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RBSim 2: Simulating the Complex Interactions between Human Movement and the Outdoor Recreation Environment

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Abstract: This paper describes advancements in recreation management using new technology that couples Geographic Information Systems (GIS) with Intelligent Agents to simulate recreation behaviour in real world settings. RBSim 2 (Recreation Behaviour Simulator) is a computer simulation program that enables recreation managers to explore the consequences of change to any one or more variables so that the goal of accommodating increasing visitor use is achieved while maintaining the quality of visitor experience. RBSim provides both a qualitative understanding of management scenarios by the use of map graphics from a GIS as well as a quantitative understanding of management consequences by generating statistics during the simulation. Managers are able to identify points of over crowding, bottlenecks in circulation systems, and conflicts between different user groups.
RBSim 2 is a tool designed specifically for the purposes of simulating human recreation behaviour in outdoor environments. The software is designed to allow recreation researchers and managers to simulate any recreation environment where visitors are restricted to movement on a network (roads, trails, rivers, etc.). The software architecture is comprised of the following components:

- GIS module to enter travel network, facilities, and elevation data
- Agent module to specify tourist personality types, travel modes, and agent rules
- Typical Trip planner to specify trips as an aggregation of entry/exit nodes, arrival curves, destinations and agents
- Scenario designer to specify combinations of travel networks, and typical trip plans
- Statistical module to specify outputs and summarize simulation results.

This paper describes the RBSim software architecture with specific reference to the trip planning algorithms used by the recreation agents.

RBSIM – RECREATION BEHAVIOUR SIMULATOR

The purpose of the Recreation Behaviour Simulator Version 2 (RBSim 2) is to simulate the consequences of management decisions on visitor flows and encounters within a defined road and trail network within an outdoor recreation setting. RBSim 2 is a computer simulation tool, integrated with a Geographic Information System (GIS) that is designed to be used as a general management evaluation tool for any visitor and recreation facility management problem on linear networks. This capability is achieved by providing a user interface that imports park information required for the simulation from either MapInfo or ESRI ArcView geographic information systems. Once the geographic data is imported into RBSim, the park manager may then build alternative management scenarios (Itami et al. 1999).

Some of the factors the manager can change include the number and kind of vehicles, the number and arrival rates of visitors, and facilities such as the number of parking spaces, road and trail widths and the total capacity of facilities.

Statistical measures of visitor experience are generated by the simulation model to document the performance of any given management scenario. Management scenarios are saved in a database so they can be reviewed and revised. In addition, the results of a simulation are stored in a database for further statistical analysis. The software provides tables and graphs from the simulation data so park managers can identify points of over crowding, bottlenecks in circulation systems, and conflicts between different user groups.

Park managers can use RBSim 2 to compare alternatives by experimenting with different policy levers that can operate within the software. Such levers may activate or deactivate rules which agents in the RBSim environment will follow as they move through the environment of the Park.

RBSim uses concepts from recreation research and artificial intelligence (AI) and combines them in a GIS to produce an integrated system for exploring the complex interactions between humans (recreation groups) and the environment (geographic space) (Gimblett et al. 1996a; Gimblett et al. 1996b, Gimblett and Itami 1997, Gimblett 1998). RBSim joins two computer technologies:

- Geographic Information Systems to represent the environment
- Autonomous human agents to simulate human behaviour within geographic space.

WHAT IS AN AUTONOMOUS AGENT?

RBSim uses autonomous agents to simulate recreator behaviour. An autonomous agent is a computer simulation that is based on concepts from Artificial Life research. Franklin as Graesser (1996) define an autonomous agent as follows:

"An Autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to affect what it senses (and acts on) in the future."

Agent simulations are built using object oriented programming technology. The 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 behaviour according to specific environmental circumstances generated by the simulation. Each individual agent has its own physical mobility,

sensory, and cognitive capabilities. This results in actions that echo the behaviour of real animals (in this case, human) in the environment.

What is compelling about this type of simulation is that it is impossible to predict the behaviour of any single agent in the simulation and by observing the interactions between agents it is possible to draw conclusions that are impossible using any other analytical process.

WHY RBSIM IS IMPORTANT TO RECREATION MANAGERS

RBSim 2 is important because until recently, there have been no tools for recreation managers and researchers to comprehensively investigate different recreation management options. Much of the recreation research is based on interviews or surveys, but this information fails to inform the manager/researcher how different management options might affect the overall experience of the user. For example a new trail may be introduced to alleviate crowding or conflicts between different user groups. How does this change increase or decrease the potential conflicts? How many more users can be accommodated and for how long? What is the impact on other facilities in the same park? Questions like these cannot be answered using conventional user survey 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. By combining human agent simulations with geographic information systems it is possible to study all these issues simultaneously and with relative simplicity.

RBSIM 2 COMPONENT ARCHITECTURE

Figure 1 shows the relationship of the major components of the RBSim 2 object hierarchy. An RBSim 2 simulation model is comprised of the following components:

Road/Trail network

The Road and Trail network is imported either from ArcView Shape files or MapInfo Tab files. On import standard fields required by the simulator are added to the associated attribute tables. Once the network has been edited and attributed it is written to a topologically structured network of Links and nodes.

Links are a series of line segments defined by a series of x,y,z coordinates that describe the alignment of the road or trail between two nodes. Link attributes include Label, Link Type, Link Category, number of lanes, maximum speed, length and slope. Links also may have access restrictions assigned to a scenario, such as open and closure times for different travel modes

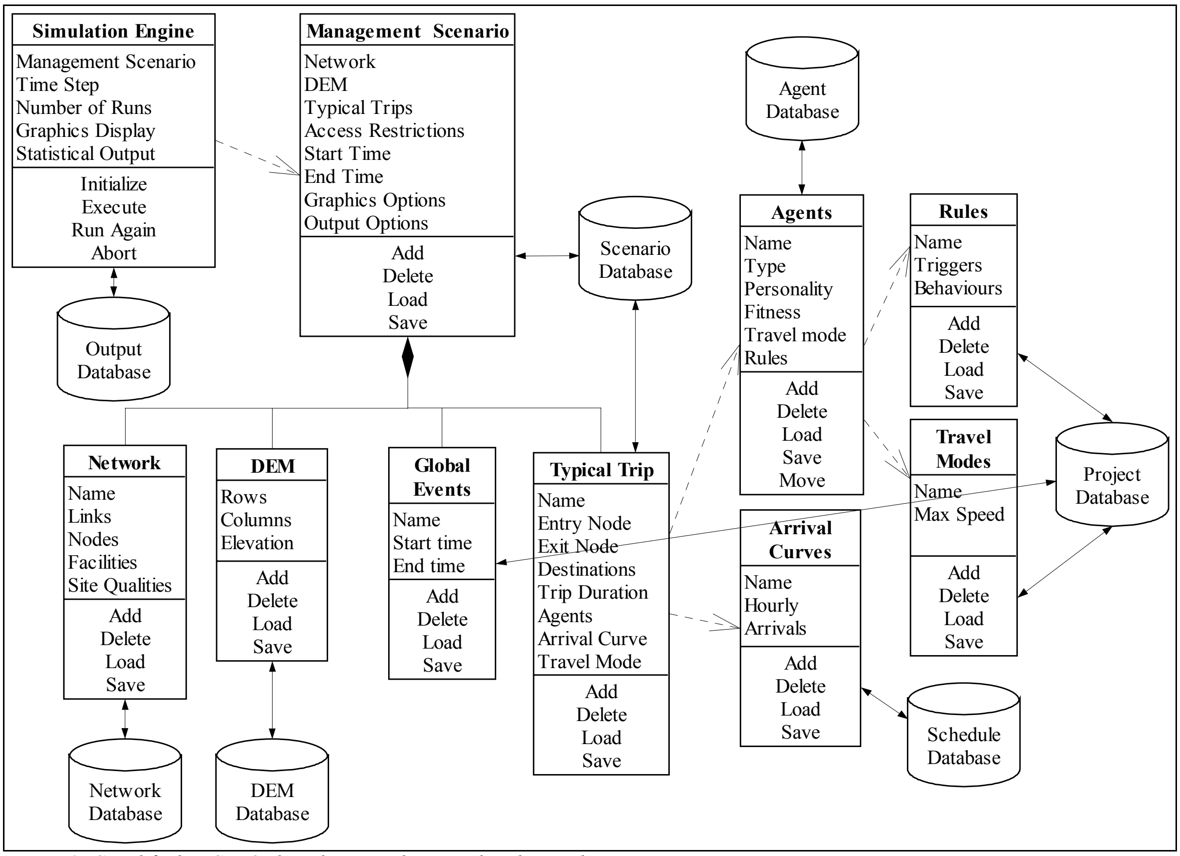

Figure 1. Simplified RBSim 2 class diagram showing class hierarchy.

A node is a point in the network representing a particular physical location at an intersection between links or where one or more facilities are located. Nodes are joined to the network by one or more links.

In addition to X,Y,Z coordinates, nodes have attributes including label, park entry, park exit, locale, facilities, and site qualities. Facilities are user defined destinations such as a visitor centre or picnic area that have a capacity and a typical duration of visit assigned to them. Site qualities, are user defined values such as scenery, history, or environment,education that are attributed to a node. A locale is a collection of one or more *nodes* with associated facilities that have a shared identity and can be grouped based on proximity to each other or common access.

Digital Elevation Model (DEM)

Elevation data is represented in a regular grid of elevations. They are used to assign elevations to the network and in calculating intervisibility between agents. DEM's are imported into RBSim from ESRI binary export files.

Global Events

Global events are user defined events that are raised during a simulation. Events have a start time and an end time and are controlled by the simulation engine. An example might be a rain storm, nightfall, temperature change, or any other event that affects the entire simulation.

Arrival Curves

Arrival Curves indicate the number of visitors arriving per hour over a 24 hour day. Arrival curves may be derived from traffic count data or estimated by managers familiar with the arrival patterns. Arrival Curves are used as part of the description of a typical trip, described later.

Agents

Agents have a number of standard attributes including fitness level, travel mode, travel speed, and preferences. Preferences are a list of values that correspond to site qualities that are attributes of network nodes. Values are weighted using Saaty's (1995) Analytical Hierarchy Process[1]. Preferences are used in the agent's logic for way-finding in locales which is described later in this paper.

Agents also have visual abilities. They can do line of site calculations to other agents at run time to count the number of other agents visible within a user defined radius.

Agent Rules

Agent rules are a set of user defined behaviours that are defined using a stimulus/response or event/action framework. RBSim 2 exposes runtime properties of the network, agent, and global events. Each of these properties will have a state or value

[1] For a more detailed explanation of the use of AHP in agent reasoning see Itami and Gimblett, 2001

which can be defined as a stimulus or event. Boolean logic can be used to combine two or more stimuli to create complex conditions for behaviour.

Behaviour is defined as a directive to search for a location or facility. An example of a complex rule is:

If (TravelMode = 'Car' AND Locale='12 Apostles' AND LocaleEntry = True) THEN Find Carpark

Agent rules are assigned to agents in the management scenario builder. The order rules are executed can change behaviour, so the user can specify the order of execution of rules. For instance, an agent should always park a car before going to a visitor centre.

Typical Trips

A Typical trip is described by an entry node and exit node to the network, an arrival curve, and probability distribution of agent types, a list of destinations (locales), and a trip duration. The concept of a typical trip is based on the premise that visitors have common patterns of use. For example day use visitors arriving during weekdays will have a different arrival pattern, a different duration of stay, and perhaps a different pattern of destinations than a traveller arriving on a weekend or an overnight visitor. Typical trips can be derived from field data or based on the experience and expertise of managers on-site.

Management Scenarios

A management scenario is an aggregation of a network, a DEM, one or more typical trips, a set of ordered agent rules assigned to one or more agents, zero or more global events, a set of access restrictions, and a set of runtime simulation conditions (see Simulation Engine).

Access restrictions (or gates) allow the manager to open and close parts of the road and trail network to different travel modes. Access restrictions are scheduled with a start time and end time. They may be hourly closures or seasonal closures.

Agent rules are assigned to each class of agent defined. Individual rules can be turned on and off for each agent, and the order that rules are executed may be uniquely defined for each agent class.

Simulation Engine

The simulation engine executes the management scenario. For each simulation run, the user defines the start date and time of the simulation, the end date and time of the simulation, and enables or disables the graphics display, statistical outputs, and agent inter-visibility.

Once these simulation conditions are defined, the user then runs the simulation. The simulation engine initialises the simulation in the following steps.

1. The network is loaded and validated
2. Each typical trip is loaded and the arrival schedule is interpolated for the duration of the simulation. All arrivals are then aggregated and sorted by arrival time.
3. Global events are scheduled
4. Network access restrictions are scheduled
5. Locales are sub-setted from the network.
6. For each locale, for each travel mode, a travel time matrix is calculated for all origin-destination pairs.
7. If output statistics are requested, the output databases are initialised.
8. If runtime graphics are requested, the graphic windows are initialised.
9. The simulation run is then commenced. The simulation engine starts the simulation clock and for each time step, reads from the arrival schedule to find all agents entering the simulation for that time step. For each agent, the simulation agent creates an instance of the agent, assigns it a personality preference profile, a set of rules, a fitness level, a travel mode, arrival mode, and a trip duration. The simulation engine then calculates a "Global trip" from the typical trip destination list. The global trip begins at the entry node for the trip and ends at the exit node. The path to intermediate destinations is generated based on least travel time algorithm. The global trip is saved as a trip itinerary and passed to the agent. Each agent then responds to a single method "Move" for each time step of the simulation. Once the agent is created, the simulation engine only issues the move method to each agent. The agent uses its own internal logic and rules to navigate through the network, selecting destinations, and determining duration of stay for each destination.

THE WAYFINDING LOGIC OF AGENTS

All agents follow a plan a global trip plan as described earlier, however these plans provide only a general trip itinerary. Once the agent begins its trip, changing conditions of the network (facilities becoming full), global events (rain storms), agent states (agent fitness, running short on time), can all act together to change the behaviour of the agent according to rules and the internal way-finding logic of the agent.

The way-finding reasoning of an agent is influenced by the following factors:

- Available time (defined by time elapsed subtracted from total trip duration).
- Travel mode as it affects travel time.
- Agent preferences
- List of rules and their order
- Currently executing rules
- Internal state of the agent
- Current location of the agent
- Condition of the network including availability of facilities, access restrictions,

and travel time to destinations on the network
- Previously visited destinations

As the typical trip defines the entry and exit node and a series of locales and durations, the simulation engine then uses travel time algorithms to find the most efficient route between destinations. However once an agent reaches a locale, it must use its internal way-finding logic to find destinations, generate a path that links these destinations, and simultaneously take into account the factors in the above list.

When an agent arrives at a locale, it checks to see if there is a duration set for this locale in the global trip itinerary. If the duration is >0 then the agent checks to see if there is enough time left in its total trip duration by subtracting the time elapsed since the beginning of the trip and the time to travel to the exit node. If the remainder is positive and greater or equal to the duration set for this locale, the agent enters the locale and performs the following initialisation procedures:

1. Loads the subset locale network for the agent's current travel mode.
2. Generates weights for the site qualities for each node in the locale by multiplying the node site quality with the corresponding personality preference value (unique to the agent)
3. Marks any nodes that have already been visited as "visited" and sets their site qualities to zero.
4. Sets its internal state to "entering locale"
5. Loads its rule list.
6. Generates a locale trip plan.
7. Executes its move behaviour for the locale.

The way-finding logic is encapsulated in step 6, generating the locale trip plan. The locale network is a topologically structured network containing the links and nodes, access restrictions, facilities, and site qualities for the locale.

Once the locale network has been initialised, the agent then evaluates all possible combinations of destinations from its current node location. These paths were pre-calculated when the simulation was initialised to enhance performance. The agent then evaluates each path and rejects any path that exceeds the available locale visit duration. The remaining paths are then ranked to maximize the site preferences and contain facilities that are on the agent's current rule list. A gravity model is used to weight the paths so paths with high priority facilities are ranked higher for facilities close to the agent's current location.

Once the preferred path is selected, the agent loads it as its current trip itinerary. The agent then traverses this itinerary as far as it can in the current time step. If the agent encounters a node that contains facilities that are on its current rule list, the agent changes its internal state to "visiting facility" and generates a visit duration for that facility. If the facility at the node has no available capacity (e.g. the parking lot is full), the agent "looks ahead" on its itinerary to see if a facility of the same class is available, if there is, the agent then continues its trip toward that node. If there is no other facility of the same class, the agent will then change its state to "queuing" and waits until the facility becomes available.

At each iteration of the simulation the agent must check its available trip time, its current travel mode, its current rule list, and its current state. Any of these can trigger a change in behaviour. The agent may abandon its current trip and calculate a path back to its car, or to the exit. If the conditions have not changed, then the agent continues to execute its current behaviour.

Though there are a lot more details to this behaviour, the above reflects the overall logic behind the agent's way-finding logic. When implemented, the logic produces behaviour that appears "smart" in that the agents generate logical paths and exhibit behaviour that is human-like.

12 APOSTLES MASTER PLAN PORT CAMPBELL NATIONAL PARK VICTORIA, AUSTRALIA

Port Campbell National Park is managed by Parks Victoria, Australia. The park is typified by spectacular coastal scenery with limestone cliffs and sea stacks against the backdrop of the forceful waves of the Southern Ocean. The park's popularity is enhanced by its proximity to Melbourne and the large number of tour buses that visit the site daily. These factors contribute to the heavy visitor use, and the inevitable crowding and decline of visitor satisfaction and environmental quality. RBSim 2 was used to examine the impact of changes in park infrastructure and increasing visitor rates over a 10 year period on the Twelve Apostles site. This site has recently been upgraded with a new parking lot and visitors centre. All parking south of the Great Ocean Road has been removed and visitors must now park in an improved parking lot north of the Great Ocean Road (see figure 2).

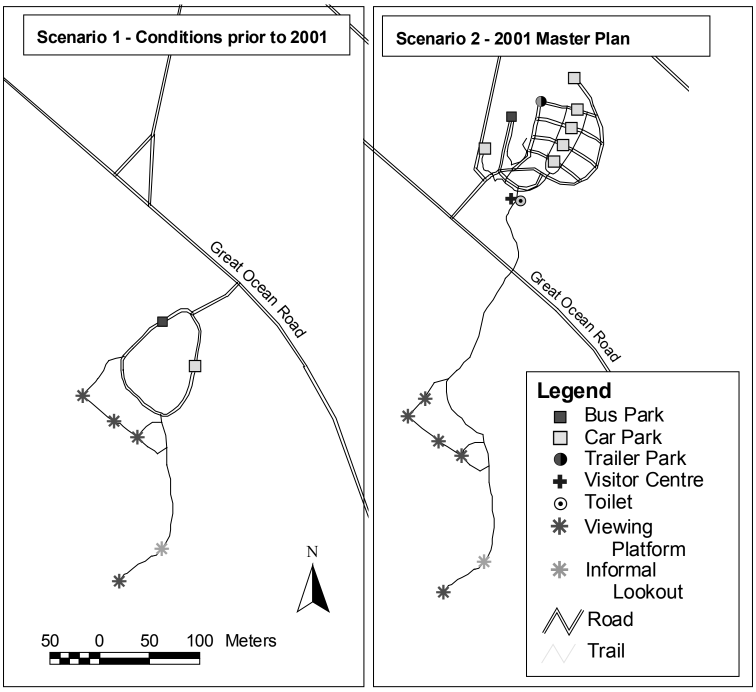

Figure 2: Network layout and facilities for Scenario 1 and Scenario 2. Limited parking to the south side of Great Ocean Road in Scenario 1 encourages illegal parking, visual impacts, and crowding. Scenario 2 shows all vehicular traffic has been moved north of the Great Ocean Road with an enlarged parking area, a new Visitor Centre, new public toilets and a pedestrian walkway that goes under the Great Ocean Road to the viewing platforms facing the 12 Apostles.

Some 701,000 people visited the site in 2001/2 and by 2006/7 this is expected to be 864,000. The new visitor centre which includes new toilet facilities and an interpretive centre provides a gateway to the site via a pedestrian tunnel that leads visitors under the Great Ocean Road along a path to the viewing platforms along the cliff edge of the spectacular views of the 12 Apostles. Traffic counts before and after the construction of the new facilities were taken to provide baseline and calibration data for the RBSim model. Simulation results are examined to answer a set of five management questions of key interest to the rangers of Port Campbell National Park.

Table 1 shows the before (scenario 1) and after (scenario 2) layouts of the 12 Apostles site.

Facility	***Scenario 1***	***Scenario 2***
Viewing Platform	***345 People***	***345 People***
Informal Lookout	***5 People***	***30 People***
Bus Park	***6 Buses***	***12 Buses***
Car Park	***30 Cars***	***245 Cars***
Visitor Centre	***None***	***100 People***
Toilet	***None***	***29 People***
Trailer Park	***None***	***12 Cars***

Table 1: Comparison of facilities at the 12 Apostles locale before (scenario 1) and after (scenario 2) the implementation of the new master plan.

Table 2 shows the arrival rates for cars over a 24 hour period for three time periods. The projections for 2006 and 2011 are based on a projected 3.55% growth rate per annum.

These figures were used for both scenarios. Rbsim 2 generates a standard set of statistical outputs these include:

Time	2001	2006	2011
5:00	2	2	3
6:00	19	23	27
7:00	6	7	8
8:00	20	24	28
9:00	54	64	76
10:00	114	136	161
11:00	153	182	216
Noon	203	241	286
13:00	230	273	325
14:00	213	253	301
15:00	235	279	332
16:00	193	229	272
17:00	90	107	127
18:00	37	44	52
19:00	10	12	14
20:00	2	2	3
21:00	7	8	10
22:00	1	1	1
Totals	3590	3893	4253

Table 2: Arrival rate for cars entering the 12 Apostles site for three time periods. These rates were used for both Scenario 1 and scenario 2.

- Car park and bus park capacity
- Trip completion rates.
- Visual Encounters. This is a measure of crowding at a particular attraction[1].
- Queuing time at parking facilities
- Length of stay

Each of the measures were analysed according to the original management questions. Space limitations do not allow discussion of the statistical methods used to analyse the results, however these are fully reported in Itami, Zanon and Chladek (2001).[2] Only results for Scenario 2 are reported here.

How well will the new facilities at 12 Apostles cope with growing visitor loads?

Results show bus parking will be inadequate during the busiest time of the day between 2:00 and 4:00 pm by the year 2006. This shortage is exacerbated by the year 2011 as bus parking is inadequate for the whole period from 3:00 pm to 5:00 pm

By 2006 the car park is full from 1:00 pm to 4:00 pm by 2011 the car park is full from 12:00 pm to 5:00 pm.

How is length of stay affected by the new configuration of the 12 Apostles site?

The longer walk from the new parking facilities to the viewing platforms extends the average length of stay an average of 6 to 7 minutes. Predictions by RBSim in this regard are confirmed by measurements on-site.

How crowded will the site get in the future?

As the number of visitors increase, there is increasing pressure on viewing platforms and lookouts. Crowding increases because of the increased duration of stay and the increased capacity of car parks.

How will visitor satisfaction be affected by the new facilities and growing visitor numbers?

It is expected that visitor satisfaction will decrease with an increase in visitors. This is caused by increased queuing times at parking lots, an increase in the length of stay, the number of visual encounters, especially at viewing platforms, and the number of visits that fail because of lack of parking at peak periods. This can partially be resolved by increasing the capacity of viewing platforms, but the long-term solution will require redistributing the visitors to other sites, especially at peak periods.

Management Recommendations

- Bus parking will need to be managed between 3:00 pm to 5:00 pm within 5 years (eg. use informal spaces near the visitor centre).
- Limit car arrivals after 1:00 pm in 10 years or build an extension to the car park.
- Viewing platforms will have to be increased in capacity in the 5 to 10 year time horizon if the overflow car park is used or if the car park is extended further.

CONCLUSIONS

RBSim 2 is a general agent-based model for simulating the behaviour of visitors in recreation environments where movement is constrained by linear networks. The open architecture allows recreation managers to build simulation models for any park and recreation area. Because RBSim 2 is designed as a management tool, managers can examine a broad range of management options and compare and contrast different strategies. By interacting with the simulation model, managers can evaluate the effectiveness of alternative facilities management plans to determine the performance on visitor flows and visitor satisfaction under different visitor loads.

RBSim is under continuous development to generalise it for a broader range of recreation environments. This development is linked to behaviour research (see paper by Gimblett et al. in this conference) in the U.S. and Australia. We are now in the process of developing simulations for a broad range of environments and recreation management problems.

The component architecture described in this paper allows us to build additional agents as new components and integrate them with RBSim using “plug and play” technology. In this regard, we are in the process of designing “shuttle bus” agents and “animal” agents such as grizzly bears. There is considerable interest in integrating the behavioural modelling of RBSim2 with traditional GIS ecosystem models to develop temporal environmental impact models.

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