The use of forestlands for recreation in the United States is increasing. Social change in the United States has resulted in a predominantly urban population that has put new pressures on forest ecosystems. Greater variety in leisure activity preferences, more urban-oriented social behavior patterns onsite, and a wider range in the ages of recreation participants can result in social and environmental conflicts, both between recreationists and...
other forest users and among the recreationists. Understanding the relationships between recreation and other important uses is essential to effective ecosystem management and will determine how management decisions can be improved (Richards and Daniel 1991).

Given the complexity of social, environmental, and economic interactions, the forest manager needs a set of tools that can provide insight into the relationships between management actions and social and environmental outcomes. Sophisticated tools are available for managing economic assets such as forest productivity, water quality and quantity, and mineral resources. But tools for modeling the social and environmental costs and benefits of recreation on forestlands are harder to come by. For a recreation model to be useful for applied forest management, it must be able to express changes in the social, psychological, and economic costs and benefits of specific forest recreation opportunities as a function of changes in physical or biological forest characteristics. An integrated modeling framework should include:

- A representation of the physical setting for recreation behavior.
- A model of recreation behavior that accounts for different activities.
- A model of management interventions that alter environmental factors or the number, type, or activities of human visitors.

Such an integrated framework will help forest managers make explicit tradeoffs between recreational use of forests and resource activities. Because the interactions between these three aspects of recreation are complex, computer simulation holds great promise as a tool to study these relationships.

### Simulating Wilderness Recreation

Computer simulation is not a new tool for studying recreation. Models such as the Wilderness Use Simulation Model (WUSM) (Shechter 1975) and its application in both river and backcountry recreation settings (e.g., Smith and Krutilla 1976; McCool et al. 1977; Borkan and Underhill 1989) have helped natural resource managers assess wilderness use and conduct tests of a variety of alternative policies. Other researchers (e.g., Wang and Manning 1999; Wing and Shelby 1999) have used models to estimate trail encounters and other measures of trail use for improving management and administration of park settings.

Although more-constrained models have been available for assessing recreation site preference and choices (Louvierre et al. 1986), as well as encounters between groups of recreationists (Shechter and Lucus 1978), little modeling work has focused on developing dynamic, spatially explicit tools that allow recreation managers and researchers to systematically investigate different recreation management options. By today’s standards, tools such as WUSM lack the flexibility to undertake discrete simulation of visitor behavior along trails or rivers and fail to provide any mechanism for studying critical interactions between humans and environmental processes. The abundance of spatially georeferenced and temporal data available today provides more opportunities for testing and improving the accuracy of simulation models and allows more direct applicability by resource managers.

### Enter RBSim

The Recreation Behavior Simulator (RBSim) was developed to address the weaknesses of other modeling approaches for examining complex land management issues by using computer simulation technology. (Detailed descriptions of the modeling techniques can be found in Gimblett and Itami 1997, Gimblett et al. 2000a and 2000b, and Itami 2000.) More generally, RBSim was developed as a prototype tool that could be modified easily for simulating many natural resource, planning, and design processes, such as traffic modeling, wildlife–habitat interactions, and recreation–wildlife conflicts.

As a pilot project, RBSim was developed in response to a need to examine conflicts between recreation groups over time in Broken Arrow Canyon near Sedona, Arizona. The canyon is popular among day hikers, mountain bikers, and visitors on commercial jeep tours because of its unique, spectacular desert scenery of eroded red sandstone. The popularity of this canyon has created a problem common to many wilderness recreation destinations: Visitors are “loving the place to death” by overuse. This overuse not only has adverse effects on the landscape but also in the quality of visitors’ experiences. Crowding and encounters between hikers, mountain bike enthusiasts, and jeep tours can lead to negative experiences in what should be a spectacular and memorable landscape setting, but very little is known about where and why these impacts occur and their intensity level.

RBSim joins two computer technologies: (1) geographic information systems (GIS) to represent the environment, and (2) agents (representing human recreationists) to simulate human behavior within geographic space. An agent is a set of computer simulation software code designed to replicate the actions of objects in the real world. These objects can be cars, humans, boats, or anything that moves independent of its environment. The human-like agents described in this article are dynamic: Once they are programmed with rules that define how they interact with the environment and each other, they can move about freely, gathering data, making decisions, and altering their behavior according to any situation in which they find themselves.
find themselves. Each of these humanlike agents has its own movement, sensory, and cognitive capabilities. By simulating human behaviors in the context of geographic space, it is possible to study the number and type of interactions over time.

To provide resource managers with the most useful tool possible, the behavioral systems of these agents must be grounded in observations of actual human behavior in the physical settings in which they naturally occur, and managers must be able to alter parameters. The behavior of RBSim agents is guided by a set of parameters whose values can be set by the manager, including the number of agents in each class (hikers, mountain bikers, and commercial jeeps); age distribution of actual hikers and mountain bikers being represented as agents; how often actual hikers and mountain bikers arrive at a trailhead and duration of visit; GIS data containing trail configurations to be simulated; duration of the simulation run; and parameters for setting up visibility for the agents.

These specifications result in actions that echo some key behavioral characteristics of humans in the environment. For example, agents can estimate how they will react when encountering other agents; at what speed they should travel through a landscape, how often, and for how long they must rest; their recreational goals; the route they will follow through the landscape; and so on. In effect, the manager can create different behavioral patterns and personality types for classes of agents based on social and demographic data gathered from the field. By continuing to program knowledge and rules into the agent, watching the behavior resulting from these rules, and comparing it to what is known about actual behavior, a rich and complex set of behaviors emerges. Because it is impossible to predict the behavior of any single agent in the simulation, by observing the interactions between agents it is possible to draw conclusions that are impossible using any other simulation process.

**How It Works**

RBSim uses agents to mimic the behaviors of three types of recreationists—day hikers, mountain bikers, and passengers in commercial jeeps—using the Broken Arrow Canyon study site in Sedona, Arizona. Each agent type has a single action called “move” that triggers the execution of a set of internal rules (e.g., stopping at attraction sites and passing other agents), energetics (rate of loss or gain of energy), and mobility (speed at which an agent traverses the landscape). Each agent enters the simulation at the trailhead depending on minimum and maximum times specified by the manager, to mimic random times visitors start their activities in the actual landscape. Agent speeds are modified by degree of slope, uphill or downhill travel, and stopping and resting times. Each agent has the spatial analytic capability to access topographic and trail data, computing the degree of slope and direction to modify its speed accordingly. Each agent type has a set of rules that define where they stop in the simulation, how long they stay there, and how they react to other agents they encounter. For example, a landscape agent that is highly motivated to seek out areas for a solitude experience will avoid crowds at attraction sites, pass other agents perceived as traveling in front, and only stop in places that are free of other agents. As each agent moves, it assesses and keeps track of perceived encounters (any other agent seen on any of the trails within a specified view area) and actual encounters (other agents encountered...
in the same cell) for each cell location along the trail.

As the simulation runs, and more agent types enter the simulation, a rich, mapped display of encounters can be observed. The location, number, and types of encounters that occur over a day, week, or month are reported in various forms (e.g., graphs, three-dimensional images, and spatial georeferenced maps). The manager can then alter the number of agents and the times they enter the trail system and test these scenarios on both existing and proposed trails to examine the spatial distribution of use patterns. Setting trail quotas, anticipating high-use areas, and controlling access are a few of the management actions that can be tested.

How Data Was Collected

During a nine-month period—April through December 1995—an onsite visitor use survey was conducted to capture data on recreational use patterns in Broken Arrow Canyon. The random survey followed a two-step process. First, day hikers, mountain bikers, and commercial jeep passengers were approached and asked to take a trail map of the canyon with them on their outing. This map contained major attraction sites, trails, and other subtle features identified as destination sites in the canyon. Visitors were asked to record when they left the trailhead, duration of outing, where they stopped (particularly if they traveled off established trails), where they had encounters with others on the trails (actual encounters), and mark the location any time they saw others in the area (perceived encounters).

When the visitors returned to the trailhead, the research team conducted a short interview to learn the type of benefits the visitors desired during their visit and to what degree they were able to obtain them. Visitors were asked if a range of benefits were desirable and whether they could obtain those benefits over time. Achieving desired benefits such as getting away from or avoiding crowds, reducing stress, and increasing physical fitness are strong indicators of recreational satisfaction. The survey for this study was used to identify anything that made the setting an ideal place for achieving these benefits or, conversely, anything that interfered with achieving these benefits. In addition, each visitor was asked to provide a detailed description of the decisions they made to stop at attractions or interact with others along the trail. This data provided the research team with the rules that define the actions that affect visitation and, in particular, travel patterns.

The sample \( n = 1049 \) was composed of day hikers (337), mountain bikers (393), and commercial jeep passengers (319). Statistical analysis was performed within each activity group to characterize individuals by day, time, and duration of visit; goals, intentions, and desired and acquired benefits; and rules that define these behaviors. Agents were then programmed with these characteristics and placed into the simulations to represent typical use patterns in the canyon. (For a more detailed description of the analysis used to define agent types, see Gimblett et al. 2000b.)

Exploring Typical-Use Days

To explore the use of the simulation system in identifying conflicting recreation behavior, experiments were conducted that represented a typical midweek use day. A mean midweek visitation pattern consisted of 13 to 16 hiking parties (averaging two people per party) arriving an average of
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15 to 35 minutes apart and spending an average of five to six hours a day in the canyon. Approximately 20 to 25 mountain biking parties (averaging two people per party) randomly appeared throughout the day and spent an average of four to five hours in the canyon. Commercial jeep tours are more consistent in their use of the canyon, averaging 15 to 18 tours per day (with four visitors per tour), with an average time spent in the canyon of three to four hours per trip. Typical destinations included geologic features such as Mushroom Rock and Submarine Rock, and popular scenic lookout and turnaround points such as Chicken Point. Using these data, the initial parameters are set and the simulation run.

To demonstrate a potential management action (e.g., restricting mountain bikes on a heavily used trail because of conflicts with hikers), an additional simulation was run using the same agent parameters as above, but substituting a proposed mountain bike trail layout. The simulation was rerun and compared to the initial simulations to assess patterns of recreational use and resulting differences in encounters.

Results of the survey indicated that of the 337 hikers, 72 percent reported negative encounters: 41 percent with jeeps, 30 percent with mountain bikers, and 29 percent with other hikers. Of the 393 mountain bikers, 35 percent reported negative encounters: 38 percent with jeeps, 58 percent with hikers, and only 4 percent with other mountain bikers.

It is interesting that even though hikers reported a moderate number of encounters with jeeps, there were very few encounters between mountain bikers and jeeps (Gimblett 2000b). Shelby and Heberlein (1986) have shown that the impact of encounters on the recreation experience varies according to the location and nature of encounters, not just the number of encounters or how they are spaced out over the duration of the trip. Our simulations, while not providing any conclusive evidence on the impact on the recreation experience, in part echo what Shelby and Heberlein found.

Figure 2 illustrates biker encounters with hikers, jeeps, and other bikers along the biking trail. Encounters are more consistent, increasing steadily from trail cells 401 through 601 as the bikers return to the trailhead. Biker encounters with hikers increase in the same trail sequence, but taper off from trail cells 601 back to the trailhead.

Figure 3 illustrates a large number of jeep encounters with hikers and bikers and only a small number of encounters with other jeeps. The encounters with hikers and bikers are concentrated around trail sequence 601 to 750 and then again at 801 through 1001. These heavily used sections of the trails coincide with scenic geologic features such as Chicken Point and Submarine Rock.

In summary, it appears that with the increased number of recreationists in the canyon, encounters between hikers and bikers are the most frequently observed. In figures 1, 2, and 3 there are minimal, sporadic encounters with...
jeeps. Although jeeps originally were suspected as being more visually and physically obtrusive, the simulations indicate this is not the case.

**Trying Alternative Trail Layouts**

RBSim was developed to help natural resource professionals manage recreational use in the canyon over time. To demonstrate this concept and assess the effect of alternative trail use and conflicts within and between recreation groups, an alternative mountain bike trail layout was extracted from information in the surveys. Mountain bikers tended not to use the conventional trails in the canyon, and they described in the survey where they preferred to ride.

As illustrated in figure 4, selecting an alternative bike trail can have a major impact on the number of encounters that occur along the trail. When the alternative bike route is used in the simulations, the number of biker encounters with hikers decreases significantly, particularly after the turnaround at Chicken Point. When compared to figures 2 and 3, the mean number of encounters dropped by two-thirds and the maximum number of encounters by half (table 1).

The number of encounters that mountain bikers will have with other recreationists when using the alternative bike route reveals a dramatic decline in both hikers and jeeps, but a steady increase in the number of bikers. In fact, an evaluation of the statistical summaries (table 1) illustrates that encounters with hikers declines to one-fifth of those that occurred in figure 1, with the same number of hikers still using the trails. This finding strongly suggests that by using the alternative trail, the distribution of hikers and bikers within the canyon is more conducive to minimizing encounters.

**Conclusion**

Simulation, using agents with behavioral traits synthesized from their human counterparts, can provide a way to evaluate and test a variety of visitor use encounters that are both spatial and temporal. Alternatives can be used to develop new facilities along the trails.
and to redirect trail use to maximize recreation use levels while minimizing impact. Watching the agents interact under a variety of constraints can give managers a better understanding of how human recreationists use and interact on public lands, and can help the public understand resulting management actions.

Although agent simulations are a relatively new concept in natural resource management, we believe they are an effective technique for modeling the spatial and temporal aspects of recreation encounters. The agent simulations provide a dynamic view of encounters between agents and identify the spatially explicit locations where they occur. The effect of these encounters on the overall recreational experience is still unknown. However, this simulation environment provides a way to test and evaluate many scenarios of recreational use. Using a complex systems approach in the development of RBSim is a significant step forward in providing practical tools to aid natural resource managers in decision-making.

Literature Cited


