A Framework for Integrating Visual Quality Modelling within an Agent-Based Hiking Simulation for the Swiss Alps

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Abstract: While the visual qualities of a landscape are often key factors in attracting and retaining tourist visitors, they have been overlooked in recent simulation approaches to recreation modelling. While there has been a long history of modelling the visual quality of a landscape, particularly in forestry, due to computational restrictions these models have tended to be rather coarse and primarily suited for avoiding catastrophic impacts due to large-scale interventions in a landscape. However, the experience of the visual quality of a landscape for recreationists is much more subtle. Relatively small changes to spatial patterns and land use, when viewed cumulatively, can have a large impact on the attractiveness of a landscape for tourists. Methods for evaluating the changing visual quality of a landscape are invaluable for comprehensive long-term landscape planning.

This paper describes a computational approach for integrating visual quality information into an agent-based simulation of summer hikers in the Swiss Alps. The benefits of microscopic modelling (where the activities of individual hikers are simulated) are combined with detailed 3D models to provide the possibility of a highly nuanced visual quality analysis of a recreational area. Using real-time computer graphics techniques, simulated agents interpret computer generated 3D images of what they 'see' as they move through the landscape. Various landscape metrics are calculated based on these representations, including visual quality indicators such as view composition, enclosure, and depth of view. These metrics are evaluated over the course of an agent's hike, and integrated with more traditional parameters (such as hike distance, steepness, congestion and availability of amenities) in an agent-based simulation. Unlike other raster based visual quality models, analyzing 3D representations allows the model to easily incorporate subtle screening effects, and allows the model to determine visibility from any location in the model. The technique allows for very detailed visual representations, and scales easily to include more detail as required by the analysis. Currently, the model represents terrain, vegetation communities, structures, path and road networks and information aids such as signage.

The paper describes a working implementation of the technique, and discusses its advantages and limitations, including its substantial data requirements. The paper uses a specific case study in the Gstaad-Saanenland region of Switzerland to articulate how this integration of visual information within an agent-based simulation has advantages over more traditional methods of visual quality modelling.

Introduction

There has recently been a revival in the use of computer simulation in many research areas related to natural resource management, including recreation. Encouraged by the rapidly increasing computing resources available to researchers, and by the dispersion of theoretical and technical ideas from other disciplines, increasingly complex models are being developed to assist researchers and resource managers understand the implications of different management options (Wang & Manning 2001). There is seldom a right answer for resource managers: modelling is a tool that allows the researcher or resource manager to test different scenarios and examine different ways that conflicting priorities can be handled.

A particularly powerful technique that has been used in recreation modelling is individual agent-based modelling. Using this technique, software agents, each representing an individual or small groups of individuals, are given individual goals, preferences and attributes. A set of rules is developed by the modeller which describe how the agents react to each other and to their environment. These agents are then introduced into a synthetic environment where they strive to complete their goals. They interact with each other and the environment, and make decisions (in the case of recreation modelling, this is usually their movement choices) based on their individual experiences. The modeller can observe how the agents react, either as individuals or as a system. By changing either the modelled environment or the calibration variables, the modeller can explore how the agents react. As Itami, Raulings et al. (2002) describe, an advantage of this technique is that complex system behaviour emerges that is difficult or impossible to predict based on the actions of the individuals.

The use of simulation in recreation modelling in general (see for example Wang & Manning 2001), and agent-based modelling specifically (see Gimblett et al. 2001, Itami et al. 2002), has generally been restricted to recreational areas where the primary concern has been to limit the amount of interaction between visitor groups or to manage large numbers of visitors that potentially exceed the sites' carrying capacity. This is a common concern in popular parks and recreational areas where there is a high demand and limited carrying capacity. Typical to these kinds of models is the assumption that demand is fixed or increases predictably in time.

In general these models investigate how changes to the available capacity of the recreation infrastructure (such as trails, campsites, and parking lots) impact the experience of users. This kind of model, while very useful for certain questions and applications, assumes that recreational infrastructure is the limiting factor that influences recreational choice.

However, in many recreational landscapes, particularly those that are not uniquely attractive or are facing non-recreational development pressures, the situation is more complex. For private communities dependent on tourism, and in particular those not operating at capacity, the concern is often how land use changes (such as increased development or changes to agricultural policy) will affect the experiences of their visitors.

As the primary attraction for many recreational areas is their scenic qualities, understanding how these land use changes affect users' satisfaction from a visual perspective is important. However, it is not enough to study visual quality in isolation, as numerous factors combine to contribute to a visitor's satisfaction with a given recreational area, and potentially entice them to return in subsequent years. It is anticipated that changes to the landscape would have a very complex effect on recreational choices, which makes these situations particularly well suited to individual agent-based modelling techniques (Bishop & Gimblett 2000). Even for areas with a single dominant recreational activity there are different types of visitors (such as couples with young children, elderly visitors or fitness oriented day-hikers) with differing expectations. Agent based modelling allows one to model how these different groups will react to changes, and to see how their reactions will impact on other groups (i.e. if one group displaces the others).

It is important to point out that while recreational managers are generally most interested in models that have been closely calibrated to reality and can therefore be easily operationalized, modelling and simulation has another, perhaps more important role to play in the social sciences: providing an inexpensive platform suitable for testing hypotheses (Gilbert & Troitzsch 1999). Data collection in this field is expensive and time consuming. For some particular questions relating to the impact of scenic quality on overall visitor satisfaction, it is far from clear how one would even go about collecting the data. A robust modelling framework that allows the researcher to experiment with scenarios and calibration value can be a great help in identifying areas requiring further investigation.

As part of the Swiss National Science Foundation's 48th Research Program, *Habitats and Landscapes of the* Alps, a software system is being developed to integrate visual quality concerns within an individual agent-based simulation in order to evaluate the impact of prospective land use changes on tourism demand in Switzerland's Alpine regions.

Study Site: Schönried, Switzerland

The specific test site is a valley in the Gstaad-Saanenland region of south-western Switzerland. The communities of Schönried and Saanenmöser are at the two ends of the site; their economies are highly tourism dependent. While the primary tourism draw to the area used to be winter skiing, long term climate change is forcing the community to focus its efforts on building up a more diversified tourism economy. This includes capitalizing on its already strong reputation for summer hiking. The landscape is a mixture of pasture and coniferous forests. The test site is characterised by significant topography and is considered ideal for walking and hiking. The trails are very accessible to a wide range of hiking abilities due to the summer operation of one chair-lift and two gondolas. In the high season, the area is busy with hikers and walkers who easily fill the two main parking lots in Schönried.

A recent study in the area (Müller & Landes 2001) identified that the biggest attraction for summer tourists are the area's scenic qualities. Hiking and walking is the primary recreational activity in the summer months. The focus on visual elements was confirmed by our own study (Cavens & Lange 2004), where views and landscape variety were identified as the most important factors that influenced hikers in their choice of hiking routes.

In addition to the community's desire to diversify its recreational economy, there are landscape policy issues that have the potential to change the desirability of the area for summer tourism. These issues include changes to the pattern of the landscape due to changing agricultural policy, shifts in forestry practices, closing of the gondolas and/or chairlifts, and increased holiday home construction. All of these changes will impact on how the valley is perceived by visitors, and any of these changes would have complex repercussions for the tourism industry: future scenarios to test the agent model are being selected from them.

Visual Quality Modelling

In order to integrate visual concerns within an individual agent-based modelling framework, the agents need to be able to percieve the visual environment around them. In effect, one needs to make the agents 'see', and make judgements based on what they see. For computer modelling, this means that one must be able to quantify visual quality.

While everyone has an intuitive idea of what makes a landscape scene visually attractive, it is not something that most people are used to quantifying. However, there is a long history of studying the visual preferences of individuals in natural settings (Daniel & Boster 1976, Zube et al. 1982, Kaplan & Kaplan 1989). By asking individuals to rate images of a landscape for their scenic quality researchers are able to gain insights into what kinds of landscapes are preferred. These studies have identified, among other things, consistent preferences for natural scenes, in particular ones with views of water. Recently, the technique has been extended to use realistic 3D computer simulation of landscapes (Lange 2001), in order to better control variables and develop a more nuanced understanding of what landscape elements influence public preferences.

While these studies are useful in advancing our understanding of what people find attractive in landscapes, their descriptive nature makes it difficult to translate these understandings to other locations, or even to other nearby viewpoints, in a systematic manner. In order to overcome this limitation over the past 30 years a number of researchers have built predictive visual preference models based on quantitative studies. These models predict, using variables such as view composition, distance from the viewer and other spatial/visual metrics how attractive a particular location or view is.

These visual quality models can be divided into two broad categories: image-based, and GIS based. Image-based visual preference models were first introduced by Shafer et al (Shafer et al. 1969). This class of model involves directly measuring perspective images, in order to calculate statistics about the view. In Shafer's case, these statistics included the area and length of edge for different permutations of landscape type and distance from the viewer. Using regression analysis against test subjects' stated preference, Shafer found that well over 60% of the viewer's preference could be explained by the variation of six relatively simple variables. These variables include the perimeter of foreground/middleground and background vegetation, the area of middleground vegetation, the area of any kind of water, and the are area of background non-vegetation.

While Shafer's model is intuitively quite simple to apply, as it is based on an analysis of perspective images it is conceptually and practically rather difficult to extrapolate it to an entire landscape. In order to overcome this limitation, and to enable visual quality to be integrated into standard GIS-based planning processes, a number of GIS based visual quality models have been developed (Steinitz 1990, Lynch & Gimblett 1992, Bishop & Hulse 1994, Bishop 1996, Palmer 2004). In general, these models use rather coarse grid representations of landscape type, coupled with a simplistic GIS-based visibility analysis to generate a map which gives a scenic beauty rating for every location in the the entire study area.

While useful for some kinds of landscapes and planning problems, the fact that these models rely upon raster representations of land types (usually at a coarseness of at least 30m), means that GIS-based visual quality models are not able to capture how small features (such as a copse of trees that provides screening for a housing development) can have a significant impact on perceived landscape quality. For agent-based models that operate at a considerably smaller spatial resolution the results might end up being nonsensical.

Recently, Bishop (Bisho et al. 2000, 2003) has proposed a return to image based visual quality models, taking advantage of recent developments in computer graphic technology. These developments, fueled largely by the demands of the visual simulation and computer gaming industries, allow for very fast rendering of 2 dimensional images from an underlying 3D model. Rather than rely on simplified GIS visibility calculations Bishop's proposed technique uses the dedicated graphics hardware present on most modern PCs to create images of what can be seen from any given point. By colour coding objects of interest, the resulting images can be analysed automatically to determine what can be seen and where in the field of view these objects are located. As a by-product of the rendering algorithm, the depth of every object in the scene is also available to be analysed. This allows for a much wider range of variables to be calculated than was available for traditional image-based visual quality models, where distance could only be estimated.

This is the approach that has been adopted for our agent visibility framework. The return to the image-based approach has the particular benefit that it is conceptually easy to make the connection between a rendered image and what an agent would "see" from a given point. And, as most GIS-based visual quality models were derived (at least in a conceptual sense) from image-based models, it provides the most flexible framework for testing different models within our agent-based system.

There are a few crucial questions that has not been addressed in the recreation or visual quality literature to date. These include: how exactly does a visitor's experience of visual quality contribute to their decision-making and overall satisfaction? Is there a minimum threshold below which a hike/walk is not considered scenic enough for a repeat visit? Does a single negative scenic experience invalidate another positive experience, or does the visitor simply require a high average scenic quality to be satisfied?

These are crucial questions for communities making decisions about land-use changes and the answers are far from clear. It is expected that as part of the construction and calibration of our visual quality model within the agent based simulation, these questions will be explored and directions for further research will be elucidated.

Integrating Visual Quality within an Agent-Based Simulation

Overall Agent Framework

Our overall model structure has been influenced by the authors' related projects in traffic simulation (see (Raney et al. 2003), and is described in more detail in other publications (Gloor et al. 2003). The modelling software is modular in nature, with each module being a separate software program (see Figure 1). The modules communicate with each other via network messages. Although all of the programs can be run on a single computer, the modular structure facilitates distributing the simulation across multiple computers when performance issues require it. While this modularity increases the complexity of the software somewhat, it also makes it easy to test different approaches without having to redesign the entire system.

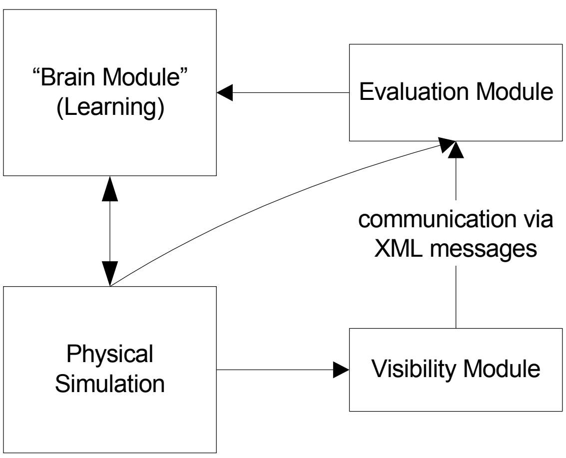

Figure 1. Modular Simulation Framework (simplified).

Every program in the framework uses the same XML data files as their source data (XML is a structured data format that is generally human readable). These files, generated automatically from specially prepared GIS coverages, describe the physical features of the landscape that the agents move in. This includes information about the underlying terrain, the road network, the locations of services such as restaurants and signage, and the location and distribution of vegetation. As each module has different data requirements, each is responsible for parsing the subset of the available data that they require.

At the beginning of a model run, the simulation is populated with agents, each having particular characteristics and goals. The characteristics include sensitivities to slope (indicating fitness), scenic quality, and walking speed, etc. Initially, goals are non-spatial (e.g. go hiking today for 3 hours, eat in restaurant, go hiking for 3 more hours). The system fleshes out these non-spatial goals into highly detailed trip plans that indicate start and end points (including when to start), as well as intermediate waypoints. However, the agents have no initial "knowledge" about features and locations within the simulated landscape, so initially their trip plans are populated semi-randomly.

In order to learn about these features, the simulation is run hundreds of times, with agents exploring their environment, and each developing a "map" of the environment which contains knowledge about which locations meet or don't meet the agents' particular goals and requirements. Some of the characteristics stored are time dependent (such as encounters with other agents, delays at public transit infrastructure, etc.), while other spatial characteristics are time independent (such as restaurant locations, slope, etc.) Currently, scenic quality evaluations are stored as being time-independent, but there is some discussion about this as the attractiveness of a given spot is influenced by the time of day and weather which are time dependent.

The physical simulation module is where fine-grained decisions are made about where the agent is, and how it moves towards its destination. This module is responsible for avoiding collision with other objects, and determining the agents' speed and direction. The module broadcasts the locations of all of the agents every 10 seconds (simulation time.) It also indicates to the other modules when an agent has reached its waypoint/destination, or is unable to complete its strategy.

The evaluation model is where a score is calculated for each segment of the agents' journey. This score is calculated based on a number of factors including (among others): energy expended; time required; congestion; as well as scenic value. These scores are compared against the agents' goals, and used to determine if the agent will use the same route in subsequent runs.

Visibility Module

Central to the vision system is the visibility module (see Figure 2). This module receives messages indicating where the agents are, and calculates what the agents can see. This information is sent to the evaluation module for interpretation. It is written in C++, and is based on the Openscenegraph (Burns & Osfield 2004) 3D graphics library.

The visibility module maintains a complete 3D model of the environment including the underlying terrain, road/trail network, vegetation, as well as other objects such as buildings, directional signs and benches. This visual model is described in the scenario XML files, and can be as simple or complex as the scenic quality model requires it to be. The visibility module reads the following information for each object from the XML file:

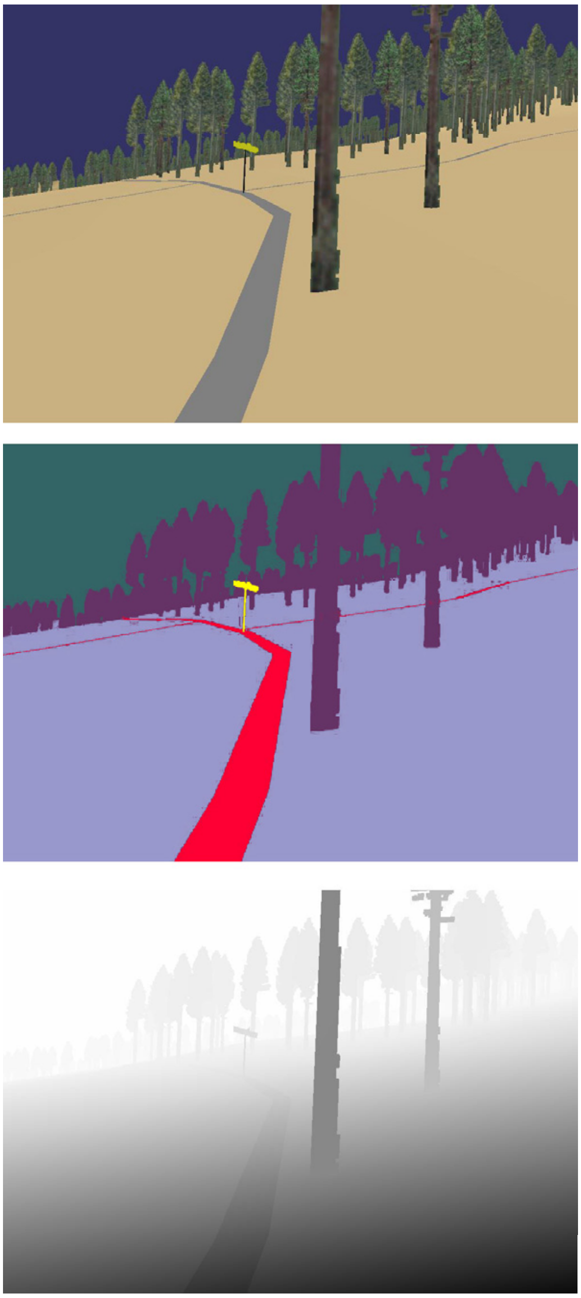

Figure 2. Images rendered by the visibility module. Uppermost image is "true" colour for previewing/ presentation purposes; middle image is the false colour, with different colours assigned to different groups; bottom image is the depth image (darkest colour is closest to viewer. The bottom two images are analyzed by the visibility module.

- **object location**: where the object is, either as an x,y coordinate pair for objects like trees and signs, or the object boundary for objects like buildings or forest stands
- **visual description:** either a link to an external 3D file (such as a house or sign), modelled using an external 3D modelling program, or a list of plant species and densities for vegetation communities
- **group ID:** an identifier which is used to classify the object, depending on the needs of the visual quality model. For instance, in our current test implementation, all objects are classified into only three categories: vegetation, water, and non-vegetation. For more complex models where one might want to distinguish based on tree species, or between different types of buildings, more groups are required
- **unique ID:** a unique identifier for each object, in case the visual model is interested in particular objects

A particular advantage of using this kind of model description is that it is very easy to add new types of objects to the visual database, or introduce new distinctions between objects. For instance, if one's visual model requires information about the visibility of park benches, they are very easily added to the object database, with absolutely no reprogramming required.

Each time that the visibility module receives a message from the physical simulation indicating that an agent has moved, it generates a perspective view of what the agent would see at this point. Depending on the requirements of the model, the module colours each object with either a unique colour, or with a colour corresponding to its group ID. The resulting image includes both objects from the environment and any other agents that are within the agent's field of view.

The visibility module analyses this image by looking the colours up in a table of object/group IDs, determining which objects (or groups of objects) are visible. Using the accompanying depth image, the distance of the objects from the viewer is also computed. The module then sends a list of objects or groups to the evaluation module with the following information:

- **object/group ID:** identifier of the object
- **percent of visual field:** how much of the agent's field of view is covered by this object
- **average, maximum and minimum depth:** how far away the object is from the agent

- **percent of object in foreground / middleground / background:** indicates how the object/group is distributed across the depth plane. Thresholds for the 3 categories are designated in a setup file.
- **self-adjacency:** how many, in percent, of the pixels are adjacent to other pixels from the same object/group (used as a surrogate for perimeter calculations)
- **view angle:** direction from agent to center of object
- **horizontal and vertical angle of object:** indicates the objects' shape in the visual field.

All of this information is sent to the evaluation module as an XML message. One downside of splitting the visibility module from the evaluation module is that huge quantities of data are produced that must be passed between the modules, as the visibility module has way of knowing which kinds of information are important or not. One can, however, filter out objects whose only value is to provide screening by not assigning them an object or group id, thereby preventing them from being recognized by the visibility module.

Speed-up techniques

While the dedicated graphics hardware makes this process much quicker than traditional GIS-based visibility algorithms, it is still too slow to be useable if the simulation is run on a single machine. While the calculation time depends heavily on the complexity of the model and on the available hardware, currently our test system is able to produce and analyze ~60 agent positions per second. As our current simulation involves about 500 agents, and the simulation requires hundreds of runs to stabilize, this is not fast enough to be acceptable in a useable model. In order to speed this up, we have implemented two alternative strategies for speeding up the process.

The first is to distribute the visibility module over multiple machines. As the visibility module is a separate program from the rest of the simulation, this is a trivial operation, and is completely transparent to the rest of the simulation. Rather than listening for all agents' positions, and handling each position event in turn, each machine in the "visibility" cluster is assigned a different set to listen for. As the bottleneck in the visibility calculation is related to the graphics hardware and analysis, adding more machines means that the performance scales nearly linearly as new machines are added to the visibility cluster (until other parts of the simulation framework become the bottleneck.)

The second strategy for speeding up the visibility module relies on the fact that for many visual quality questions, the landscape is essentially static and does not need to be recalculated every time an agent moves during the simulation. Instead, visibility is pre-computed before the simulation starts, in a preprocessing phase. As the physical simulation operates in continuous space (agents are not restricted to walking on the path), the entire landscape is presampled in a regular grid pattern. At each point in the grid (currently using a grid cell size of 5m), the visibility calculation is done for 30 degree slices of the complete 360 degrees. The resulting output is stored in a database. During a simulation run, the visibility module determines the nearest point in the database to the current agent location, and reconstructs the view from the 30 degree slices. (i.e. if the agent has a field of view of 150 degrees, then the software combines the database entries from the 6 slices that overlap with its field of view.) While this does result in a considerable speed increase, it has the disadvantage that the simulation is unable to calculate whether or not other agents are visible. While this can be computed using other means – such as those used in RBSim2 (Itami 2002), this adds another layer of complexity to an already complicated modelling framework.

Evaluation Module

Although the visibility module provides a key and innovative part of the visual quality framework, the heart of the visual quality model resides in the evaluation module. This module is responsible for interpreting data sent by the physical simulation and the visibility module, and interpreting it to ascertain if the goals and expectations of the agents have been met. This information is calculated at different spatial scales, depending the scale at which the brain module is operating (this ranges from the scale of a single trail segment to that of an entire day's trip)

Two different visual quality implementations have been implemented: one roughly corresponding to Shafer's original visual quality model (1969), and another to Bishop et al.'s (2000). The two implementations calculate a visual quality score for each agent every 10 seconds during the simulation.

The module also uses the data from the visibility module to calculate a landscape variability metric, based upon the degree variation between views over time (see Kistler 2004 for a description of how this variability metric is calculated). In the current implementations, it is assumed that the agents' visual goals are to achieve at least a minimum average scenic value and variability over time.

Calibration and Validation

The model is currently operational, and current effort focuses on calibrating the model. A crucial part of this calibration is determining the relative weights between scenic value and other factors such as time, steepness, and availability of services (i.e. a restaurant.) For instance, is it better for an agent to spend slightly longer than expected on a 3 hour hike in order to avoid a particularly steep section or visit a scenic point?

The goal of the calibration is to have an agent simulation where the agents' behaviours are both plausible and reflective of existing usage patterns with current landscape conditions. Only then will one be able to have some degree of confidence that the agents will react appropriately to a changed landscape. As part of a study conducted in 2002 (see Cavens & Lange 2004), existing usage patterns in the area were identified (see Figure 3).

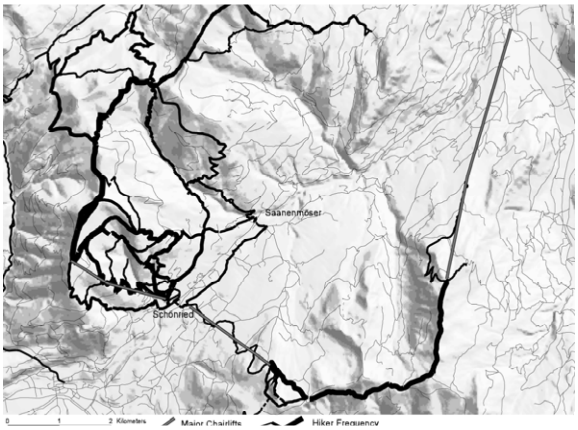

Figure 3. Summer usage patterns near Schönried in the study area.

Work is also being done to investigate how the visual quality ratings of different paths in the area correspond to observed usage patterns. At first glance, the most heavily used trails are the ones with the highest scenic value, but it is not clear if scenic value influences the secondary choice of trails.

Unfortunately, as this form of modelling is relatively new, very little literature exists to assist in the determination of calibration values, so initial calibration values will be a combination of expert opinion with some empirical backing.

Conclusion

We have described a framework for integrating visual quality into an agent-based recreation simulation. While considerable work remains in the calibration phase, the framework provides a test bed for examining how visual quality evaluations influence recreationists' decision making.

While the visual perception system described above was originally designed for integrating visual quality evaluations with agent-based simulations, it could also be applied quite easily to other related research questions, such as the analysis of wayfinding systems (see Filippidis et al. 2003).

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