions, and then assigning the "Locale" attribute to the nodes. This function assigns all the selected nodes the same locale name. The locale is important so that site-specific rules can be created for agents. Also, agent rules are only active when an agent enters a locale, otherwise the agent follows its global trip plan. Each locale must also have at least one entry node. In the case of the Twelve Apostles locale, the entry node is assigned to the intersection of the Great Ocean Road and the entry road for both Scenarios 1 and 2.

Visitor Characteristics

Agents—The visitor simulation for Twelve Apostles utilizes RBSim's capability of using autonomous intelligent agents to simulate onsite visitor behavior. For both Scenario 1 and Scenario 2, two agents were defined to represent visitors arriving by bus and those arriving in private automobiles. This reflects the source of visitor data from road traffic counts, which differentiates between buses and cars. In this simulation, because of the simplicity of the site, the main constraint on site behavior is the duration of stay. Agents are assigned two different travel modes. The "default" travel mode is walking by foot. Agents are assigned a second "Arrival" travel mode as part of the typical trip. In this case the arrival travel mode for automobiles is car, and the bus arrival travel mode is bus. Agents are also assigned a maximum travel speed for their default travel mode. In both cases the maximum travel speed is 4 km/hour.

Table 15—Facilities at the Twelve Apostles locale before (scenario 1) and after (scenario 2) the implementation of the new master plan.

Facility	Scenario 1	Scenario 2
Viewing platform	345 people	345 people
Informal lookout	5 people	30 people
Bus park	6 buses	12 buses
Car park	28 cars	165 cars
Visitor centre	None	100 people
Toilet	None	29 people
Trailer park	None	12 cars

Arrival curves—Parks Victoria has a policy of managing visitor use for the 95th percentile busiest day. This means facilities should be planned for the 19th busiest day of the year. From several detailed traffic analyses conducted over a period of 5 years, it was determined that on the 95th percentile day (Easter Saturday), 44 buses visited the Twelve Apostles. In 2006, at 7 percent growth per year, this is estimated to rise to 62 buses (40.3 percent growth from 2001). In 2011, visitation is estimated at 87 buses (96.7 percent growth from 2001).

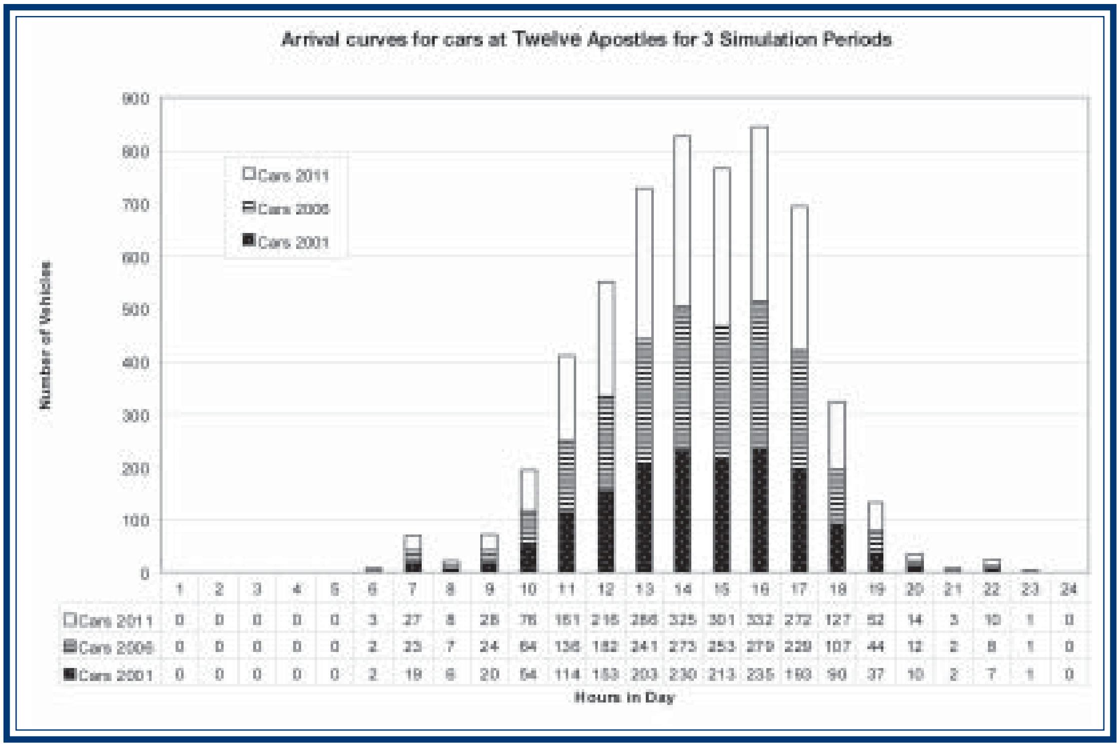
Car projections are factored for the average growth of Twelve Apostles visitation (3.5 percent). On the 95th percentile day (Easter Saturday), 1,589 cars visited the Twelve Apostles. In 2006, at 3.5 percent growth per year, this number is estimated to rise to 1,887 cars (18.8 percent growth from 2001). In 2011, visitation is estimated at 2241 cars (41.1 percent growth from 2001). Figure 30 shows detailed arrival curves for cars; similar data were developed for buses.

Agent rules—Agent rules are a set of user-defined behaviors that are defined using a stimulus/response or event/action framework. RBSim exposes runtime properties of the network, agent, and global events. Each of these properties will have a state or value that can be defined as a stimulus or event. Boolean logic can be used to combine two or more stimuli to create complex conditions for behavior. Behavior is defined as a directive to search for a facility. An example of a complex rule is:

> *If (TravelMode = 'Car' AND Locale = '12 Apostles' AND LocaleEntry = True) THEN Find Carpar**k***

Agent rules are assigned to agents in the management scenario builder. The user can specify the order in which the agent considers rules for execution. For instance, an agent should always park a car before going to a visitor center. Agent rules are a set of user-defined agent actions that are triggered by changes in the agent's location, travel mode, or other characteristics of the network or agent. An interface for designing rules exposes the set of simulation properties that can act as triggers. Agent rules are active within the context of a locale.

Table 16 shows the agent rules used in the scenarios. Scenario 1 used rules 1, 2, and 5; and Scenario 2 used all five rules. These rules direct the behavior of the agents once they enter the Twelve Apostles locale.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
□Cars 2011	0	0	0	0	0	3	27	8	28	76	161	216	286	325	301	332	272	127	52	14	3	10	1	0
▤Cars 2006	0	0	0	0	0	2	23	7	24	64	136	182	241	273	253	279	229	107	44	12	2	8	1	0
■Cars 2001	0	0	0	0	0	2	18	6	20	54	114	153	203	230	213	235	193	90	37	10	2	7	1	0

Figure 30—Car arrival curves used in the simulations for Twelve Apostles, for 2001 Easter Saturday traffic count data as well as projections for 2006 and 2011.

Table 16—Rules used by agents during the simulation runs.

Rule ID	Rule
1	If Arriving at a locale in a car then find a car park.
2	If arriving at locale entry in a bus then find bus parking.
3	When at Twelve Apostles find visitor centre.
4	At Twelve Apostles find toilet.
5	At any locale find viewing platform (repeatedly).

Note that special rules (3 and 4) are needed in Scenario 2 for the new visitor center and toilet facilities.

Typical trips—The typical trip represents a pattern of visitation within the park. The typical trip is defined by an entry and exit node to the travel network, one or more destinations, a travel mode (car, bus, and so on), a set of rules, trip duration and an arrival curve. Two typical trips were assigned to each scenario—one for buses, the second for cars. The trips to Twelve Apostles are all round trips, so the entry and exit nodes are the same (just offsite). The destination node is the entrance to the site on Great Ocean Road. Buses follow rules 2, 3, 4, and 5. Cars follow rules 1, 3, 4, and 5. Table 17 shows the duration for each type of typical trip. The duration for the trip varies randomly within the range specified. The durations are estimated from analysis of traffic count data.

Model characteristics—All agents follow a global trip plan. These plans however provide only a general trip itinerary. Once the agent begins its trip, changing conditions of the network (facilities becoming full), global events (rain storms), and agent states (agent fitness, running short on time), can all act together to change the behavior of the agent according to rules

Table 17—Typical trips, with durations generated randomly by the simulator between the minimum and maximum duration (in minutes) for cars and buses.

Description	Min duration	Max duration	Travel mode
Buses Easter Saturday 2001	60	80	Bus
Cars Easter Saturday 2001	30	40	Car

and the internal way-finding logic of the agent. The way finding reasoning of an agent is influenced by the following factors: (1) available time (defined by time elapsed subtracted from total trip duration), (2) travel mode as it affects travel time, (3) agent preferences, (4) list of rules and their order, (5) currently executing rules, (6) internal state of the agent, (7) current location of the agent, (8) condition of the network including availability of facilities, access restrictions, and travel time to destinations on the network, and (9) previously visited destinations.

When an agent arrives at a locale, it checks to see if there is a duration set for this locale in the global trip itinerary. If the duration is greater than 0 then the agent checks to see if there is enough time left in its total trip duration by subtracting the time elapsed since the beginning of the trip and the time to travel to the exit node. If the remainder is positive and greater or equal to the duration set for this locale, the agent enters the locale and performs an initialization procedure. Once the locale network has been initialized, the agent then evaluates all possible combinations of destinations from its current node location. The agent then evaluates each path and rejects any path that exceeds the available locale visit duration. The remaining paths are then ranked to maximize the site preferences and contain facilities that are on the agent's current rule list. A gravity model is used to weight the paths so paths with high-priority facilities are ranked higher for facilities close to the agent's current location.

Once the preferred path is selected, the agent loads it as its current trip itinerary. The agent then traverses this itinerary as far as it can in the current time step. If the agent encounters a node that contains facilities that are on its current rule list, the agent changes its internal state to "visiting facility" and generates a visit duration for that facility. If the facility at the node has no available capacity (for example, the parking lot is full), the agent "looks ahead" on its itinerary to see if a facility of the same class is available. If there is, the agent then continues its trip toward that node. If there is no other facility of the same class, the agent will then change its state to "queuing" and waits until the facility becomes available.

During each iteration of the simulation, the agent must check its available trip time, current travel mode, current rule list, and current state. Any of these can trigger a change in behavior. The agent may abandon its current trip and calculate a path back to its car, or to the exit. If the conditions have not changed, then the agent continues to execute its current behavior.

Although there are many more details to this behavior, the above reflects the overall logic behind the agent's way-finding logic. When implemented, the logic produces behavior that appears "smart" in that the agent generates logical paths and exhibits behavior that is humanlike.

Simulation Outputs and Management Recommendations

Several model outputs were produced to both predict the future effect of increasing use on current facilities and to compare Scenarios 1 and 2. The RBSim simulation runs for 2001, 2006, and 2011 produce visitor loads and capacities for each facility in the simulation including car and bus parking, visitor center, restrooms, and viewing platforms. The status of each facility is written to a database at each time step of the simulation. These outputs are then summarized for each hour of the day.

Trip Completion Rates—Trip completion rates measure the failure rate of visits to the Twelve Apostles site. If all parking is full, agents cannot enter the site, and the trip is counted as failed.

Trip completion rates in 2001 are around 100 percent, primarily because the available capacity (average or minimum) never reaches zero (fig. 31). In 2006, with average car park capacity projected to fall to 5 percent with current facilities and minimum capacity projected to reach zero for at least three hours of the day, trip completions fall to the 91 to 95 percent range. As visitors arrive at the facility and find no parking spaces, they are forced to leave the locale. By 2011, with average car park capacity around 3 percent for 3 hours of the day, and minimum capacity at zero for approximately 5 hours, trip completions fall to 80 percent during peak loading.

Visitor Encounters—Visual encounters are generated using line-of-sight calculations between each agent and all other agents within a 200-m radius. Screening effects of terrain are also incorporated into the calculation. The summaries can be generated for any link, node, or facility, or summaries can be made for each individual agent. Figure 32 shows the average visual encounters per visitor at lookouts. The number of encounters peaks around 3:00 in the afternoon with around 60 people visible at one time.

Queuing Times for Parking—RBSim simulates queuing behavior for parking with current facilities. The simulator records for each agent the total time in minutes that each party waits for parking. Projections in figure 33 show that average queuing, by 2011, will be double that of 2001. Average peak queuing time is expected to rise to approximately 1.25 minutes by 2006 and to almost 2 minutes by 2011.

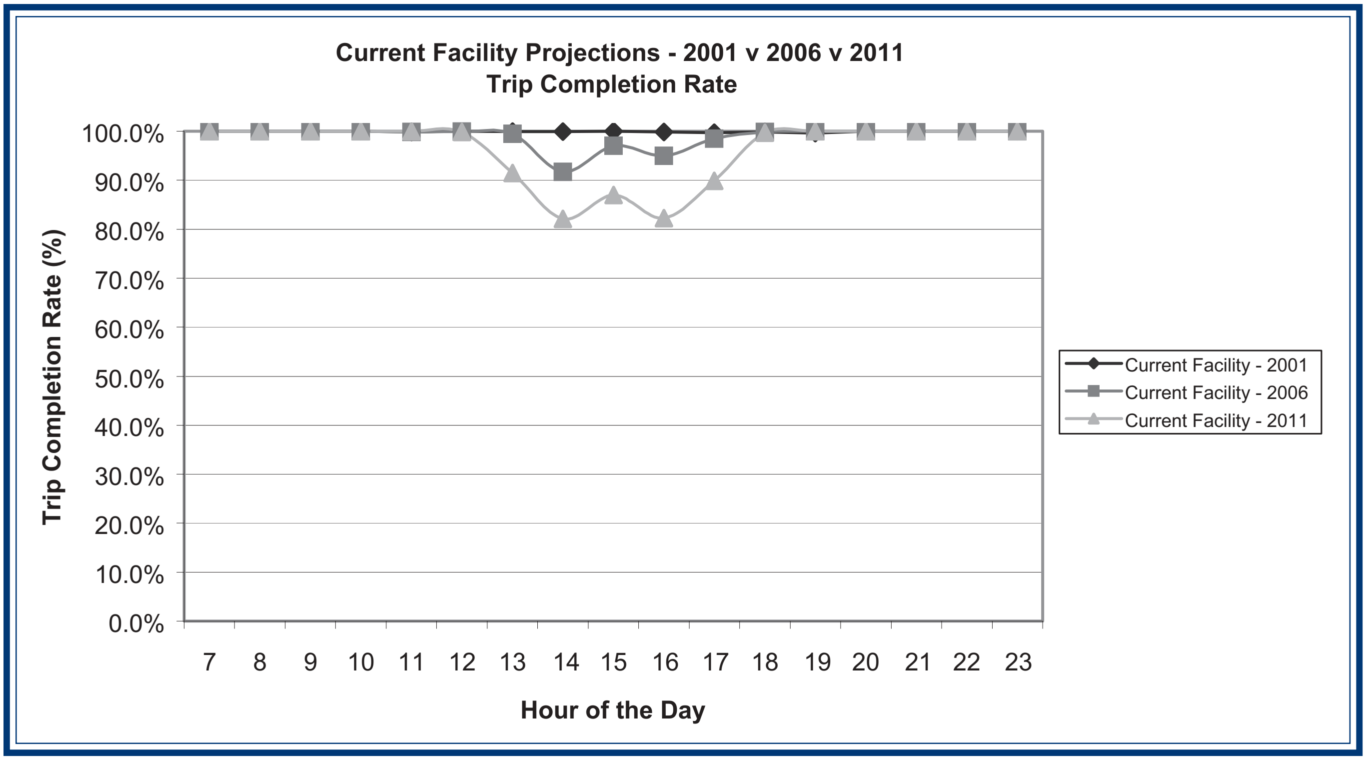


Figure 31—Trip completion rates in 2001 and projected rates for 2006 and 2011.

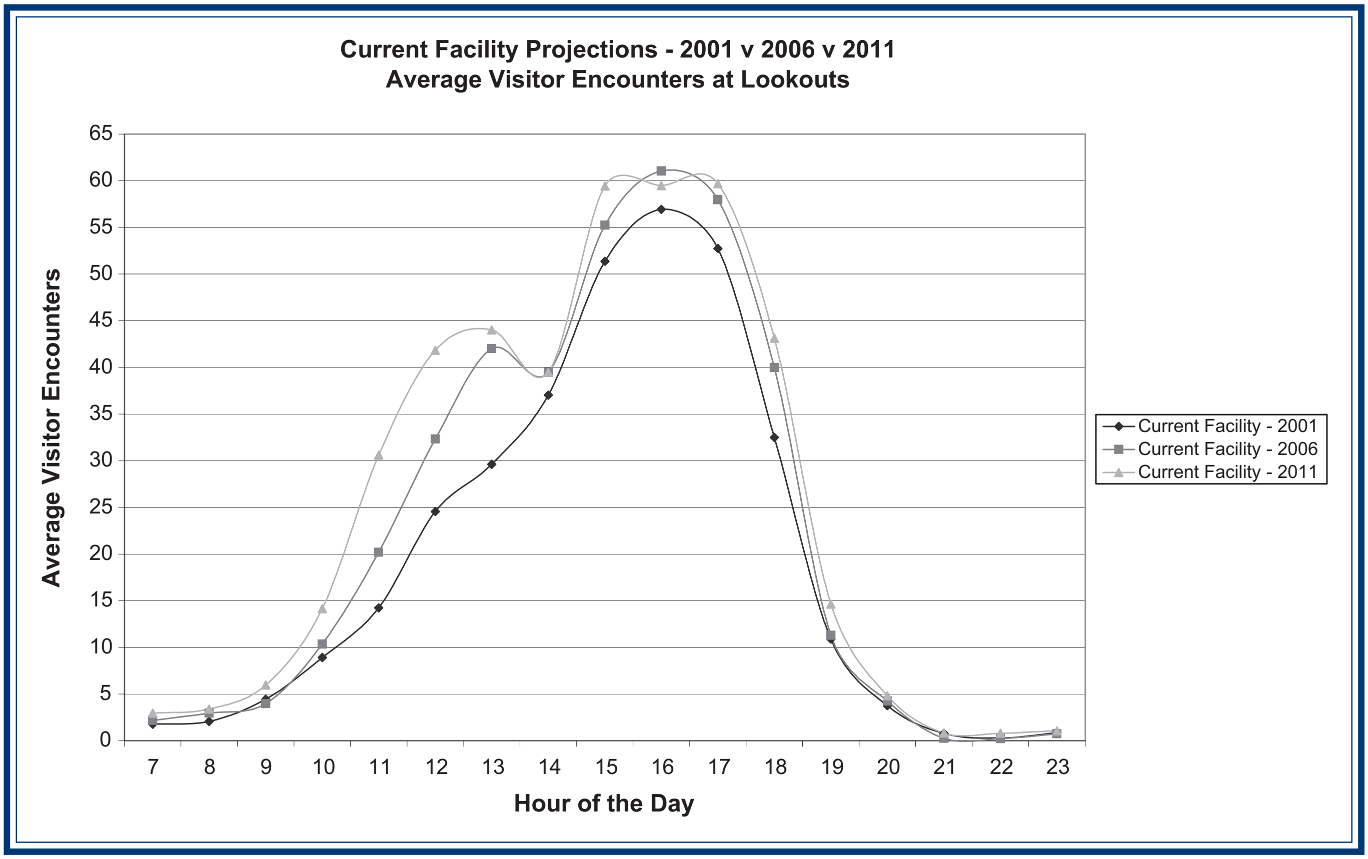


Figure 32—Average visitor encounters at lookouts in 2001, 2006, and 2011.

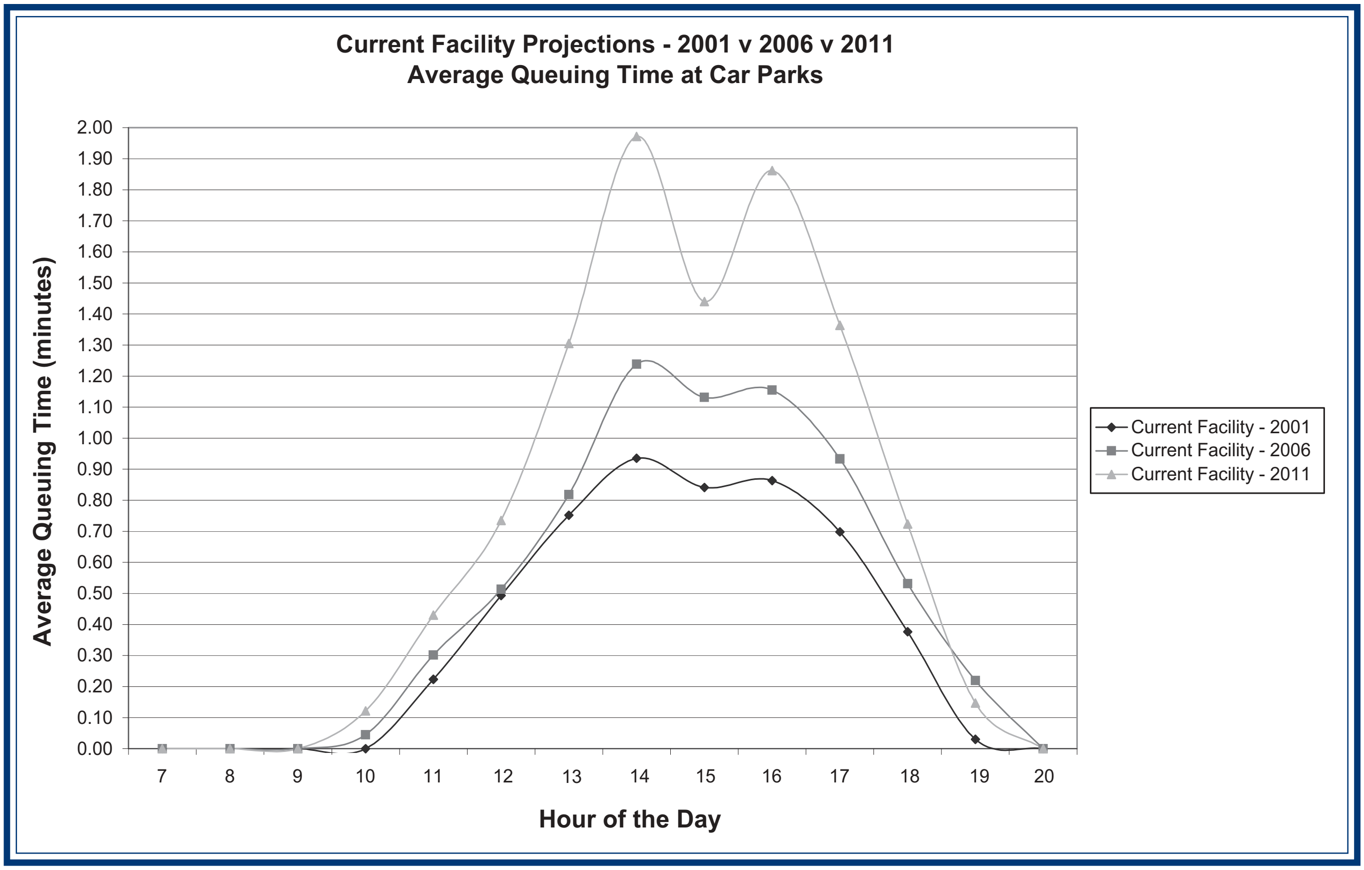


Figure 33—Average queuing times at car parks in 2001, 2006, and 2011.

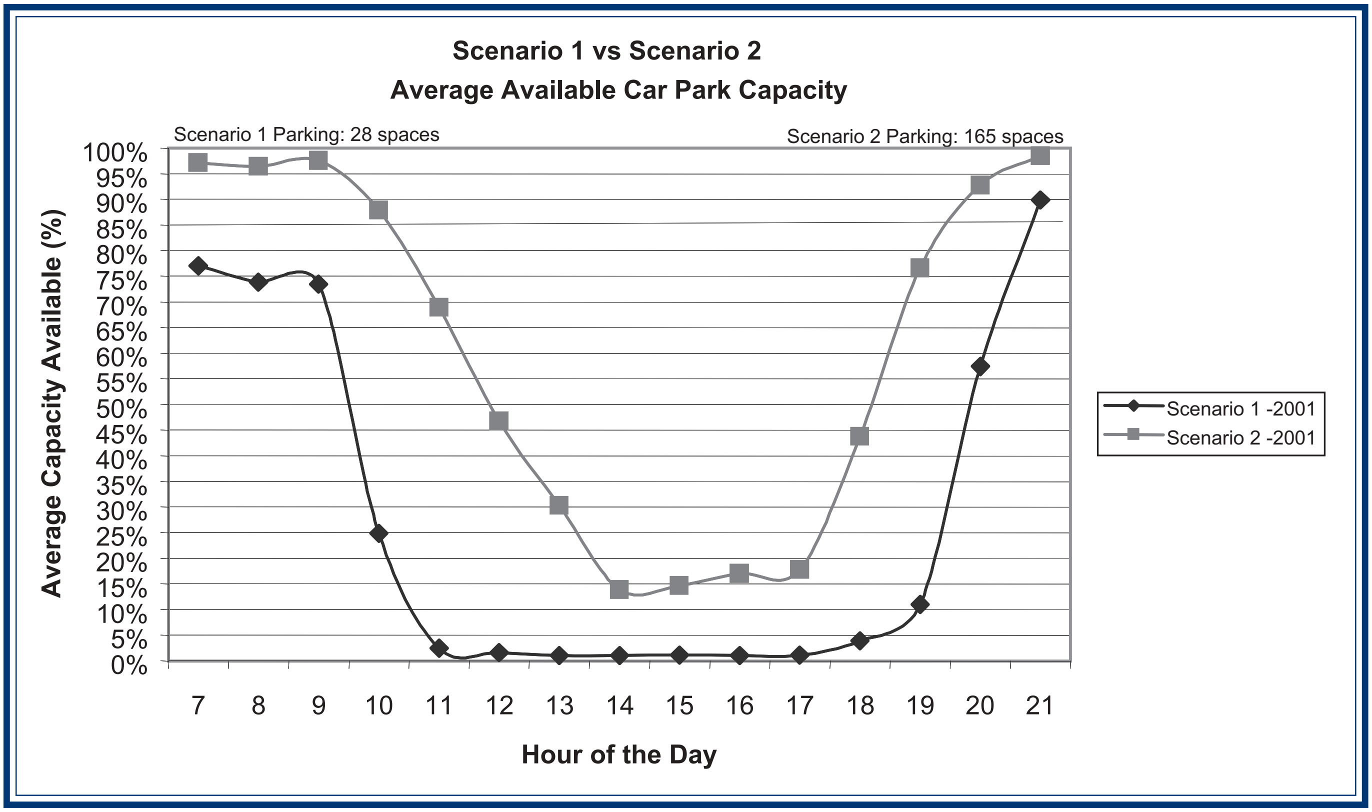


Figure 34—Average available parking capacity for Scenario 1 and Scenario 2 for 2001 traffic data.

Car Park Capacity—Figure 34 shows the average available capacity for the car park over the day. At 100 percent, the car park is empty; at 0 percent, all spaces are taken. The figure shows that for Scenario 1 the parking lot is full from 11:00 a.m. until 5:00 p.m. In Scenario 2 there currently is excess capacity throughout the day.

Management Implications

Simulation results predict that bus parking will be inadequate during the busiest time of the day between 2:00 and 4:00 p.m. by the year 2006. This shortage is exacerbated by the year 2011, as bus parking is inadequate for the whole period from 3:00 to 5:00 p.m. By 2006 the car park is full from 1:00 to 4:00 p.m. By 2011 the car park is full from 12:00 to 5:00 p.m.

The longer walk from the new parking facilities to the viewing platforms extends the average length of stay an average of 6 to 7 minutes. As the number of visitors increase, there is increasing pressure on viewing platforms and lookouts. Crowding increases because of the increased duration of stay and the increased capacity of car parks. It is expected that visitor satisfaction will decrease with an increase in visitors. This is caused by increased queuing times at parking lots, an increase in the length of stay, the number of visual encounters, especially at viewing platforms, and the number of visits that fail because of lack of parking at peak periods. This can partially be resolved by increasing the capacity of viewing platforms, but the long-term solution will require redistributing the visitors to other sites, especially at peak periods. Bus parking will need to be managed between 3:00 to 5:00 p.m. within 5 years (for example, use informal spaces near the visitor center). Car arrivals will have to be limited after 1:00 p.m. in 10 years or an extension to the car park will have to be built. Viewing platforms will have to be increased in capacity in the 5- to 10-year time horizon if the overflow car park is used or if the car park is extended further.

Mount Rainier National Park: Collecting Data to Model Visitor Use on a Complex Frontcountry Trail System

Mark E. Vande Kamp

Purpose

The purpose of this case study is to illustrate novel data collection procedures that were developed to model a complex frontcountry trail system in Mount Rainier National Park.

On clear summer days when the avalanche lilies are in bloom and blue ice is visible in the glacial crevasses high above, it is easy to understand why Paradise Meadow is the most heavily used area in Mount Rainier National Park. In 2003 an estimated 370,000 people drove, rode, or hiked to the lodge, visitor center, and climbing facilities at 5,400 feet on the south flank of the mountain (NPS 2004). Of those, about 70 percent took walks or hikes on the system of paved and gravel trails (fig. 35) in the subalpine meadow north of the visitor center and lodge (Vande Kamp 2001). Those walks and hikes are an important aspect of many visitors' experiences of Mount Rainier (Johnson and others 1991). At the same time, the level of visitation in the meadow has created negative impacts on the physical resources and the quality of visitor experiences found there. Offtrail hiking has damaged vegetation in many areas of the meadow (Rochefort and Swinney 2000), and at peak times, visitor movement on popular trails is impeded by high visitor density (Vande Kamp and Zweibel 2004).

To set policies that protect the physical resources and the quality of visitor experiences, managers of Mount Rainier seek to understand the relationships between manageable aspects of visitation (where visitors go, what visitors do, how many visitors are present) and important resources or experiences directly threatened by visitation. Toward this end, Mount Rainier is developing computer simulation models of visitation patterns in Paradise Meadow that can be used:

- To estimate potentially informative measures of visitation that are difficult to observe directly (such as the square cm of trail per hiker) and to relate those estimates to more easily measured and managed measures of visitation (such as the number of vehicles in the parking lot).
- To identify "bottlenecks" in the trail system where hiker density is highest and changes in trails or hike routing information might be most effective.
- To explore the impacts of hypothetical changes in management policy, trail construction, or visitation yet to occur in the real world (while acknowledging the assumptions necessary for such prediction).

The Challenge of Modeling a Complex Trail System

Simulation models have generally been applied to either complex trail systems that are remote and extensive, such as wilderness areas, or simple trail systems that are readily accessible, such as overlooks and visitor facilities (refer to other case studies in this report). The itinerary information necessary to

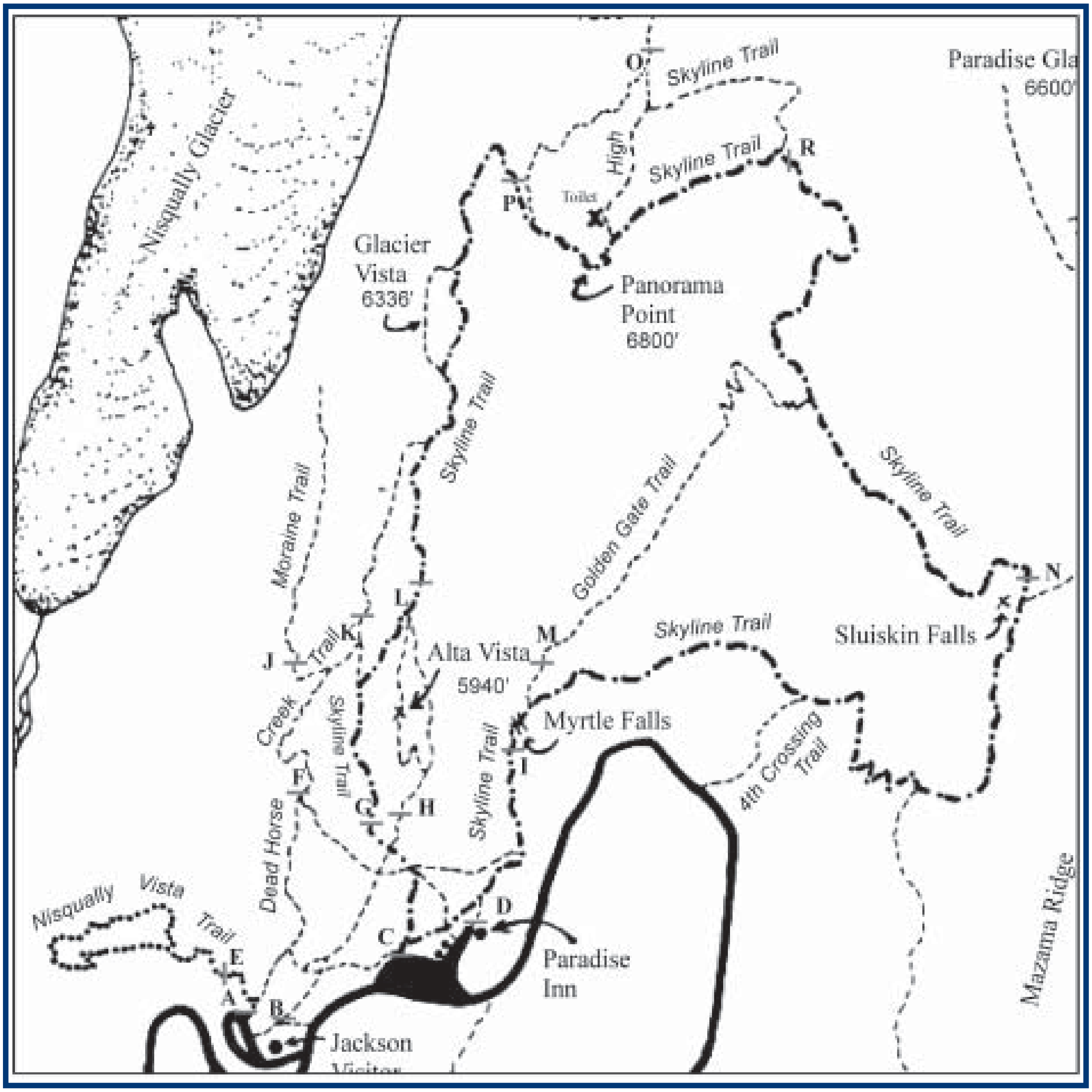


Figure 35—Trail system and waypoint sign locations at Paradise Meadow.

develop simulation models of those environments has most often been collected by contacting visitors after their hikes and recording the route and time information that they recall. This method can yield accurate itinerary data for both types of situations because hikers in remote and complex trail systems usually pay close attention to navigation, and hikers in simple systems don't have complex itineraries to recall. An alternate method of collecting itineraries in which visitors to remote and extensive systems are given map-diaries before their hikes and asked to record their movement has also been used to obtain accurate itinerary data.

It is more difficult to collect accurate itinerary data in Paradise Meadow because the trail system is both complex and readily accessible. Many visitors do not have a clear destination when entering the meadow, and they meander through the trail system without maintaining their geographic orientation. Visitors to specific locations such as Alta Vista or Myrtle Falls often depend on directional signs for guidance and do not know which of several possible routes they followed. Recall of hiking itineraries in subsequent interviews is often vague and inaccurate. Providing a map-diary and asking visitors to keep a detailed record of their movement is also problematic. Hikers who keep such itinerary records are required to pay considerable attention to both the map and the environment. Such attention is likely to alter their hiking itineraries and thus lead to simulation models that accurately estimate the visitation patterns of hikers who attend to maps but not the visitation patterns of typical visitors.

A method of collecting itinerary information is needed that (1) can provide detailed route and time information and (2) poses a small burden on hikers that is unlikely to alter hiking behavior. The rest of this case study describes a method of collecting itinerary information that is particularly well suited for use in complex and readily accessible trail systems like Paradise Meadow. The waypoint card method combines waypoint signs with recording of the time when visitors pass strategic locations to create a method of collecting itinerary data that is simple for visitors to complete but does not require large numbers of survey workers.

Methods

The goal of sampling was to produce a random sample of visitor parties entering Paradise Meadow via four access points leading from the parking lots or visitor center. Figure 35 shows the trail system with the four entry points labeled A, B, C, and D. A survey worker was stationed at each entry point and instructed to approach every third party who passed. If the number of survey workers is smaller than the number of entry points into the trail system, a more complex sampling schedule in which workers rotate to the different entry points can be used to produce a representative sample of hiker itineraries. The sample was collected on August 23 and 24, 2003, between 9:00 a.m. and 6:00 p.m.

When approaching a hiking party, survey workers introduced themselves, stated that they were conducting a study of visitor movement for Mount Rainier, and asked one member of the party to participate in the study. A laminated copy of the Office of Management and Budget disclosure statement was handed to those visitors who agreed to participate. Then the survey worker asked for the visitor's home zip code, the size of his or her party, the number of party members who were less than 18 years old, and the party's hiking destination. The survey worker then instructed the respondent how to complete the remainder of the survey by explaining:

> There are waypoint signs like this one (pointing to the entry waypoint) placed along trails throughout the meadow. Every time you pass one of these signs, please write the letter of the sign and the time on your card. I'll fill out this first one for you (writing down the time and entry waypoint letter on the card). If you pass the same point more than once, please write down the time each time you pass. There are pencils and clocks on each sign. When you are done hiking, please leave your card with the survey worker where you leave the meadow, or place the card in the survey box like this one (point to exit sign and box) if no one is there.

Most respondents returned their cards directly to a survey worker. When they did, the worker asked them if there were any places that they stopped for more than 5 minutes during their hike. If so, the worker noted the location and duration of the stop on the waypoint card.

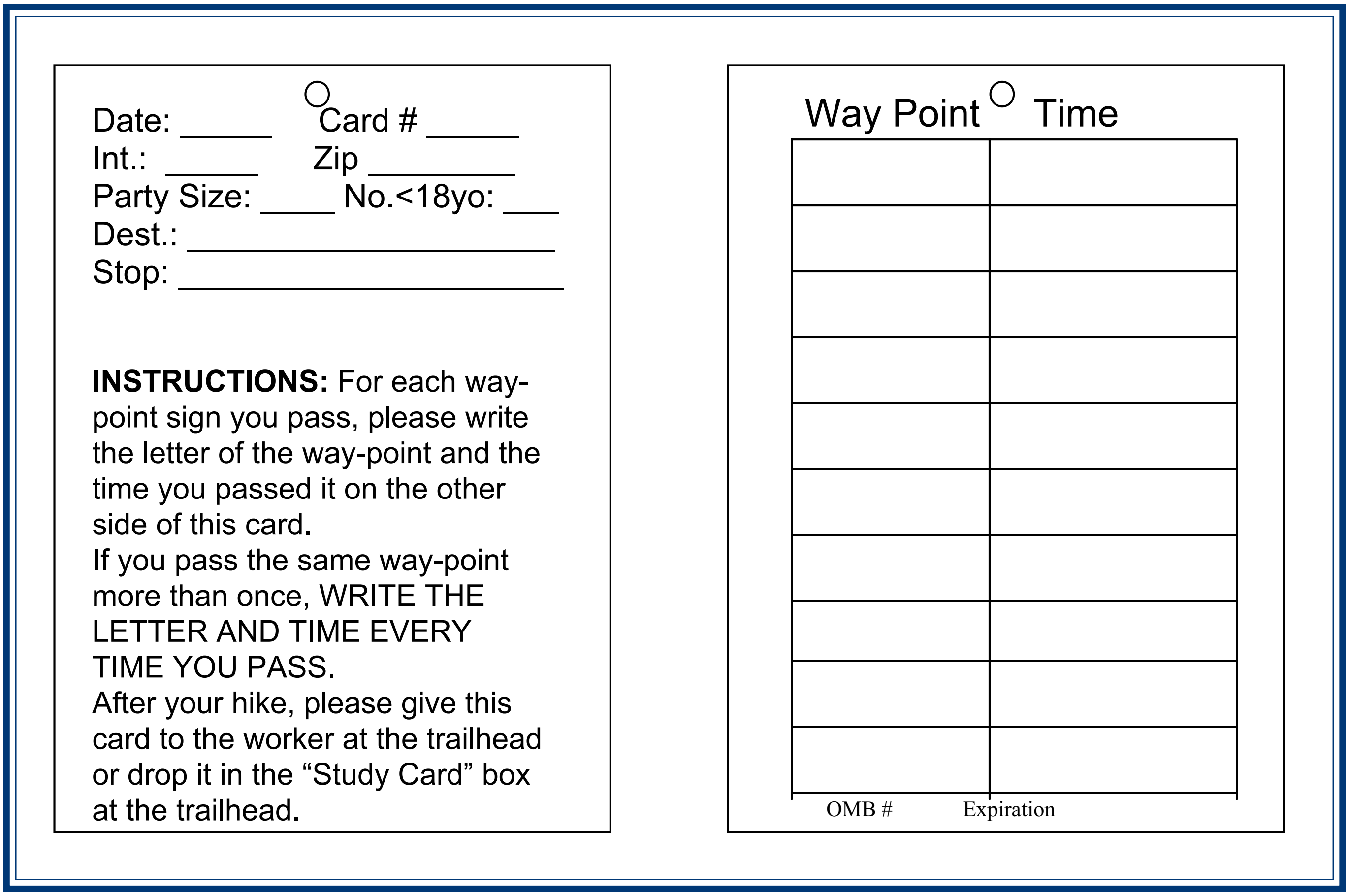
Figure 36 shows the front and back of the waypoint cards on which data were written. The cards were printed on waterproof card stock and included a twist-tie that could be used to attach them to a belt loop or backpack strap so that they would be handy for respondents to write on as they hiked. Figure 37 shows the front of a waypoint sign. Each sign was printed on 8.5- by 11-inch card stock, attached to a metal stake, and covered with a clear plastic bag to protect it from rain or fog. A small LCD clock was attached to the center of the sign. The clocks on all signs were synchronized. The back of each sign was identical to the front, with the exception that the clock area included text explaining that a clock could be found on the other side.

Waypoint signs were placed at locations in the meadow selected to define most common hiking itineraries. For example, common sequences of waypoints passed included C, I, I, D for hikes to Myrtle Falls, or C, G, K, P, R, M, I, C for the loop hike to Panorama Point. The sign locations were selected to define general boundaries for the lower, middle, and upper meadow. The number of signs necessary to provide precise information about hiking routes in the lower meadow (locations below the F, G, H, and I signs) was likely to impose an unreasonable burden on hikers because the signs would have been only yards apart. Because the trail system becomes simpler as one moves away from the parking areas, longer hikes into the upper meadow were more precisely defined by the waypoint card data than were shorter hikes in which visitors did not leave the lower meadow.

Exit signs (fig. 38) also measuring 8.5 x 11 inches and attached to metal stakes were also placed at the entry/exit points. Plastic boxes were attached to the base of each staked exit sign where respondents could deposit cards if the survey worker was not present when they finished hiking.

Results

Of the 351 parties asked to participate in the study, 17 refused at the initial contact and 265 returned



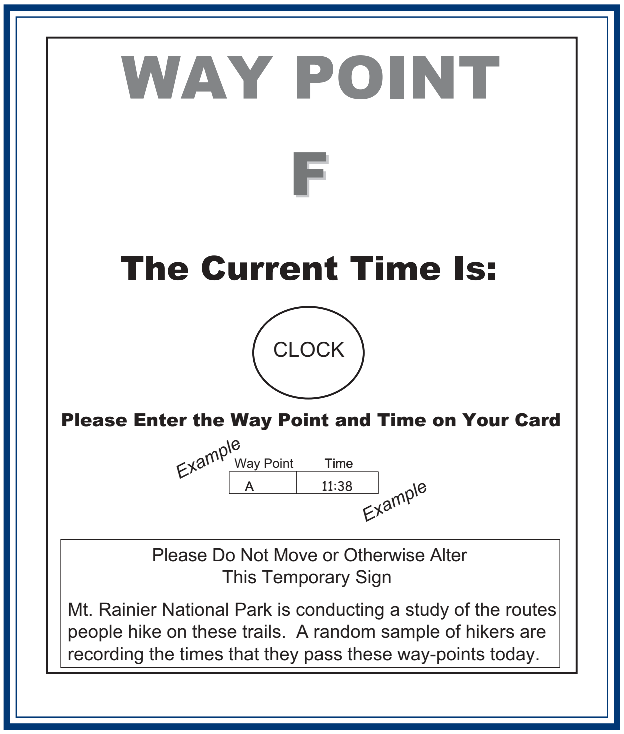
Date: _____ ○ Card # _____
Int.: _____ Zip ________
Party Size: ____ No.<18yo: ___
Dest.: ______________________
Stop: _______________________

INSTRUCTIONS: For each way-point sign you pass, please write the letter of the way-point and the time you passed it on the other side of this card.
If you pass the same way-point more than once, WRITE THE LETTER AND TIME EVERY TIME YOU PASS.
After your hike, please give this card to the worker at the trailhead or drop it in the "Study Card" box at the trailhead.

Way Point ○	Time

OMB # Expiration

Figure 36—Front and back of the waypoint card respondents used to record the waypoints they passed while hiking.



WAY POINT

F

The Current Time Is:

CLOCK

Please Enter the Way Point and Time on Your Card

Example

Way Point	Time
A	11:38

Example

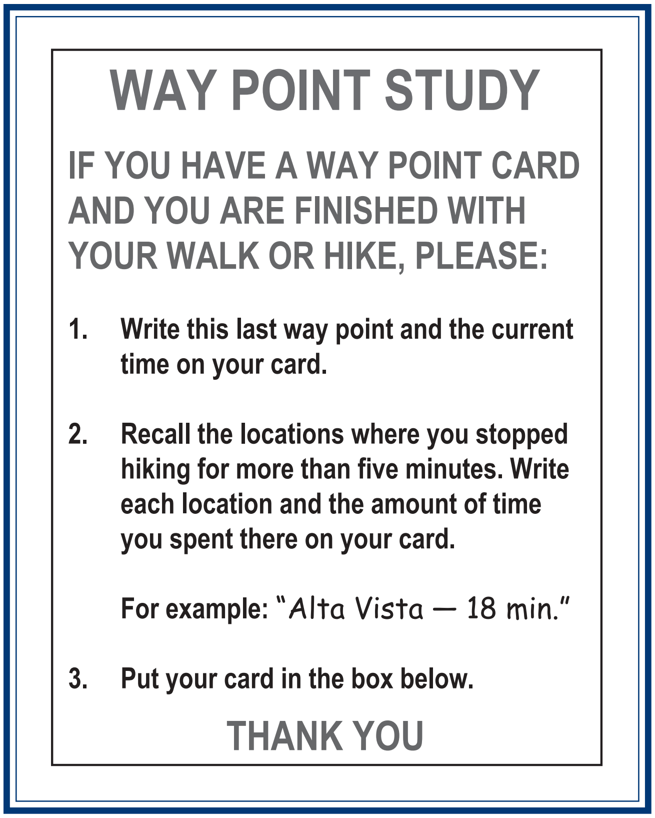
Please Do Not Move or Otherwise Alter
This Temporary Sign

Mt. Rainier National Park is conducting a study of the routes people hike on these trails. A random sample of hikers are recording the times that they pass these way-points today.

Figure 37—Typical waypoint sign placed alongside the trail.

completed cards, yielding a total response rate of 76 percent. Anecdotal reports from survey workers indicated that respondents found it easy to follow the survey instructions. An initial check of the 265 completed itineraries found that 48 (18 percent) included sequences of waypoint signs that were impossible to encounter. However, closer examination of those impossible routes suggested that 27 occurred because respondents overlooked a single waypoint sign. If the overlooked signs are replaced in those itineraries, the incidence of impossible routes falls to 8 percent. In total, 70 percent of all parties approached for the study returned waypoint cards that traced possible hiking routes.

Many visitors found it difficult to recall the locations and durations of the times they stopped hiking for more than 5 minutes. In addition, survey workers often found it difficult to talk with returning parties while maintaining the sampling interval for entering parties (particularly at the busiest entry point, waypoint D). Thus, a relatively small number of respondents described the places they stopped and the duration of their stops. Table 18 summarizes the duration data for three locations at which hikers commonly stop.



WAY POINT STUDY

IF YOU HAVE A WAY POINT CARD AND YOU ARE FINISHED WITH YOUR WALK OR HIKE, PLEASE:

1. Write this last way point and the current time on your card.
2. Recall the locations where you stopped hiking for more than five minutes. Write each location and the amount of time you spent there on your card.

   For example: "Alta Vista — 18 min."
3. Put your card in the box below.

THANK YOU

Figure 38—Exit sign placed at entry/exit points instructing respondents how to return waypoint cards when the survey worker was not present.

Table 18—Duration of stops at three locations in Paradise Meadow.

Locations	Duration of stops Mean minutes	 Standard deviation	N
Myrtle Falls	10.6	3.7	20
Alta Vista	11.7	4.1	7
Panorama Point	17.2	13.7	16

Discussion

The high response rate, low incidence of impossible routes, and anecdotal reports all suggest that respondents found it easy to accurately record and report their hiking routes by filling out the waypoint cards. Thus, waypoint cards offer a clear advantage over retrospective interviews when applied in Paradise Meadow.

The relative usefulness of the waypoint card method in comparison to map-diaries is currently more difficult to determine because this initial study was not designed to compare and contrast those data collection methods. For example, a comparison of the degree to which participating in the waypoint card study or a map-diary study would alter hiking routes is not possible. (The question of whether the waypoint card method altered hiking itineraries at all will be tested by future work in which simulation models based on the waypoint card itineraries are constructed and their validity is tested.) Other comparisons of the waypoint card and map-diary methods of collecting itinerary show a mixture of advantages and disadvantages. The data provided by the waypoint cards are ideally formatted for the building of computer simulation models, and are much easier to code and enter into a computerized database than the data from map-diaries. However, the waypoint data do not provide the same level of detail as a complete map-diary. In perhaps the most extreme case from the current study, figure 35 shows at least seven possible hiking routes through the lower meadow for a hiker whose waypoint card began with points B, G.

When the results of the waypoint study were used to construct a simulation model of use for the observed weekend, three shortcomings of the data were identified: (1) a lack of detail describing hikes in the lower meadow (discussed above), (2) poor information about the durations and locations of hiking breaks, and (3) lack of information about hiking patterns on the trail loops at Alta Vista, Glacier Vista, and Panorama Point. For the construction of the preliminary model, these shortcomings could be addressed by making assumptions about hiker behavior. However, future applications of the waypoint card method could be improved by addressing each shortcoming.

The data describing hiking breaks were limited, but were generally consistent with observations that most hiking breaks occurred at a few locations in Paradise Meadow (Myrtle Falls, Alta Vista, Panorama Point). The validity of the computer simulation would be improved if the distribution of stop durations at those locations could be more accurately described. In future studies, visitors at those sites will be systematically observed to collect such descriptive data.

More detailed description of hikes in the lower meadow can most easily be obtained by adding waypoints in that area. The initial success of the method and verbal reports from respondents indicating that participation was not a concern suggest that such additions will not pose a significant burden. Thus, waypoint signs will be added at several more junctions in the lower meadow.

The specific changes necessary to obtain more detailed description of hiking patterns on trail loops has not been determined. Waypoint signs could be added, systematic observations could be made, or some combination of those two techniques might be adopted. Inspection of each trail loop prior to the next waypoint card study will determine the alterations or additions to the study design.

Currently available GPS receivers offer a means of collecting hiker itinerary data that is superior to the waypoint card method or any other paper-and-pencil instrument. Unfortunately, the receivers are not yet cheap enough that they can be distributed to a large number of hikers without unacceptable costs due to breakage, loss, and pilfering. Nonetheless, small numbers of GPS receivers might be used to collect information that could be used to validate the waypoint card information (for example, by asking some visitors to both fill out a waypoint card and carry a GPS receiver). Such validation studies could develop procedures useful in future large-scale studies of hiker itineraries using GPS receivers.

Conclusion

Computer simulation modeling holds great promise as a management tool. As models are developed for a variety of recreational settings, novel problems will inevitably arise. This case study discusses how a new data collection procedure was used to address the problem of collecting information describing use of a complex trail system at Paradise Meadow in Mount Rainier National Park.

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Chapter 5:
Future Directions for Simulation of Recreation Use

David N. Cole

Introduction

As the case studies in Chapter 4 illustrate, simulation modeling can be a valuable tool for recreation planning and management. Although simulation modeling is already well developed for business applications, its adaptation to recreation management is less developed. Relatively few resources have been devoted to realizing its potential. Further progress is needed in refining the models, and their inputs and outputs. Equally important is work to assess the validity of models as well as to understand the precision of model estimates and the appropriateness of using model outputs for various purposes. Finally, there is substantial potential to link models of recreation behavior to transportation modeling and to models of biophysical impacts to provide more holistic perspectives.

Software Development

One of the keys to making simulation modeling of recreation a more easily used tool is to automate as many of the steps in data entry, model development, and model output as possible. That has been a primary focus of work on RBSim, given its development as an application specific to recreation. For example, users can navigate through the program using drop-down menus. More generic software packages, such as Extend, could also be more automated and focused on specific recreation applications. While this would require substantial work, it is a means of taking advantage of the considerable developmental effort that has already gone into the generic software package and would greatly improve its usability.

The ability to use simulation modeling could also be improved by specifying the most useful generic data inputs and outputs, along with efficient means of collecting data and displaying model outputs. For example, table 19 lists most of the common types of data needed to develop a computer simulation model. The case studies illustrate some of the ways such data can be collected. More comprehensive and detailed descriptions of data collection methods might be useful. Table 20 lists some of the more important outputs that can be displayed. Software developed in such a way that common types of data are easily input and outputs are readily produced would be a major step forward.

Other needed improvements include linkage to Geographic Information Systems (GIS) and the ability to produce visualizations. The ability to import data directly from GIS files would greatly decrease the time required to get models up and running, while the ability to automatically display outputs on maps developed using GIS would increase the interpretability of model results. Visualization capabilities also increase the utility of the modeling as a communication device. Linkage to GIS and visualization capabilities have been fundamental aspects of component architecture in the development of RBSim. Linkages to GIS and visualization in the models based on Extend are also being developed.

Current simulation modeling requires contracting with academic or consulting institutions. Much can be learned from working with academics and consultants, but much of the value of simulation modeling lies in the ability of managers and planners to use it routinely. It must become a tool that managers themselves can develop and use. Although we are currently far from that capability, if there is sufficient interest in simulation modeling, procedures and software could be developed to make it a reality. Recent experience with Geographic Information Systems (although clearly more broadly useful) provides an example of the possibilities for modeling in the future.

Table 19—Common data inputs for simulation models of recreation.

1. Network Information
    - a. headways (trailhead,…)
    - b. links (trail segment, road segment, river segment,…)
    - c. nodes (campsite, picnic site, attraction site, trail junction,…)
    - d. travel routes
2. Environmental Data (desirable but not always necessary)
    - a. digital elevation model
3. User Information
    - a. proportion of groups with differing modes of travel
    - b. proportion of groups with differing group sizes
    - c. other means of differentiating between groups
4. Travel Route Information
    - a. when groups arrive at headways by user type (mode of travel, group size…) may vary by season within year, week within season, day within week and hour within day
    - b. travel routes (links and nodes visited) that groups take by user type (mode of travel, group size…)—may vary by season, week, day of the week and hour of the day
    - c. travel speeds on links
    - d. delay times at nodes
5. Data for Verification Purposes
    - a. encounters per unit of time per link and/or node (encounters need to be carefully specified—they can be defined in various ways)
    - b. amount of use per unit of time per link and/or node

Table 20—Common outputs from simulation models that are useful in recreation management.

1. Amount of use per unit of time for each link and/or node, as well as aggregations of links and nodes
    - a. common time units are per season/year, per day/night and at-one-time (PAOT, PPV)
    - b. metrics can include both measures of central tendency (mean, median, mode) and distribution (maximum, minimum, proportion of days/nights/instances with varied encounter levels or above or below some standard)
    - c. differences by group type (mode of travel, group size…) might also be desirable
2. Encounters per group per unit of time for each link and/or node, as well as aggregations of links and nodes
    - a. common time units are per trip and per day/night
    - b. metrics can include both measures of central tendency (mean, median, mode) and distribution (maximum, minimum, proportion of days/nights/instances with varied encounter levels or above or below some standard)
    - c. encounters need to be carefully specified—they can be defined in various ways (for example, visual on link, overtaking on link, meeting on link, node)
    - d. differences by group type (mode of travel, group size…) might also be desirable
3. Identifying maximum use levels that can enter without violating some standard
4. Queuing times

Improved Data Collection

Data input can be improved by making the collection of visitor data more routine and by taking advantage of improvements in technology. In many parks and protected areas, data on natural resources are collected routinely, while the collection of data on people is ignored. Such data are important, not only because recreationists can significantly degrade the integrity of natural resources but also because management is often charged with providing opportunities for quality recreation experiences. Several techniques for monitoring visitors are well established (Watson and others 2000); they simply need to be applied more frequently and more consistently.

New technologies are also emerging to simplify the process of collecting visitor data (Cessford and Muhar 2004). In particular, there have been recent improvements in the utility of video, time recording of use distribution data, and the ability to download data remotely, reducing the frequency of onsite equipment maintenance. Chip technology and tracking devices have advanced to the point where they can sometimes be used to obtain data on the routes that visitors take. Further development of these technologies will increase the cost effectiveness of model development.

Improved Model Outputs

The case studies in the preceding chapter illustrate the wide range of recreation situations that can be modeled, as well as some of the important applications of model output. However, the appropriateness of different types of simulation models and model outputs as means of addressing the issues facing recreation managers needs attention. The current state of computer simulation of recreation is better able to address some of these situations and applications than others.

Currently, procedures for conducting terminating simulations are better developed than those for conducting steady-state simulations. Terminating simulations are clearly well suited to modeling day use; however, it is unclear whether or not steady-state simulations would be a better way to model what is happening during periods of peak use by visitors on multiday visits. If we should deem steady-state simulation to be appropriate, there are some further challenges that must be addressed. One of the most difficult challenges of steady-state simulation is determining the appropriate runtime length needed to generate statistically valid model outputs (that is, outputs that are not biased by start-up effects or autocorrelation). Centeno and Reyes (1998) have developed techniques to establish steady-state runtime lengths needed to achieve specified levels of accuracy for model outputs, but they were designed primarily for manufacturing applications and may be of limited utility in recreation applications. For example, the 2,000-day runtime length for the steady-state simulations used in the John Muir case study had to be selected arbitrarily. While intuitively one would expect this runtime length to be adequate, the methods developed in the simulation literature could not be used to test our intuition. Before the full potential of computer simulation can be realized for outdoor recreation management, more research is needed to develop and standardize methods to establish steady-state simulation runtime lengths.

The precision of model estimates has not been adequately estimated in recent applications. For example, we hope to use computer simulation as a means of estimating encounter rates in the interior of large backcountry areas, without needing to directly monitor encounters within the area. This should be possible if model estimates are precise enough. Current models can produce estimates of encounters (as illustrated in the case studies), but we do not know whether the estimates are precise enough to be useful for this purpose.

To explore precision further, we employed a procedure proposed by Freese (1960), based on a chi-square test, for computing the potential error associated with model estimates in relation to observations of the real world. We used the validation data collected at Arches National Park presented in Chapter 4. The number of cars at parking lots was observed for 4 days and compared with model estimates of cars in parking lots. At the Delicate Arch parking lot, the mean number of cars observed was 29 when the model predicted 25. Freese's procedure indicates that, at a 95 percent confidence level, the error associated with model estimates is 24 percent or about 7.7 cars. This error estimate can be used to interpret the finding in the Arches study that the maximum number of hikers who can visit Delicate Arch in a day, without violating standards, is 315. Given a 24 percent error, the maximum that can be allowed is somewhere between 240 and 390 hikers per day—not necessarily 315. Even this estimate of error should be used with caution, however, because 4 days of observation at parking lots may not be sufficient to provide an accurate estimate of real-world conditions. With a larger sample, we would have a more accurate estimate to compare with the model.

Validation

A related but different issue is validation, how well the model mimics the real world. The difference between problems with precision and the need for model validation can be clarified with an example. We may use a simulation model to estimate the maximum persons-at-one-time (PAOT) at a recreation site for which we have a standard of no more than 100 PAOT. Our model may estimate, based on the mean of numerous simulation runs, that currently the PAOT does not exceed 90. Either low precision or an invalid model can reduce the utility of this estimate. For example, perhaps this estimate has an error of about 50 percent (it is not very precise)—the real estimate could be anywhere between 45 and 135. If this were the case, it would be impossible to conclude from a mean model estimate of 90 whether the standard has been exceeded or not. The mean model estimate would have to be greater than 150 before we could confidently conclude that the standard was exceeded. An invalid model is similarly problematic. If the model estimates a mean PAOT of 90 when the estimate should be 110, results are not very useful. Validation is a means of assessing the likely accuracy of model outputs.

In the case studies presented in Chapter 4, model validation is generally limited to techniques that rely on intuitive judgments. For example, in the John Muir case study, sensitivity analyses conducted with the simulation model suggest that when total simulated use is increased, estimates of hiking and camping use and encounters increased. This analysis supports the internal and face validity of the simulation model. The model works the way that experts believe it should and outputs seem reasonable. However, such analysis is less useful for making conclusions concerning how well the simulation model outputs correspond with data for the real world—the actual trail and campsite system. Due to lack of sufficient data concerning actual hiking and camping use and encounters, quantitative validation techniques were not possible in the John Muir case study.

The above example underscores the need to collect data that can be used not only as inputs to a computer simulation model, but as the basis for quantitative validation of the simulation model. Furthermore, while there is a relatively extensive body of literature describing validation techniques for simulation models of manufacturing systems, there is a lack of recent research concerning the appropriateness of alternative statistical techniques for validation of computer simulation models of parks, wilderness, and related outdoor recreation systems. More research is warranted to develop standardized, quantitative methods to assess the validity of computer simulation models designed for outdoor recreation management.

Linkage to Transportation Models

Park planning could be greatly improved by linking recreation models to transportation models. Historically, the term “modeling” has been used in the transportation planning and engineering field to refer to travel forecasting models. Applications of transportation forecasting models have focused primarily on urban environments with complex transportation systems; however, forecasting models have been developed to forecast vehicle traffic volumes for Yosemite National Park. In general, transportation networks within National Parks and related areas are relatively simple in comparison to typical applications of forecasting models. Data used to develop forecasting models for urban areas include trip diaries describing travel patterns within the transportation network, data on the characteristics of the transportation system, land use and/or activity data, and census data.

More recently, transportation modeling applications have broadened to include simulation modeling. In many ways, transportation simulation modeling resembles the recreation simulation modeling techniques described in this report. In particular, both are probabilistic. In other words, simulation results will vary across simulation runs or replications in a manner that represents the stochasticity or uncertainty and time-varying nature of the system being modeled. While transportation and recreation simulation modeling approaches have comparable capabilities, transportation modeling software may not be as well suited to park management applications because it has been purpose-built to represent urban transportation system elements such as streets, highways, and light-rail transit lines. In contrast, simple spreadsheet modeling is usually deterministic, meaning that for a given parameter value (such as total daily use level) the model output will be the same for each replication. In this way, spreadsheet modeling is similar to regression modeling and other statistical or mathematical modeling approaches.

The output from transportation models should correspond closely with the input to the recreation simulation models described in this report. Hence, development of linkages between the two sets of models is equivalent to developing a more comprehensive model.

Linkage to Biophysical Impacts

Another possibility, fraught with both promise and pitfalls, is linking models of visitor distribution with models of biophysical impact. If successful, such a linkage would make it possible to estimate and/or predict impacts across both space and time from easily collected data on visitor inputs to the system. Alternative management scenarios and futures could be evaluated on the basis of detailed information about where and when different types of impact might occur. This capability could improve the ability to assess environmental impacts, within planning contexts, by an order of magnitude.

The most obvious barrier to achieving this potential is inadequate knowledge about the relationship between visitation and resultant biophysical impacts. Lack of investment in research on recreation impacts is a fundamental contributor to this problem, as is the complexity of the variables that interact to explain variation in impact levels. The relationship between the amount of use and the amount of impact is nonlinear (Cole 2004). Moreover, variables such as visitor behavior and environmental characteristics commonly explain at least as much of the variation in impact as amount of use. Some of the impacts of most interest and concern, such as long-term effects on the viability of animal populations, are difficult to study. Despite these challenges, the potential insight that could be gained by linking visitation and biophysical impact models suggests that it is worth attempting.

Conclusions

As this report illustrates, computer simulation modeling of recreation can contribute significantly to recreation planning and management. Valid models of visitor distribution and flow can be developed and linked with transportation models and possibly with models of biophysical impact. The result would be a greatly improved ability to assess the operation of entire systems (as opposed to single elements in isolation), with continuous information across space (as opposed to discrete locations) and across time (as opposed to discrete times) for measures that may be difficult to assess directly. Such a comprehensive perspective would vastly improve the ability to plan and manage wisely.

Progress to date has been exciting. But it has also been limited, opportunistic, and not well coordinated. Funding of the collaborative work that resulted in this report provided the opportunity to improve coordination and mutual learning, to assess the current state-of-the-art, and to make progress on a few issues. As is often the case, this effort identified many issues that need additional attention. Software needs to be further developed and made more user-friendly. Data need to be more routinely and carefully collected. More modeling projects need to be undertaken, with funding sufficient to better assess the precision of estimates and the validity of models. Finally, the kinds of information that models can provide need to be more commonly incorporated in decisionmaking processes.

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