Modelling Human-Landscape Interactions in Spatially Complex Settings: Where are we and where are we going?

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Keywords: integrated modelling, spatial agent based simulation, human-landscape interactions

Extended Abstract

There is a growing body of research focused within the context of human-environment interactions. This research has been initiated to provide tools to aid decision makers who must plan and manage lands to accommodate increasing human use while at the same time, maintaining the ecological integrity of those lands. Conventional methods used in planning and management of human- landscape interactions fall far short of the needs of decision makers who need to evaluate the impacts of humans in different landscapes. Many public land agencies, local governments and international organizations are exploring the use of multi-agent simulations coupled with social science data for developing long-term strategies for evaluating human-landscape interactions. In particular, spatial agent-based models are being explored with some success to provide a better understanding of the spatial and temporal patterns of human-landscape interactions and to predict how distributions of this use are likely to change in response to both management actions and factors not subject to managerial control. While the application of simulation to study human-landscape interactions is in its infancy, there is need to develop a comprehensive and empirically based framework for linking the social, biophysical and geographic disciplines across space and time. This paper will explore the current state of spatial/temporal simulations that integrate human behavior and environmental factors as applied to decision-making in spatially referenced dynamic environments and will provide some insight into what has been learned and more importantly discuss some ideas for development and application of this type of modelling in the future.

Introduction

There is a growing body of research focused within the context of human-environment interactions. This work examines the need to develop a comprehensive and empirically based framework for linking the social, biophysical and geographic disciplines across space and time. Authors such as Matthews et al. (this volume) suggest that while not all problems require the integration of human-landscape interactions, those that do, frequently are non-linear where the landscape is affected by human-decision making over time which in turn leads to some form of impact on the landscape. This need to link dynamic biophysical simulation models with emerging agent-based simulation models is evident in many researchers such as the paper in this volume by Deadman (this volume). In this paper and others presented at this conference, some form of environmental change has occurred and these studies attempt to link land use change to local factors. Examples include linking household demographics and soil quality, and regional factors such as commodity prices, government credit policies, and inflation. Without the advances in agent based modelling approaches linked to land use change models, questions related to agents of change have remain unanswered. Fox et al. (2003) in their book "*People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS*" conclude that "The human dimensions research community, Land use/Cover Change (LUCC) program, and human and landscape ecology communities are collectively viewing the landscape with a spatially-explicit perspective, where humans are viewed as agents of landscape change that shape and are shaped by the landscape and where landscape form and function are assessed with a space-time context." The need to examine human-landscape interactions has become an important focus for funding agencies such as National Science Foundation in programs such as *Biocomplexity in the Environment, Coupled Human-Natural Systems* and with federal public land agencies such as Parks Canada. A national priority with Parks Canada's, National Parks directorate for human use management within the Ecological Integrity Branch, human use simulation is perceived as having the potential to bridge a significant social science knowledge gap to improve their ability to positively and proactively manage park human use to promote long-term ecological integrity.

Many public land agencies, local governments and international organizations are exploring the use of multi-agent simulations coupled with social science data for developing long-term strategies for evaluating human-landscape interactions. Common underlying questions among the research community are as follows:

- How does land use shape landscapes over the long-term?
- What processes drive the long-term socio-ecological consequences of many types of land use?
- How can humans be simulated in association with their environment (individuals, parties or households) through empirically based agent models using demographic and socio-economic data collected in the field using household and community surveys?
- How can behavioral rules at multiple scales be constructed from this data to simulate human interactions with the landscape across space and time?
- How can land use and land cover dynamics be measured through the use of GIS and Remote sensing and then be associated with human interactions in these same landscapes?
- How can drivers of change be explored through the integration of social, biophysical and geographical modelling?

These and other questions drive much of the research using spatial agent-based models. While there are many successes, there are still many roadblocks to overcome before a high degree of confidence can be placed in the results of these models. The purpose of this paper is to explore the current work on human-landscape interaction modelling, evaluate their limitations and to set the stage for the many papers being presented at this conference focusing on this topic area. Most importantly to provide some insight and hopefully lead to a discussion regarding future steps for integrating simulation modelling into the decision making process.

There are two sessions at this conference that deal specifically with Agent based Model (ABM). I will be focusing primarily on spatial/temporal simulations that integrate human behavior and environmental factors that some are referring to as Spatial ABM's as a primer for what will be heard following this address in the "*Advances in multi-agent simulations in geographic space* (Itami & Gimblett) & hopefully provide some common concepts that will be found in the session on "*Human ecosystems modelling and management with agents*" (Batten, Ferrand & Perez). The significance of this topic area discussed at this conference is of international concern. The American Association of Geographers frequently has sessions related to land use/cover change, the Human Dimensions of Global Environment Change Conference just held at the University of Bonn, Germany and the upcoming Third International Conference on Monitoring and Management of Visitor Flows in Recreational and Protected Areas, September 2006 in Switzerland (previously held in Vienna and Finland), are evidence of this critical need to address the topic area.

Spatial Agent Based Modelling Approaches

While there are many journal papers and book chapters focused on spatial agent-based simulations (Gimblett, 2002; Parker et al. 2003; Janssen, 2003; Bousquet & Le Page, 2004) there are two dominant approaches (from which hybrids have been developed), that will be discussed further in the following session and serve as a focus for this presentation. They are Agent based models linked to Land use Land Cover Change (ABM/LUCC) models and the use of remote sensing data and Agent Based Models (ABM) Linked to Geographic Information Systems. These modelling approaches differ both in the nature of the agents that are developed (autonomous versus stationary) and the choice of data structures that represent the landscape (cellular versus network). Both however are commonly linked by methods for collecting human/household data, the need to derive and implement behavioral rules at multiple scales, the need to develop accurate simulations and outputs as well as to fit these models into some planning or management framework for decision making. But first, let us examine these two modelling approaches.

ABM/LUCC models

Land use and land cover change emerged as a central issue in the broader debate of global change, a debate that has its origins in the concerns about human-induced impacts on the environment and their implications for climate change. Land cover change is driven largely by land use and management practices, which in turn are a function of environmental opportunities and constraints but also of a complex web of social, economic and political processes – how these processes interact is a central research question of the Human Dimensions of Global Environmental Change Program (http://www.ihdp.uni-bonn.de/). Large and medium scale land cover conversions in tropical ecosystems, such as deforestation, have so far received the bulk of attention (e.g. Skol et al. 1994), due to their prominent role in global biogeochemical cycling, one of the 'big issues' of land use and land cover change science. Land cover modifications, by contrast, are more subtle and therefore more difficult to detect, but are no less a factor in global change.

The complexity inherent in the human-environment system and the diversity of real world situations, even within a local setting, pose a real challenge to modelling human-environment interactions and resulting land cover changes. Agent-based modelling integrated with Geographic Information System (GIS) and remote sensing to explain and model land use and land cover changes and evaluate them as to their degradation or potential for regeneration are currently being explored. The agent-based perspective is centered on the nature of land use decision making by individual agents, which can be households or institutions, embedded in an environment. The spatial dimension provided by the GIS allows the research community with the ability to ask the question about why and how landscapes are changing and to evaluate the spatial location or proximity in which it is occurring. This has many advantages when developing site specific, long term planning and monitoring strategies.

The advantage of this approach is that information on the human dimension of land use and land cover change and degradation issues are collected focusing on individual households as decision-makers while at the same time utilizing and evaluating the larger socio-economic context in which these decisions are made. While this methodology is gaining momentum and has been explored in many situations (Fox et al. 2003), there are inherent problems in the work currently being implemented. Spatial ABM's using household/local data in conjunction with cellular databases or growth models:

- Suffer from inherent problems with accuracy and resolution particularly when linking up individual households with land use/cover data and representing landscape change at local levels;
- Many cellular layers are required for site level rule generation and decision-making;
- Models frequently negate any form of verification or validation;
- Rules developed from household survey data are not explicitly detailed nor validated;
- Stationary household agents lack the advantages of autonomy (ie. being altered by the changes occurring in the landscape);
- Both spatial and household data can be expensive and problematic to acquire;
- Linking geospatial and agent models to study interactions and outcomes pose many challenges in studies where requirements vary at both spatial and temporal scales;
- Outputs from these models are seldom field validated.

While these limitations are apparent throughout much of this body of literature they are not surmountable and some potential methods to resolve these issues are being discussed at this conference.

Agent Based Models (ABM) Linked to Geographic Information Systems

Spatial-agent based simulations (ABM's) linked directly to Geographic Information Systems hold great promise for studying complex systems such as wildlife population dynamics, urbanization processes, human behavior, traffic flows, and other phenomena (Itami & Zanon, 2003; Gimblett 2002; Soulie & Thebaud (this volume); Batty et al. 2003). These simulations link spatial agents to represent the phenomenon being modeled (ie. humans and other modes of travel) with landscape characteristics (ie. roads, trails and other linear networks such as flight lines etc.). Many of these simulations utilize behavioral data collected in the field to generate agents from a variety of sources (ie. Traffic and trail counters, Global Positioning Systems (GPS), Radio Frequency Technology, race timing devices, diaries, observation and a variety of other techniques) and local knowledge to aid in framing both global and local rules that mimic human decision making processes. Simulating existing baseline conditions using this type of data create a true realization of field data collected. Data is entered into the simulation and human use and interactions are measured and assessed along linear networks and nodes. This type of simulation provides an opportunity for decision makers to explore through scenarios the change of human patterns over time. They provide mechanisms to identify points of over crowding, bottlenecks in circulation systems, peak periods of human use, conflict between different human user groups and many other social or ecological indicators. Common in these simulation models is the development of a baseline simulation that replicates the field data collected. Given that a statistically representative sample of field data can be acquired that captures both spatial and temporal variability of travel patterns, probabilistic simulations can be developed for making long-term, highly reliable predictions. A review of many of the models developed using ABM's and GIS, suffer from a few of the same problems outlined above and yet because of their uniqueness have the other challenges such as the:

- Applications are currently limited to those using a topological derived network of links and nodes and have seldom incorporated raster datasets;
- Minor limitation of the data structure (number of links and nodes) that represent the landscape can restrict accurately representing the landscape;
- Networks to date lack sufficient contextual information required for site level rule generation and decision-making;
- Both network and human behavioral data can be expensive and problematic to acquire;
- Landscape alteration, impact or change in response to human use is not currently implemented;
- Probabilistic simulations require an extensive amount of adequate sampling data to represent spatial and temporal variability of human patterns on the landscape and model verification and validation;
- Model verification and validation has been limited or non-existent in past applications;
- Limited studies have attempted to link human flow models to other resource based landscape models;
- Integration of these models into existing management or decision-making framework.

Challenges for Modelling of human-landscape interactions

Both of the modelling approaches above have many challenges. Both are developing and continue to add the essential components to develop credible, predictive models. Ultimately the goal of any spatial modelling system should be to function on the minimum amount of input data that is both statistically valid and representative and yet accurately portrays the system being modeled. In addition, the maximum amount of knowledge should be output that is appropriate to address the problem at hand. How much detail is enough? How much real data should be collected that meets social science statistical sampling methodologies and model verification and validation standards? How much and diverse a data sample is required to capture the spatial and temporal variability of the social system being modeled? These and many more questions still remain partially answered and remain problematic for modelers. A review of the modelling approaches above, many journal papers and those from this conference reveal the following challenges to those modelling human-landscape interactions that will be addressed further:

1. Collecting valid data on human behavior/movement, households required for agent based models;
2. Acquiring social data to represent spatial and temporal variability, model verification and validation;
3. Translating field based data and local knowledge into useful and valid rules at multiple spatial scales;
4. Transferability of modelling results across different spatial scales;
5. Building valid complex dynamic spatial models;
6. Developing innovative ways to analyze and display spatial agent simulation outcomes;
7. Integrating simulation modelling into the decision-making framework.

1. Collecting valid human behavior or movement data required for spatial agent based models

Emerging technologies are improving the way that valid human movement and behavior data can be acquired as input into spatial ABM's. In Cole (2005), Arnberger et al. (2002) & Sievänen et al. (2004), There are many good examples of methods for collecting valid human behavior data - Guerrin et al. & Morris et al. & Xia & Arrowsmith (this volume), O'Conner et al. (2005). Spatial ABM's using GPS or other spatial tracking systems (ie. mechanical road or trail counters, RFDI technology, observation, race counters etc.) have been well proven technologies for capturing movement patterns from point to point destinations. If the motive behind the simulation is to mimic the finer decision making qualities of humans such as interactions or reactions to other human in a landscape or detailed adaptive decision making strategies, surveys, diaries, interviews or group sessions are required. However there are still many questions that need to be addressed using these technologies such as: What are the current limitations of using GPS in canopied environments? What is the accuracy level required transforming GPS data for route determination and to parameterize simulation models? What are the important questions to ask to acquire the knowledge needed for a finer level of decision making and ultimately encoding rules that represent those actions?

2. Acquiring social data to represent spatial and temporal variability, verification and validation

The problem of sample size is of critical importance when building, verifying and validating agent-based models. Since agent based models deal primarily with non-linear systems, it is important to not only collect enough social data for building, testing and verifying the model but there is a critical need to collect data that represents the spatial and temporal variability of the system being modeled. In a recent study of patterns of human use in National Parks in the Canadian Rockies, Itami & Gimblett (2005) have concluded that simulations using survey data can provide excellent information on the dynamics of existing travel patterns, if and only if the sample is representative of the population over the period of simulation. Projecting future visitor use volumes on the basis of existing data requires that the simulation must be generalized. For example, in their study Itami & Gimblett (2005) this was done by making statistical generalizations from a baseline simulation in the form of probability distributions for arrivals and trip itineraries for each arrival point. This process creates a "probabilistic simulation", and can be used as a basis for "ramping up" or projecting use levels into the future.

To develop a strategy for sampling trip itineraries for each day of a simulation, it is necessary to define of "pool" of trips with common patterns of destinations over the course of a year. If itineraries are changing through the year the pool of trips must change to reflect changing patterns of use. The idea of a sampling pool of trips is to capture the variability of trips that may occur on any given day of the year. If the pool is limited to only the trip itineraries sampled for the corresponding day, the effect is to "overfit" the simulation model to the sample population. This may increase the statistical validity of the resulting simulation, but lowers its utility from a management perspective since the model is not representative of the true variability of trip itineraries selected by visitors on any given day (Morris et al. (this volume).

Itami & Gimblett (2005) reported that the data collected in the study did not meet the requirements for building valid agent based travel simulations. While the sample size acquired in this study is a representative sample for social/economic profiling of visitors, the sampling design fell short of the requirements needed to develop valid simulation models. While there appeared to be a consistent sample across all seasons, a closer examination of return rates averaged out weekly over the sampling period reveals approximately 17 surveys a week at one entry area and a range of 1.2 to 7.4 at the other entries. These samples were inadequate to make any statistical generalizations about rates of arrivals and whether or not trip itineraries are changing by weekday or by time of day. The study concluded that based on the minimum requirements to do a chi-square test on daily arrival distributions a minimum of 5 arrivals per day for 80% of the cases being compared is required. This means that for weekdays 6 out of 7 weekdays with a minimum of 5 arrivals or 30 arrivals per week (realistically something closer to 50 surveys a week) are required in order to make any statistical generalizations or comparisons between the results of the trace simulation to the probabilistic simulation. This is one example of the type of data sampling requirements that are being discovered in studies using complex dynamic agent-based models. More precise sampling, data collection and monitoring protocols are being developed and implemented in response to these types of studies.

3. Translating field based data and local knowledge into useful and valid behavioral rules at multiple spatial scales

Commonly in spatial ABM's, household or survey data are statistically analyzed to derive important spatial and temporal indicators of the system being modeled. These are sometimes stratified by mode of travel, party or household size, economic income, type of recreation or land use activity and many more. From this data the modeler develops a series of rules, interactions and specifications for the agents and their environment, and then allows agents to interact within the simulation environment. In some simulations, agents are autonomous because once they are programmed they can move about their environment, gathering information and using it to make decisions and alter their behavior according to specific environmental circumstances generated by the simulation. Each individual agent has it's own physical mobility and cognitive capabilities. Agents use a set of high level, way finding logic incorporated with a set of user defined rules that allow them to navigate in the landscape. Agent rules are usually a set of user-defined behaviors that are constructed using a stimulus/response or event/action framework. Each of these properties will have a state or value that can be defined as a stimulus or even and triggers to create complex conditions for behavior.

Many of the studies reviewed for this paper (using either autonomous or stationary agents) tended not to explicitly indicate how those rules are developed. Once the simulation is executed, there is no way to determine how valid these rules are. A challenge to the research community is developing valid rule based simulations. Along those same lines of thinking is to investigate how to define what constitutes a good rule. Some studies use strategies like developing a set of rules and then tracing the agents to determine if the agents actually behave or follow the rules. If not, then the rule structure is tweaked or adjusted to obtain the behavior expected as observed in the real world. The challenge is to come up with the right rule sets that define the behavior expected and test those rules to ensure they are working.

For example, in a recent study in Alaska by Lace and Gimblett (2005), where rules were developed related to hunters pursuing black bears. Model verification was accomplished by executing tests on the outputs to ensure a set of rules were firing in sequence and the relative outcomes of the agents were as desired. The rules used in this project are a simple set that keep the agents active for the duration of the trip.

Validation of a rule-based simulation is essential. Some form of reliability measure is required to be placed around the set of rules developed. If 80% of the variability in decision-making can be accomplished with three rules are they valid rules? Is 80% good enough for planning work? These and many other forms of reliability on rules need to be established when developing and implementing complex spatial agent based models. There are many spatial statistical procedures that can be implemented to evaluate if the spatial and temporal patterns of agent behavior is being captured by the rules being utilized.

4. Transferability of modelling results at different spatial scales

Xia & Arrowsmith & Matthews et al (this volume) bring up some interesting issues about spatial scale. Xia & Arrowsmith are focused on the issues of temporal and spatial scale appropriate for the modelling of tourist movements at different spatial scales. This paper conceptually reveals the differences of tourist movement tracking and modelling methods between these two scales but also explains the transition of tourist movement between two scales using spatial-temporal zooming theory. This holds great potential for dealing with the issues of spatial scales.

Matthews et al. (this volume) are interested in an approach that links existing models into a fully integrated system with shared ontologies for each of the model components. This includes a fully integrated model that works seamlessly at multiple scales. While there are challenges in doing this, there will be many benefits to this approach. The challenge according to Matthews et al is "incorporating enough sophistication in such models to capture all relevant processes, and keeping them simple enough so that understanding of these processes and their interactions is not obscured." Both of these papers reveal both the issues as well as some potential solutions to dealing with spatial scale issues.

5. Building Valid Complex Dynamic Spatial Models

Building valid spatial dynamic models has posed many challenges to researchers. In many traditional mechanical models a single mean performance indicator has generally been used. In complex spatial dynamic models, performance indicators may change through space and time by location, enhancing the problem many fold.

While many simulation projects and papers presented at conferences like this never bother to attempt any form of verification or validation. A quandary results about whether the:

- Parameters and starting configuration of the simulation are the best ones for the system being modeled;
- Outputs from the simulation are representative what has been or could be observed in the world;
- Similar results would be obtained if the simulation were run again with slightly different parameters;
- Model is the simplest that yields the desired output and is therefore to be preferred over other, more complex models;
- How good the initial transition and behavioral rules represent the dynamics of interactions.

There are many ways to determine how well the simulation is functioning and representing the social system being modeled. Some are as follows:

- Optimizing simulation model parameters to real life data especially for the case where such empirical data are rather sparse (i.e. short time series) which is most often a problem in social science research practice;
- Sensitivity analysis allowing for a wide scope of variation of parameters and initial values and a sophisticated analysis of the simulation results obtained during parameter and initial value variation.

Several papers in this volume are actively experimenting with methods for building valid spatial simulation models – Campbell et al., Itami, Deadman and others (this volume). Within the field of MAS/LUCC modelling, a great deal of interest is currently focussed on the validation of these models. In early MAS/LUCC modelling efforts, validation was not often extensively addressed. More recently, a number of approaches have emerged which are designed to measure either the predictive or explanatory power of these models. In many of these models the goal is not to produce a specifically predictive model, but rather one in which relationships between different elements in the study system can be explored. The models serve to illustrate and explore particular phenomena, while acting as a tool for generating and testing new theories. The approach to validation taken here has been to compare overall trends in the output of LUCITA, measured as aggregate changes in land use over time for the entire study area, to quantitatively measured trends in land use, and to theoretical models of individual household decision making. Deadman (this volume) will specifically talk about using landscape metrics, numerical measures of pattern in land cover, have been previously used to evaluate the outcomes of LUCC/ABMs.

In spatial simulations, determining the number of replications needed to construct confidence intervals for performance indicators is much more complex than in non-spatial simulations. Itami (this volume), suggest "because of the use of random variables in spatial simulations, it is unwise to draw conclusions from a single replication of any given simulation." He goes on to say that while standard practice is to calculate confidence intervals for a given alpha level for *n* replications of the simulation model, spatial simulation models are much more complicated where performance measures are distributed across space. His paper has provided a review of alternative methods for estimating the number of replications and has shown how to apply these methods in spatial simulations using the Bonferroni Correction when multiple performance indicators are used.

One example of determining the number of replications needed to construct confidence intervals for performance indicators in a complex, spatial simulation was undertaken in Itami & Gimblett (2005). The baseline trace simulation was built and run repeatedly using a different set of random numbers for each replication. The simulation is run for the entire year of the survey period, which was from January 1, 2003 until December 31, 2003.

During this period the 1620 trips are simulated using the trip itineraries generated in the previous section. Standard practice is to run the simulation for 5 replications for baseline trace simulations and calculate the confidence intervals for the key output variables (in this case, daily node and link use and node and daily link encounters). This analysis was performed at a 95% level of reliability and with 5 replications and a user defined confidence half interval of + or – 1 visitor. The results of this analysis showed that for node use, link use, and overnight node encounters the required 95% confidence intervals could be achieved within the 5 replications. For link encounters however, because of the higher impact of small variations on encounters, 95.7% of the links produced 95% confidence intervals within 5 replications, another 2.82% requiring an estimated 6 to 10 replications and the remaining 1.5% requiring an estimated 11 to 104 replications to achieve 95% confidence intervals.

6. Developing Innovative ways to analyze and display spatial agent simulation outcomes

With recent advanced in computer graphics more effective communication of simulation outcomes are being developed. Virtual reality (Bishop & Gimblett, 2000), 3-D mapping of spatial outcomes is more prevalent than ever before. Spatial agent-based models such as REPAST linked to ArcGIS provides both innovative and effective ways to both spatially analyze and display the complex outcomes of these simulations (Collier, 2000). Critical for many decision makers is the ability to run a simulation, obtain statistically valid results with confidence intervals around those results and convey those in an effective way to the public. Much research work is currently being undertaken integrating agent based modeling into interactive sessions with the public.

7. Integrating simulation modelling into the decision making process.

Itami & Gimblett (2005) has outlined a tentative framework for integrating spatial agent based simulation into a planning and management framework. This framework will be outlined in detail in the presentation but incorporates all aspects of the process from defining goals and objectives through to evaluating and selection of alternatives. There are many components to this framework that have been touched on in this paper but the key is embedding agent based simulations that have been shown to provide effective planning and management outcomes. This places simulation into an exploratory framework in decision-making process.

Conclusions

There is a growing body of research focused within the context of human-environment interactions. This work examines the need to develop a comprehensive and empirically based framework for linking the social, biophysical and geographic disciplines across space and time. This paper has outlined the spatial ABM approaches that are being used to model human-landscape interactions in many settings. It appears that the issues surrounding data collection, model development through to model validation overlap. One common thread among both approaches is that human use simulation modelling has the potential to bridge a significant social science knowledge gap to improve the ability of decision making to positively and proactively manage human-land use interactions and promote long-term protection of the landscape. Spatial agent-based simulations provide:

- A comprehensive and dynamic understanding of human behavior, interactions between humans and their environment;
- A framework for a more holistic and comprehensive way of incorporating human-landscape information into the planning and management process;
- A way of measuring human interactions that are difficult or expensive to do in the field;
- A way to test alternative management scenario's and place planning and management into an exploratory and experimental framework;
- Communicating complex inter-related issues in human-landscape management to the public and decision makers.
- A comprehensive framework for human monitoring, understanding human use patterns, and as a decision support system for defining and testing alternative management responses to changing condition.

As with the introduction of any new methods, they do not come without growing pains. While the spatial agent-based modelling community has come a long way in adopting and adapting techniques from many disciplines and developing new ones specific to agent modelling, it is apparent that there is much more research and development work that needs to occur before the decision making community can have full confidence in the results these models provide. This paper has outlined some of the issues that still need further development from data collection, model development through to model validation and presentation. Critical to all the technical pieces of the simulation puzzle that need to be worked on is the integration of spatial agent-based simulation modelling into a planning and management framework. This would place simulation into a useful and effective position as an integral part of decision-making. It is only when this occurs that the true value of simulation will be realized as an integral and essential component of a decision-making process. Like GIS in the 70's and early 80's, the early beginnings of spatial agent-based simulations will become common practice in the future. So what is next?

In the short term the research community should:

- Continue to develop decision-making processes that integrate simulation technologies;
- Work towards a standardized set of data collection and monitoring procedures that are comprehensive and cost effective;
- Explore new technology for collecting data and analyzing data on human-landscape interactions;
- Continue to explore and improve upon the reliability and validity of the simulation models;
- Combining technologies such as traffic counters, pedestrian counters, and traditional social survey techniques can provide comprehensive information on human behavior;
- Integrate models of visitor flow, traffic, wildlife and environmental impact within the context of planning and management.

In the longer term:

- Continue to apply simulation in a diversity of environments to demonstrate the advantages of using human use monitoring and simulation in the planning and management process;
- Continue to coordinate at the national level to incorporate visitor monitoring and simulation in the planning and management process.

Hopefully this paper and others presented at this modelling conference will stimulate discussion and lead to improved techniques for developing and implementing spatial agent-based models.

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