

Simulation modeling of visitor flows: where have we been and where are we going?

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Abstract: The Wilderness area Simulation Model was developed in 1972 by Resources for the Future with programming assistance from IBM. It simulates parties moving through a wilderness and records the number of encounters each party experiences. The model has been applied to the Spanish Peaks Primitive Area in Montana, the Adirondack Forest Reserve in New York, the Desolation Wilderness in California, the complex of the wilderness areas surrounding and including Yosemite National Park, the Green and Yampa Rivers in Dinosaur Monument, the Colorado River in Grand Canyon National Park, and the Appalachian National Scenic Trail in Vermont. In its time, the model was a useful tool for establishing the relationship between use levels and encounters and testing management alternatives. As innovative as the model was, recent advances in behavioral science and computer technology have rendered it out of date.

Introduction

Recent application of simulation modeling to wilderness and river settings has revived interest in the Wilderness Simulation Model first developed by Smith and Krutilla (1976). The model was stimulated by ideas expressed by Stankey (1972) in a book on the theoretical and applied analysis of natural environments (Krutilla 1972). He hypothesized that visitors' satisfaction with a wilderness experience was inversely related to the number of encounters they had with members of other parties. Fisher and Krutilla (1972) conceptualized this idea into a model that established the optimum level of use of a wilderness area to be the point at which the incremental benefit of an additional party is just offset by the decrease in the benefits of the parties encountered. The practical application of this concept required that an empirical relationship between the benefits enjoyed during an outing and the number of parties encountered be determined and that a means for estimating encounters be developed. 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.

In order 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.

Visitor data required to run the model 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. Area information included the trail segments and camps in the network and the time it took parties of different sizes to hike or ride each trail segment in each direction. Finally, the various routes that might be taken were enumerated along with their probability of being selected. The model scheduled parties of different sizes and types to arrive on different weeks, days of the week, and hours of the day. It then assigned each party a route that included the trails over which they travel and the campsites they used. 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.

Prototype testing of the model was conducted on the Spanish Peaks Primitive Area (Smith & Krutilla 1976) and the Adirondack Forest Reserve (Smith and Headly 1975). Subsequently, the model was enhanced by Resources for the Future under contract with the Forest Service (Shechter 1975). This new model was applied to the Desolation Wilderness in California (Shechter & Lucas 1978) and to the complex of wilderness areas surrounding and including Yosemite National Park (van Wagtendonk 1979). Modification of the model for river settings allowed it to be applied to the Green and Yampa Rivers in Dinosaur Monument (Lime et al. 1978) and to the Colorado River in Grand Canyon National Park (Underhill et al.

1986). A final application of the model to a trail system was done by Potter and Manning (1984) on the Appalachian National Scenic Trail in Vermont.

Spanish Peaks Primitive Area

Smith and Krutilla (1976) were the first to apply the Heck and Webster (1973) model to a field area. They used the Spanish Peaks Primitive Area, now a 63,300-acre (25,320-ha) unit of the Lee Metcalf Wilderness Area, located in the southwest corner of Montana, USA, just northwest of Yellowstone National Park (Figure 1). The area was administered by the Gallatin National Forest. Data collected by the Forest Service in 1970 and 1971 were used to initialize the model and develop different simulation scenarios. Examination of USGS 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-four unique routes of various lengths were identified, with up to six 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 four-week period (Smith & 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 familiar with the Spanish Peaks judge the reasonableness of the inputs and the outputs and 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

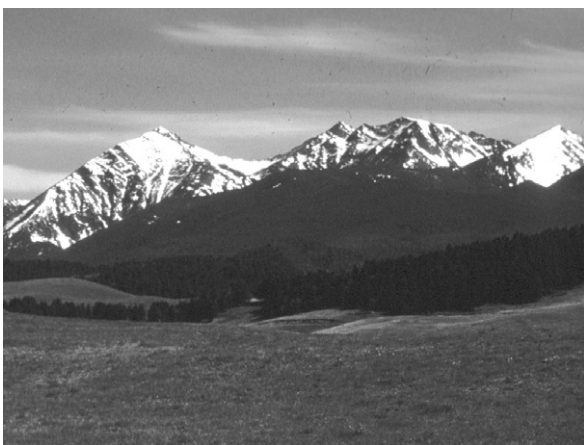


Figure 1. The Spanish Peaks in the Lee Metcalf Wilderness. Photo courtesy of Ryan Turner.

use levels were directly related to encounters, and that evenly distributing arrival patterns reduced encounters. Based on these analyses, the model was considered valid, although further testing was recommended.

Adirondack Forest Reserve

Smith and Headly (1975) conducted a limited application of the simulator to the West Canada Lakes Wilderness Area in the Adirondack Forest Reserve in 1974. Interviews with 76 people in 22 hiking parties were used to develop the base case scenario. During a four-week simulation period, these parties had an average of 2.2 trail encounters per day. Even with such a small sample, the study showed that there was a linear relationship between total use level and mean encounters.

Desolation Wilderness

As a result of the Spanish Peaks experiment, Smith and Krutilla (1976) suggested that a large-scale field test be conducted. The Forest Service contracted with Resources for the Future to conduct such a test on the heavily used Desolation Wilderness in California. A workshop was convened in Missoula, Montana, in 1974 to gather information and to plan for the Desolation application. In attendance was a team of scientists from Resources for the Future, the Forest Service, and Yosemite National Park, as well as field personnel from the Desolation Wilderness and Region Five of the Forest Service.

The Desolation Wilderness is located in the Sierra Nevada of California east of Lake Tahoe. The 63,475-acre (25,390-ha) wilderness was originally established as a primitive area in 1930 and was designated as a wilderness area in 1969. The wilderness is managed by the El Dorado National Forest and the Lake Tahoe Basin Management Unit. Visitor use was over a quarter million visitor-days in 1975 and continues to be heavily used today.

The workshop participants suggested model modifications to the model. These 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 period of time in complex trail networks, and the ability to set probabilities for trailhead selections before routes are selected. The visible encounter suggestion was based on my personal experience of settling into camp only to be passed by a large group of hikers on their way to my next day's destination. Because trailhead quotas are one alternative that managers can use to regulate use, I also felt that it was important to be able to simulate various trailhead allocation patterns. All of these suggestions were incorporated into a new version of the simulator written by Shechter (1975).

The team helped gather use data from mandatory wilderness permits, trip map-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 most of them (38 percent) arrived on Friday or Saturday. A review of existing maps showed 16 trailheads feeding a network of 111 miles (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 by the team 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.

Thirteen different scenarios were run on the model depicting various use levels and trailhead allocation patterns (Shechter & 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 a strong linear relationship (Figure 2).

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 5 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-

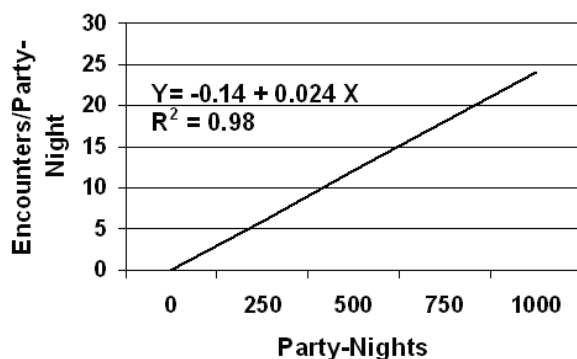


Figure 2. Encounters per party-night for the Desolation Wilderness.

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 scientist 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 felt that an indirect benefit of the simulator derived the information required to run it; data about the area and its use would be valuable for making management planning decisions.

Yosemite National Park

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 Wagten-donk 1979, 2003). The Yosemite Wilderness was designated in 1984 and encompasses 704,638 acres (281,855 ha) of the park (Figure 3). Contiguous wilderness areas include the 112,227-acre (44,891-ha) Emigrant Wilderness on the Stanislaus National Forest, the 48,601-acre (19,440-ha) Hoover Wilderness on the Toiyabe and Inyo National Forests, and the 93,958-acre (37,583-ha) Ansel Adams Wilderness on the Inyo and Sierra National Forests. There are 55 trailheads that lead to 695 miles (1,112 km) of trail and 375 traditional campsites in the Yosemite Wilderness. An additional 46 trailheads feed 416 miles (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 Wagten-donk 1981). Approximately four 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

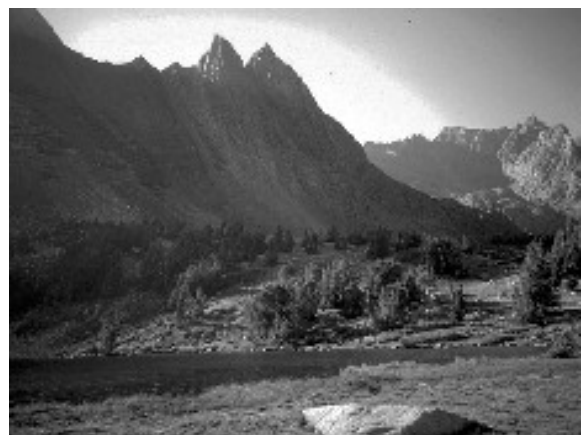


Figure 3. Matterhorn Canyon in the Yosemite Wilderness. Photo courtesy National Park Service.

1971. Because most of the information needed to run the simulator is recorded on the permits, it was decided to use permits as the primary data source (van Wagtenonk 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 Wagtenonk (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 that do not get permits was also determined. In Yosemite, van Wagtenonk 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 one-mile trail segments (van Wagtenonk & 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 all of 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. The decision to concentrate on campsites was based on work by Absher and Lee (1981) that 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 (Figures 4 and 5). A single encounter with an ill-behaving party could have much more impact than meeting numerous

parties exhibiting acceptable behavior. In areas where people expected to meet others, the impact of an encounter was less than in areas where they were not expected. Trailhead quotas were selected by Yosemite managers as the preferred method for rationing use because external controls allowed maximum freedom to visitors consistent with wilderness experience and resource constraints (van Wagtenonk & 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 Wagtenonk 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 Wagtenonk & Coho 1986). The program compared actual levels of use levels in zones to desired levels and reallocated entries until no zone exceeded its limit. Desired zone use limits were based on van Wagtenonk (1986). The second trailhead scenario rounded the daily quotas up to the nearest number divisible by five.

Across all runs, the relationship between camp encounters per party-night and party-nights was positive and linear (Figure 6). The resulting number of encounters was less than half that predicted for the Desolation Wilderness. Two reasons accounted for this difference. First, a greater number of trailheads gave visitors more opportunities to disperse and, consequently, experience 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



Figure 4. Encounters with others is a matter of personal choice. Some prefer to experience wilderness alone. Photo by Jan W. van Wagtenonk.



Figure 5. Others are willing to tolerate a greater numbers in the same setting. Photo courtesy of National Park Service.

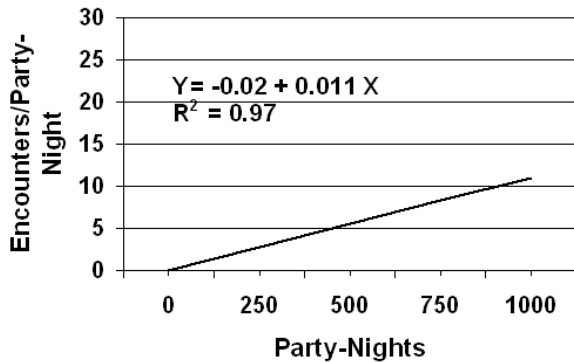


Figure 6. Encounters per party-night for the Yosemite Wilderness complex.

used trailheads to over 100 people per day through three of the most popular trailheads. The scenarios based on the trailhead quotas reduced the peaks both temporally and spatially but did result in 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 US\$ 1,000 per scenario, limiting the feasibility of further experiments.

Dinosaur National Monument

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 determined by the flow. The first application of the simulator to a river was by McCool et al. (1977) on the Green and Yampa Rivers in Dinosaur National Monument in Utah. They chose these rivers because the problems and issues there were representative of those experienced on other rivers in the US, and much of the information necessary to run the model was available.

The Green River runs for 53 miles (85 km) through the monument and is joined there by a 43-mile (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 et al. 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. From these data, detailed travel behavior including lunch stops, stops to scout rapids, and hikes up side canyons were included in the routes.

A one-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 for increasing the number of parties, redistributing launches over the days of the week, and adding or eliminating campsites (Lime et al. 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 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 et al. (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 et al. (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.

Grand Canyon National Park

The Colorado River runs through Grand Canyon National Park in Arizona for 255 miles (360 km) from Lees Ferry in Utah to Diamond Creek in Arizona (Figure 7). Underhill et al. (1986) adapted the wilderness use simulation model for application to the Colorado River. 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 motorboats 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 five-week simulation period. Of these parties, 18 were commercial motor trips, six were commercial oar trips, and four 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 et al. 1986). Because the Park Service was considering phasing out motorboats, two of the scenarios were for different number of oar boats only. Two more sce-



Figure 7. The Colorado River in Grand Canyon National Park. Photo courtesy of the National Park Service.

narios increased use for both oar boats and motorboats 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. Interestingly, the scenarios with only oar boats resulted in more visitor days of use because these trips took longer to float the canyon. Underhill et al. (1986) 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 motorboat parties had their travel times changed as 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.

The conclusions were that that higher flows allowed more time at attractions sites, that low flows increased delays at rapids, and that an increase in the number of parties increased the encounter rates (Borkan & Underhill 1989). This study showed that

the simulator was useful for evaluating different management alternatives beyond the normal scope of wilderness managers.

Appalachian National Scenic Trail

The Appalachian National Scenic Trail traverses 2,160 miles (3,456 km) in 14 states from Georgia to Maine. From a simulation stand point, 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 63-mile (101 km) section of the Appalachian Trail in Vermont. Access to this is through five roads and ten 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 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 two-week period resulted in an average of 3.3 trail encounters per party-day and 2.3 camp encounters per party-night (Potter & Manning 1984). 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 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.

Future Applications

The Wilderness Use Simulation Model has proven 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 levels; management alternatives that reduce use will lead to reduced encounter levels. In addition, the model was effective for evaluating the temporal and spatial effects of various trailhead allocation patterns that were then applied to a complex of wilderness areas in California. Equally effective was a test of the impact of fluctuating dam releases on encounters and use levels in the Grand Canyon.

Recent advances in computer technology and behavioral science have rendered the wilderness use

simulation model out of date. As early as 1985, Rowell (1986) presented a version of the model that ran on a personal computer. That model had the capability to be used interactively and geographically display outputs. It does not appear that it was ever applied on the ground, and, since it was written in the Pascal, it probably will not be. The concepts developed by Rowell (1984) have been incorporated into newer models, however.

Wang and Manning (1999) used an object oriented dynamic simulation package to model carriage road use in Acadia National Park in Maine. Lawson et al. (2002) applied the same model to simulate user encounters at Arches National Park in Utah. A geographic information system was used to derive routes for the model, but graphical output was not part of the model. Gimblett et al. (2000) combined object-oriented technology with geo-referenced temporal data to dynamically simulate visitor behavior in a heavily used natural setting in Sedona, Arizona. Output from the simulator can be displayed in graphs and as two-dimensional or three-dimensional maps. Using the same autonomous agent-based model, Daniel and Gimblett (2000) simulated river trips on the Colorado River in the Grand Canyon. Gimblett et al. (2002) plan to apply their model to derive patterns of dispersed use in the Ansel Adams and John Muir Wilderness areas in California, returning to one of the areas where the Wilderness Use Simulation Model was first applied. These innovative new models show how far the science of simulating wilderness has come in less than three decades. The old Wilderness Use Simulation Model is probably gone but not forgotten.

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