Chapter 2: Historical Development of Simulation Models of Recreation Use

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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:

Encounters/Party-Night = –0.14 + 0.024(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:

Encounters/Party-Night = –0.02 + 0.011(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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