An Individual-Based Modeling Approach to Simulating Recreation Use in Wilderness Settings

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Abstract—Landscapes protect biological diversity and provide unique opportunities for human-nature interactions. Too often, these desirable settings suffer from extremely high visitation. Given the complexity of social, environmental and economic interactions, resource managers need tools that provide insights into the cause and effect relationships between management actions and social and environmental outcomes. Object-oriented technology, along with spatial geo-referenced temporal data, provides new opportunities for developing, testing and improving simulation models. This paper describes a case study in Sedona, Arizona, that utilizes prototype software package the *Recreation Behaviour Simulator (RBSim)*, to dynamically simulate the behavior of human recreationists' in high-use natural environments.

Many people who travel to wilderness areas do so out of a desire to experience an environment that is uninhabited or appears to be unaffected by the activities of man. However, the activities of visitors in these environments, and their interactions with one another, may degrade the quality of their own experience. People according to Fege and others (1989) "come to wilderness with differing expectations about their recreation activities and wilderness resource, personal involvement in the activity or place, mode of perceiving or experiencing the wilderness, status-consciousness, and tolerance for other lifestyles." All of these have been shown by many researchers to be influenced by crowding and encounters in wilderness settings (e.g., Daniels and Krannich, 1990; Ewert and others 1993; Fege and others 1989; Ivy and others 1992; Jacob, 1977; Jacob and Schreyer, 1980; Schreyer, 1990; Scenic Spectrums Pty Ltd. 1995; Watson and others 1994).

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Recreation Use of Wilderness Settings

In order to manage for optimal recreation use of wilderness, managers must understand the needs, goals and desires of those sharing that environment and where encounters occur within and between groups of recreationists'. This is by no means an easy task with an evolving wilderness clientele and a resource base that is holding constant. In order to manage for optimal use of wilderness areas, managers must first acquire a better understanding of the nature and extent of encounters. It is quite clear from a review of the growing body of literature surrounding the issue of encounters and their affect on experience quality that:

- It is through encounters that "use levels" affect experience quality.
- Encounters lead to a sense of crowding for at least some (not all) visitors.
- Managers of Wilderness (as opposed to other lands) care especially about this sense of crowding and in particular "use levels" since they are legally obligated to provide opportunities for solitude.
- The effect of encounters appears to depend on the number and location of encounters, the type and behavior of those encountered and dispositional factors of the user (e.g., goals, expectations).

There is strong evidence that the distribution of recreation use across time and space in wilderness areas has profound effects on whether a certain level of use causes high levels of encounters among groups and perceived crowding (Scenic Spectrum Pty Ltd. (1995). Time and location of use not only affects the number and location of encounters, it also influences how these encounters are evaluated.

The purpose of this paper is to describe a prototype computer simulation system that was developed to study the affects of time and space on levels of use in wilderness settings. Specifically this paper will describe a computer simulation model that was developed as a tool to examine the number of encounters and their associated salient features (e.g., type and age of group) between and within activity groups over space and time under varying use scenarios in Broken Arrow Canyon, Sedona, Arizona.

Computer Simulation Models in Wilderness Settings

Computer simulation models have been proposed as one tool to resolve this complex problem of encounters in wilderness areas (Romesburg 1974; Cesario 1975). Because time and space (location) have a profound affect on levels of encounters, it is surprising that computer simulation has not been more extensively used. Computer simulation is not a new concept in studying natural processes, but it has seen limited use in studying wilderness recreation.

The Wilderness Use Simulation Model (WUSM) (Shechter 1975; Smith and Krutilla 1976; Shechter and Lucus 1978) was developed in the 70's to assist natural resource managers in assessing wilderness use. The simulator was developed and tested in both Spanish Peaks Primitive Area in Montana (Smith and Krutilla 1976) and the Desolation Wilderness in California (Smith and Others 1976) and subsequently modified for river recreation management (USDA Forest Service 1977) for use on the Green and Yampa Rivers in Dinosaur National Monument (McCool and others 1977; Lime and others 1978) and the Colorado River in the Grand Canyon (Underhill and Xaba 1983; Underhill and others 1986; Borkan 1986; Borkan and Underhill 1989).

While the tool was extremely innovative for its time, by today's standards it lacks the flexibility to undertake simulation of discrete visitor movement and associated behaviors along trails or rivers and fails to provide any mechanism for studying critical interactions between humans and environmental processes (such as communication and negotiation among visitors, adaptive learning for developing coping strategies, autonomous movement patterns according to individual needs and behaviors, beliefs, desires and intentions etc.). In addition, the current abundance of spatial georeferenced temporal data, which describes the earth's surface, provides more opportunity for testing and improving the accuracy of simulation models and with more direct applicability for resource managers.

Simulation approaches presented by (Manning and Ciali 1979; Manning and Potter 1984; Potter 1982; Potter and Manning 1984) and their recent studies (Wang and Manning 1999) incorporating Geographic Information Systems (GIS) to capture environmental data have shown great promise for modeling the impacts of recreation use in these settings but have not yet overcome some of the problems encountered with the WUSM. Their work does however clearly illustrate the usefulness of simulation for generating and testing alternative management scenarios to reduce encounters and improve the quality of the recreation experience.

While there have been more constrained models for assessing recreation site preference and choices (Schroeder and Louviere, 1986; Schroeder and others 1990), as well as encounters between groups of recreationists', there has been no dynamic, spatially explicit tool that provides recreation managers and researchers with the ability to systematically investigate different recreation management options. For example, with the introduction of a new trail one might expect that encounters would be reduced, but to what extent? How do recreationists' use coping behaviors to offset the impacts of encounters and crowding on their recreational experience? If some type of limited access is selected as a management option, what will be the impact on use patterns? More important, when there are different, conflicting recreation uses, how do different management options increase or decrease the conditions that lead to conflicts? None of these questions can be answered using conventional tools. These questions all pivot around issues such as time and space, as well as more complex issues such as inter-visibility between two locations on a map

In summary, there still appears to be a widespread gap between what the manager needs to adequately manage for high-quality wilderness recreation and the knowledge and tools that are available for doing so. Information about wilderness recreationist attitudes and behavior is increasingly viewed as important to the planning and management process, but collection of this data can be costly and sometimes produce very little that the manager can actually use in developing management options. With the rapid development of technologies such as Global Positioning Systems (GPS), GIS, and artificial intelligence, many new opportunities now exist to gather the kinds of data needed to build, test and validate a more elaborate modeling structure that incorporates a dynamic interplay of time, space and people/landscape interactions. A more appropriate concept calls for the interaction of four models: a model of desired and influential recreation setting parameters; a model that expresses the outcomes of recreation behavior in those settings; a model of recreation behavior that predicts the number of users per unit of time, in those settings from which personal, social and economic value estimates can be made, and a model that minimizes encounters within and between recreation groups (Richards and Gimblett 1995).

There are a number of alternative approaches to modeling and providing decision support for visitor management. An application of computer simulation and modeling technology, presented in this paper, is intended to demonstrate the potential for developing a practical model readily usable by wilderness recreation managers. The application will show:

- How decision-makers, such as natural resource managers, would benefit from inexpensive, simulation techniques that could be utilized to explore dynamic recreation behavior, develop thresholds of use and test ideas, before expensive management plans are implemented.
- How resource managers can have confidence in the use and results of these simulations, since the design of the behavioral systems that are utilized in the simulations are grounded in observations and data of actual human behavior in the physical settings in which they naturally occur.
- How simulation technology can be used to refine management strategies, as well as promote greater public understanding of management decisions.

Modeling Complex Human-Environment Interactions Using Statistical Analysis and Computer Simulation

To obtain a more thorough understanding of and manage for complex human-environment interactions, models that systematically and precisely specify the interrelationships

between the relevant human and environmental variables are required. There are significant obstacles, however, to the development of such models. The number of potentially important environmental variables is very large. Moreover, these variables are often complexly interrelated and interdependent. Many environmental interactions strongly depend on spatial/geographic factors, and they may change on a temporal scale ranging from moment-to-moment to century-to-century. The number of potentially important human variables is also large and completely interrelated and, in most contexts, includes the effects of interactions with other humans. Finally, both the humans and the environments involved may affect each other, altering subsequent environmental experiences and responses for affected humans and changing the environmental context for others who may follow.

Modeling human-environment interactions is a matter of discovering and representing the interrelationships between two complex constellations of interrelated variables. Empirically based statistical modeling methods, such as regression and variants thereof, provide a robust and well-tested approach for representing such multivariate relationships. Statistical models use rigorous method to make explicit the quantitative relationships among variables in complex data sets. These models can provide high degrees of precision and specified levels of sensitivity and reliability. However such approaches are limited. Relationships that may be relatively simple to specify at one point in space and time will require much more complex specifications if the relationship is spatially and/or temporally dynamic. As the number of variables increases, the amount of empirical data demanded can increase substantially. The form of statistical models can rapidly become very complex and difficult to understand. Moreover, it can be difficult to determine the extent to which an empirically based statistical model can be generalized to new situations where values for one or more relevant variables fall outside the range represented in the originating data set. Process models have a quantitative specification essentially like empirically based models, but the specified relationships are deduced from know relational principles and/or theories. These models can solve some of the problems encountered by empirically based approaches, and they have been used successfully to represent many important biophysical components of environmental systems. The development of these models requires a more detailed understanding of the processes that mediate relationships between variables than is typically known.

An alternative modeling approach is to use artificial intelligence techniques to capture and represent expert knowledge about relevant variables. These models can take several forms, but underlying most is a system of "rules" that specify how inputs (such as, environmental and/or social conditions) and outputs (such as, human reactions) are related. The rules in these systems are often initially derived from the opinions of domain experts, reducing empirical data demands. Rules are then abstracted and organized into a model, an interrelated system of rules, which is typically coded into a computer simulation program. The specific rules and interrelations among rules are extended and modified heuristically by iterative execution of the computer simulation and observing the patterns of inputs and outputs ("model behavior") under a variety of operating conditions.

Model performance may be evaluated by comparing outputs against relevant parameters of existing empirical data, perhaps including the calculation of indices of fit. More often, performance of the model (sensitivity, reliability and validity) is based on the judgement of the modeler and/or the domain experts involved. Good models are those that produce behavior perceived to be similar to the observed (or assumed or expected) behavior of the human-environment system being modeled. The level of "goodness" achieved is rarely quantified. Models can be queried to determine which rules were implemented to produce specific input-output relationships. This feature can be used to evaluate (via expert judgement) how closely the model reproduced processes thought to be operating in the modeled system. Making the operative rules explicit can also facilitate understanding of the model and, presumably of the system represented. In more complex systems, however, it may be as difficult to understand the behavior of a model as it is to understand the behavior of the human-environment system being modeled.

Pilot Project in Using Simulation to Study Recreation Encounters in Sedona, Arizona

The Recreation Behavior Simulator (RBSim) was developed to address the weaknesses of other modeling approaches (outlined above) and for examining complex land management. Detailed descriptions of the modeling techniques can be found in Gimblett and others (1996a; 1996b); Gimblett and Itami (1997); Bishop and Gimblett (1998); Gimblett (1998); Gimblett and others (1999); Itami (1999). RBSim was developed as a prototype tool that could easily be modified to simulate many other natural resource, planning or design processes (traffic modeling, wildlife/habitat interactions, recreation/wildlife conflicts).

As a pilot project, RBSim was developed in response to a need to examine encounters between recreation groups over time in Broken Arrow Canyon near Sedona, Arizona. The canyon is popular for day hikers, mountain bikers and people on commercial jeep tours because of the unique spectacular desert scenery of eroded red sandstone. The very popularity of this canyon represents a problem common to many popular wilderness recreation destinations. People are "loving the place to death" by overuse, with resulting negative impacts on the landscape and in the quality of the experience people have when they visit. Crowding, conflicts between hikers, mountain bike enthusiasts and jeep tours can create negative experiences in what should be a spectacular and memorable landscape setting, but very little is known about where, why and the intensity at which these encounters occur.

By simulating human behavior in the context of geographic space, it is possible to study the number and type of interactions a typical visitor will have. Interactive modeling techniques are used to instill human-like behavior into artificial agents to explore recreation planning alternatives. The recreationist agent developed in RBSim can gather data from their environment, make decisions from this information and change their behavior according to the situation

they find themselves in. Each individual agent has it's own physical mobility, sensory and cognitive capabilities and keeps track of encounters. The behavior of RBSim agents is guided by a set of parameters for social setting, individual disposition and environmental setting.

These behavioral parameters determine how an agent reacts when encountering other agents, at what speed an agent travels through a landscape derived from a Geographic Information Systems database, how often and for how long an agent must rest, the recreational goals of the agent for a given landscape, the route the agent will follow through the landscape and for how long the simulation will run. In effect, the user is able to create different behavioral patterns and personality types for classes of agents, and program (individual and interaction rules into each agent), based on social and demographic data gathered from field study.

Defining Characteristics of Individuals to be Represented by Artificial Agents

For the Sedona example which characteristics of groups of recreationists' were developed using a pre and post trip on-site visitor use survey employed over a nine-month period to capture data on recreational use, desired beneficial outcomes and conflicting recreational uses in the canyon. Trip motives, expectations, use density, reported contacts and place of encounters have been identified as contributing factors to a recreational experience (Scenic Spectrums Pty Ltd. 1995). The two-phased measurement technique used to solicit response on the type of benefits that were desired (trip motives and expectations) during their visit and to what degree they were able to obtain them. This measure of conflict coincided with Jacob and Schreyers's (1980) goal interference definition of conflict. Visitors were asked if a range of benefits were desirable (*goals and intentions*) and whether they could obtain those benefits over time (*goal interference*). The benefit types used in this study are well documented in Bruns and others (1994) and Lee and Driver (1992), based on research undertaken on other public lands.

Of the (n = 1041) visitors sampled, three significant recreation use groups were identified; day-use hikers (n = 337), mountain bikers (n = 393) and commercial jeep passengers (n = 319). For more detailed demographic data, see Gimblett (1998). While there could be many combinations of personality traits derived from the visitor data collected, to demonstrate the utility of the agent modeling system, the recreationist patterns were aggregated into two unique types for both the hikers and mountain bikers. These two types are referred to as either a '*landscape*' or '*social'* recreationist type. Each desired significantly different benefits from their recreation experience at Sedona. Due to the nature and mode of travel, commercial jeep passengers were modeled as a jeep unit.

A *landscape recreationist or agent type* is one who seeks out landscapes that are *physically challenging and avoids crowds,* subsequently leading to a *reduction in stress*. In the exit interviews, visitors representative of this agent class indicated that they would only stop in locations where there were no other recreationist and move as fast as possible along the trails. Physical exercise was a strong motivation in this recreation group and common to both hikers and mountain bikers. These recreationists fall within the personal well being and health benefits class identified in Bruns and others (1994).

A *social recreationist* or *agent type* is more group-oriented, one who seeks out those landscapes which *are not necessarily physically challenging* but tend to build *self-confidence*, provide more *opportunity to learn more about the natural and cultural history* of the area and interact with others who share these goals. Visitors that were associated with the social agent class were more tolerant of meeting others along the trail. During the exit interviews, recreationists who represented this class indicated that they liked social interaction while engaging in their favorite recreational activity and would spend longer periods of time wandering through the landscape, sitting in special locations and contemplating life. For more details on the statistical analysis, see Gimblett (1998).

Rules for Artificial Agent Behavior

Rules for providing simulation agents with the social behaviors of human recreationists were derived from surveys of what respondents told us about their experiences, statistical analyses presented earlier and through interviews following their outing. While the surveys clearly documented that visitors spent a minimum of two hours performing their activities, the benefit questions provided the goals and intentions for their visit. Survey maps were used to provide a clear indication of where they rested, their final destination or where they stopped to view cultural and geologic features. Many of those recreationists that subsequently fell into the social agent class indicated that they stopped at all the locations, regardless of the numbers of other hikers or bikers that were present, and stayed primarily on the appropriate trail for their activity. Some mountain bikers and hikers who fell into the landscape agent classes indicated in both the survey and later in the exit interviews that they would stop at the cultural and geologic features only if there were a limited number of other recreationists' present. They also indicated that they would go out of their way to pass others along the trails quickly and avoid them if possible.

For the testing of the prototype agent simulator, a number of the rules were developed that conformed to what was learned about the intensity of use, interactions and subtle behaviors of visitors using Broken Arrow Canyon. They are:

1) All hikers and bikers rest when down to 25% energy level (was calculated from what visitors told the research team about how often they needed to rest during their trip).

2) Landscape agents, pass other agents in front traveling 25% slower than themselves and if they have at least 50% energy left.

3) Landscape agents slow down at landscape features if no other recreationists are present.

4) All agents stop at all landscape features.

5) Social hikers change their velocity to match other social hikers they encounter.

6) Hikers and bikers will not stop at features if more than five other agents are present.

How It Works

The RBSim runtime simulation engine runs in discrete time steps. At each time step in the simulation, each recreationist class (hikers, bikers and jeeps) is evaluated to determine if a new instance (agent object) of that class should be created (i.e., Enter the area). For each class of recreationist, a timer is set, which begins incrementing from the start of the simulation run and is reset to zero each time a new recreationist agent is generated. In the model parameterization, the minimum and maximum times between agents are specified. A random start time is generated between the minimum and maximum time each time a new agent is generated. A new agent of the respective class is generated once the timer reaches the randomly generated time.

Recreationist agents of the hiker, biker and jeep types are placed in collections for each type. The simulation engine then tracks each agent in each collection. Since the simulation engine is running on a synchronous clock, the order in which the agents are executed will affect consequences such as crowding and visibility. In order to avoid order effects from starting each agent's movement in a set sequence, it is randomized within each collection for each iteration of the simulation. Each agent has a single method called "Move," which triggers the execution of the internal rules and mobility for that agent. Once the agent has completed execution of all its behaviors for that time step, the run time simulation engine then executes the move method for the next agent in the randomized list for that iteration.

Each agent begins its journey in the GIS-based environment. Since agents have GIS analytic capabilities, they compute the slope of the cell they will move into next and scan around their neighborhood to locate the trail. They adjust their speed according to how steep the slope is and whether they are going up or down hill. When each agent moves, it computes both whether it can see any other agent in the simulation and also keeps track of encounters along the trail for further analysis. The agents will stop at viewpoints or any other suitable location depending on their personality type and interaction rules. This process continues in a loop until either all agents have completed their journey or the maximum time set for the simulation run is reached.

Example of a Typical Simulation Run

On the following page are examples of the type of simulation runs that can be undertaken using RBSim. These images show the run time interface to the simulation with jeep, mountain bikers and hikers during the simulation. Agents turn white on the screen when they have stopped to view the landscape or red when they have stopped to rest. As the simulation executes, agents can be seen evaluating where all other agents are in the landscape and using their rule sets to modify their behaviors. The accompanying graphing tool illustrates the number of visual encounters the agents are having with one another throughout the landscape (fig. 1). The graphic output provides a spatial view of where encounters are occurring, while the statistical data collected in memory for each agent are also spatially referenced but can be statistically analyzed to determine patterns of encounters.

Simulation using personality traits and behavioral rules synthesized from human recreationists provides a way to evaluate and test the effects of a variety of recreationist use densities over time. These alternatives can be used to develop new facilities along the trails, and to redirect trail use to maximize user satisfaction while minimizing impact. The ability to see the agents interacting under a variety of constraints can help the manager acquire a better understanding of how human recreationists use and interact on public lands.

One example that shows the power of using simulation is the impact of alternative routes on recreationist encounters. An examination of the biker trail alternatives, with routes suggested by the respondents to the survey, illustrates the importance of a well-thought out trail design on recreational encounters. In Sedona, two alternative trail designs would significantly reduce the number of encounters with other recreationists. It is clear that the simulation environment can assist in evaluating existing and proposed trails in attempts to minimize encounters and conflicts that can limit the quality of the recreational experience.

Summary

Although there has been extensive research into and development of multi-agent systems in robotics, artificial intelligence and automated decision-making, but few have incorporated the power of autonomous agent technologies with GIS to solve natural resource-related problems. This paper has presented and described some initial attempts at doing so. Multi-agent models have many advantages compared with those previously applied. Using agents to represent individuals or parties, incorporating GIS to represent the environment, and utilizing agent technology in natural resource management decision-making provide the following advantages:

Agents to Represent Individuals or Parties

- Agents have communication and negotiation abilities (for example, to decide to stop and camp or alter their plans to avoid encounters with other recreationists').
- Agents can be programmed with strategies, goals and intentions (where they want to hike and how they want to achieve that goal, how long they plan to spend and how difficult a route they wish to choose).
- Agents have adaptive learning capabilities to adjust to their surroundings and others they encounter (coping behavior) that are more in tune with current research into recreation behavior.

GIS to Represent the Environment

- GIS can provide a geo-referenced environment in which to view agent interactions and assess the number of encounters and where they occur over time.
- Makes the simulation model easy for policy-makers, planners, managers, and the public to understand

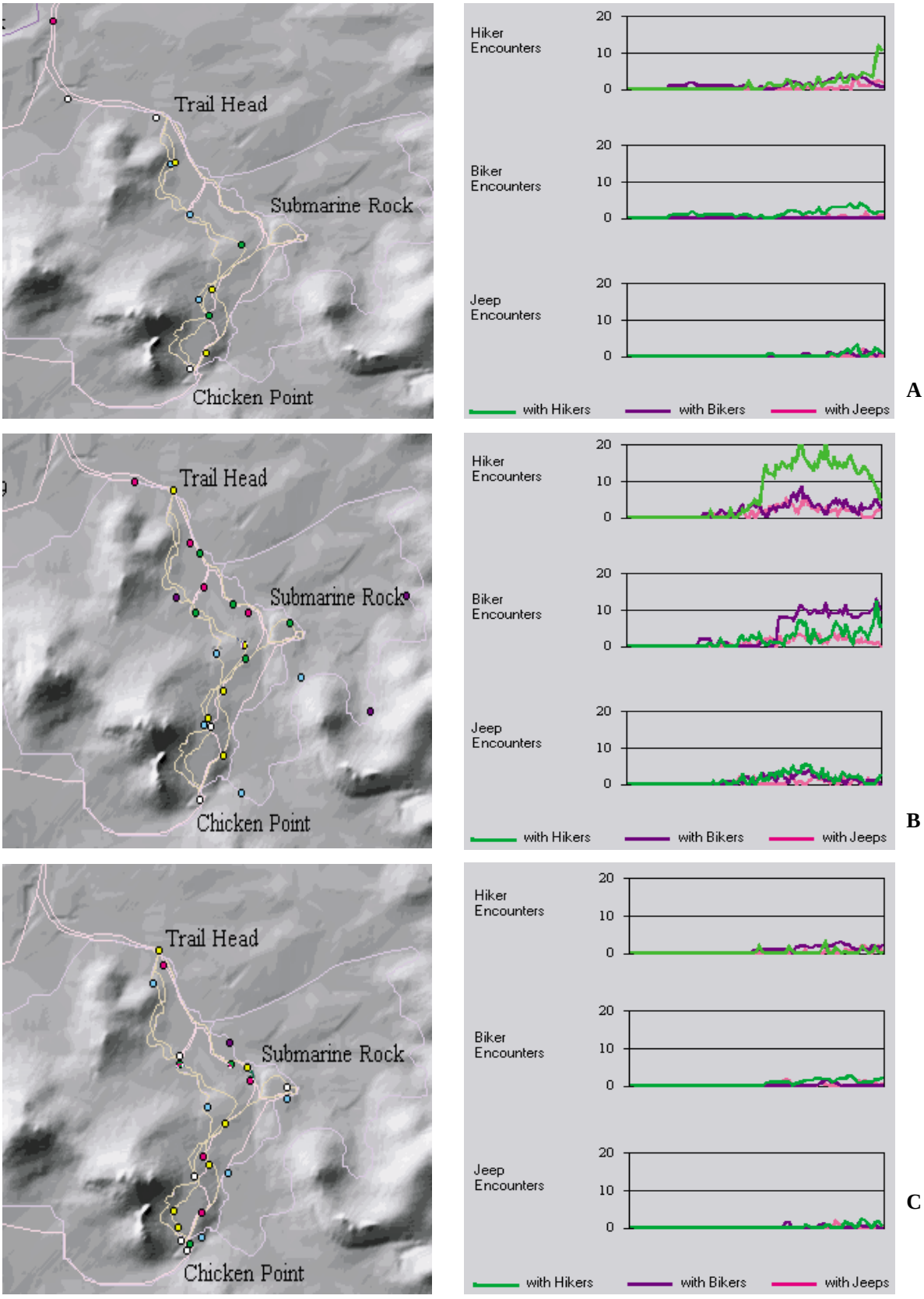

Figure 1—Examples of output from the simulation. Insert A is one slice in time during the simulation run. The graph is a measure of the number of encounters each of the recreation type is having with others as the simulation is running. Inserts B and C illustrate the differences in numbers of encounters when the same simulation conditions are repeated, but an alternative trail (C) is selected. It is clear from insert C that the number of encounters dramatically decreases when an alternative trail is selected. Both illustrate the power of using this simulation tool for examining a variety of management scenarios.

- GIS can be used to update the simulation with changing environment conditions (that is, as new information is captured in relationship to land use changes).
- Spatial analytic GIS classes (neighboring statistical summaries, inter-visibility analysis, distance measure, travel time, travel cost, slope, solar aspect, slope direction) provide a "tool box" of analytical capabilities that can be programmed into the agents. This decreases computation time and provides the agent with an enormous pool of spatial reasoning abilities.

Using Agent Technology as a Visitor Management Tool

- Agent technology allows wilderness managers to develop "what if" scenarios and provide options that will guide management decisions in resolving recreation use conflicts.
- Using a simulation environment composed of agents derived from data synthesized from human recreationists (individuals or parties) provides a way to evaluate the effects of a variety of recreationist use densities on different types of users.
- Using the visual display during the simulation of the agents interacting under a variety of constraints can give managers and others a more thorough understanding of how human recreationists use and interact on public lands.
- Agent technology can allows wilderness managers to explore the consequences of changes to any of the variables to manage desired experiences.
- Agent-based simulations provide a way for wilderness managers to explore and compare alternative management scenarios and evaluate them in terms consequences of policy actions and social, environmental and economic impacts.

Conclusion

This paper has introduced the idea of using multi-agent systems coupled with GIS and visitor use data to simulate and examine recreation use and associated interactions as a method for devising management strategies to reduce them. While the study outlined in this paper is by no means conclusive, it does illustrate great promise for modeling human/landscape interactions. However, much work needs to be undertaken to improve the predictability, reliability and validity of the proposed modeling framework.

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