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Ecological criteria, participant preferences and location models: A GIS approach toward ATV trail planning

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ABSTRACT

This paper presents a geographic information system (GIS)-based method for recreational trail location for all-terrain vehicles (ATVs) which considers environmental factors, as well as rider preferences for trail attributes. The method utilizes the Least-Cost Path algorithm within a GIS framework to optimize trail location. The trail location algorithm considered trail impacts and benefits associated with water bodies, slope, land ownership, noise, trail separation, views, and rider preferences for vegetation types and loop trails. Alternative trails were generated to highlight the influence of different preferences for trail attributes and to demonstrate the capabilities of the Least-Cost Path algorithm as applied to trail location. The method shows promise for use in generating ATV trails, as well as other types of recreational trails, for consideration in recreational planning and analysis.

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Introduction

Trail-related activities constitute an important component of the recreation landscape. A recent study (Outdoor Industry Foundation, 2006) estimated that 72% of Americans aged 16 and older participated in an outdoor activity in 2005, with hiking, running and bicycling on trails being three of the most frequently reported activities. Trail use by motorized recreational vehicles is also growing in popularity. All-terrain vehicles (ATVs) entered the recreation and tourism marketplace in the early 1970s and, since then, ridership has grown rapidly. The Specialty Vehicle Institute of America (SVIA) estimates that ATV sales have increased over 280% nationwide in the US since 1994 (SVIA, 2006). ATV recreation participation is expected to continue to increase across the US through 2015 (Cordell, Betz, Green, & Owens, 2005). Within Minnesota, the State's Department of Natural Resources (DNR) projects the number of registered ATVs, estimated to be just under 250,000 in 2006, to grow by approximately 39% by 2014 (Personal Communication, Tim Kelly, MN DNR, 7/17/07).

Of growing concern is the question of where ATV riders will find suitable and/or desirable places to ride. For states like Minnesota, which are experiencing high rates of sale, transfer and development of private forest lands (Kilgore & MacKay, 2007), pressures on public lands for ATV riding opportunities may become particularly great. Displacement of current ATV users from private lands, coupled with rapid increases in overall ATV use, may create an increase in and concentration of

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ATVs on county, state, and federal lands. This scenario could lead to greater conflicts among user groups for access to certain trails and displacement of non-ATV recreators on public lands (e.g., Dolesh, 2004; Meersman, 2006). Public land managers are increasingly concerned about the ability to accommodate this rise in ATV recreation as well as mitigating potential adverse effects, such as environmental impacts and visitor displacement that can occur from unmanaged ATV use.

One hypothesis of recreational trail design is that trail users are more likely to stay on designated trails if the trails provide appropriate interest, challenge, experiences and safety (Dolesh, 2004; Vail & Heldt, 2004; Tim Wegner, International Mountain Bicycling Association, personal communication, 6/21/06). Following this tenet, we suggest that one way to optimize rider experiences may be to consider ATV rider interests and preferences, in conjunction with ecological and safety issues, when designing trail networks. Trails designed to rider specifications, to the extent possible, may also help to keep ATV riders on designated trails, which in turn may reduce conflict with other trail users and adverse impacts to the environment. To that end, this research had two objectives. The first objective was to identify ATV rider preferences for trail attributes and experiences. The second objective was to develop and demonstrate a new, geographic information system (GIS)-based method for generating optimal ATV trail layouts that considers ecological impacts, rider preferences for trail attributes, and noise and safety concerns of other trail users. GIS tools have not been widely used to assist in trail layout and planning for ATVs, or motorized recreation in general, but offer significant potential to do so through their ability to analyze complicated sets of spatial data and criteria and in generating optimal paths. The method is demonstrated through a case study application of ATV trail location on state forest lands in Minnesota. It is important to note that the purpose of the research is not to supplant legal processes for trail designation, but rather to demonstrate an analytical method that could be used to identify viable ATV trail segments to consider in a variety of different trail planning situations.

Background

Trail design elements

A variety of criteria is typically considered when designing or locating an ATV trail. Environmental or ecological impacts associated with trail location and design are of significant concern. Off-road vehicles can adversely impact the landscape through soil compaction, increased run-off and erosion, and decreased vegetation cover and density (Groom, McKinney, Ball, & Winchell, 2007; Tuttle & Griggs, 1987; Webb & Wilshire, 1983). Thus, it is important to consider soil type, slope and drainage features when designing motorized trail systems. Trails constructed in areas with highly erodible soil and/or on steep slopes can contribute to soil erosion and sedimentation, which can adversely affect aquatic ecosystems and species. Well-drained, fine-textured loam or clay loam, or rocky soils are preferred soil types for motorized recreation trails, while soils composed of silt, sand and clay would be more problematic as they represent a higher erosion and compaction potential (MN DNR, 2004; Tuttle & Griggs, 1987). Steep slopes are typically avoided because of erosion considerations, as well as for rider safety. Guidelines vary with respect to maximum allowable slopes for ATV trails, but generally range from 5% to 15%.

Guidelines suggest stream and wetland crossings should be minimized when designing ATV trails to avoid damage to riparian zones (MN DNR, 2004; USDA Forest Service, 2005). To address this, the DNR recommends that ATV trails be kept 15–30 m away from water bodies (MN DNR, 2004). In the interest of safety of both ATV riders, motorists, and other trail users, ATV trails are typically located so as to avoid crossing public roads (Dale Weigel, Hoosier National Forest, personal communication, 12/16/2006) and non-motorized trails.

Land ownership is another important consideration when designing trails. Many federal and state forests contain a mix of land ownership classes within their administrative borders, including private in-holdings. Thus, when designing trail segments in mixed ownership areas like this, efforts are typically made to avoid locating trail segments through these privately owned in-holdings.

Dolesh (2004) asserted that off-highway vehicle (OHV) noise is a serious concern for wildlife, other forest users, and adjacent landowners, and is a major source of trail-use conflict with non-motorized recreators. While decibel emissions standards for vehicles such as snow mobiles, off-road motorcycles and ATVs are enforced in many states, surprisingly little research has been done to estimate the distance at which ATVs can be heard or the impact of such noise on wildlife or people.[4] Preisler, Ager, and Wisdom (2006) studied responses of elk to ATVs and found that they responded to ATVs in terms of increased probability of flight at distances up to 1000 m. Heath (1974) noted that it is difficult to accurately quantify the sound effects of off-road vehicles because decibel levels from vehicles vary with temperature, wind, ground conditions, and vegetation.

[4] Some research on noise impacts and conveyance associated with snowmobiles has been conducted (e.g., Hastings, Fleming, & Lee, 2006).

ATV trail designation methods

Many federal and state agencies are working to develop strategies for addressing OHV and ATV recreation on public lands. As a result, a variety of guidelines, methods, criteria and standards has been adopted by public land management agencies for locating or designing OHV trails on the landscape (USDA Forest Service, 2004, 2005; MN DNR, 2003). The Forest Service is currently making decisions about areas, trails, and roads to keep open to motor vehicles, by vehicle class and time of year on federal forest land ("Travel Management; Designated Routes and Areas for Motor Vehicle Use;" 36 CFR Parts 212, 251, 261, 295). The USDA Forest Service OHV route designation process considers trail effects on natural and cultural resources, public safety, recreational opportunities, access needs, user conflicts, and trail maintenance needs and cost.

The Minnesota DNR, like many states, is also focusing on OHV issues and is under a mandate to identify trails, roads and regions of the state forests that will become part of a dedicated OHV trail system. To assist in this, a trail evaluation process has been developed that considers a number of screening criteria related to trail need, suitability, and potential impacts (MN DNR, 2003). Both the Forest Service and DNR take a similar general approach to OHV route designation in that a team of analysts uses a rating system to determine potential impacts and recreational value of trails. Impacts are calculated by evaluating the trails against a number of screening criteria. Each criterion is assigned a value (e.g., a numeric score, High/Medium/Low rating, Acceptable/Unacceptable condition) based upon the desirability, suitability or level of impact likely to result from a particular trail segment. Recommendations are then made about which routes to create, keep open or to close based upon a compilation of the criteria scores.

Efficiencies in trail evaluation and location processes like these could be gained by identifying and evaluating candidate trail segments within a GIS framework. A GIS approach is well suited to an ATV trail location problem because many of the data elements a recreation planner are likely to consider are available in formats readily usable or configurable for display and analysis in this format. In addition, a GIS framework offers a structured approach for the evaluation and display of complex data elements, particularly when dealing with multiple attributes or data layers. Most important to our application, though, is that many GIS software packages have the capability to generate optimal paths between specified origin and destination points through the Least-Cost Path algorithm. This capability has remained unexplored in the generation and assessment of ATV and OHV trails. Application of this path optimization feature to an ATV trail location problem is where this work makes a new contribution.

The method considers the major environmental screening criteria that both the DNR and Forest Service recommend in locating suitable areas for trails, as well as additional rider preference criteria collected among riders. This method can be used to specify where to locate a new trail given designated origin and destination points. While ground-truthing and public and rider input would be part of any trail location process, this approach provides a starting point to generate viable alternative trail layouts for further consideration by planners, riders and the public.

Methods

Understanding ATV rider preferences

ATV rider preference data are evolving, but a paucity of information exists regarding preferred experiences and trail attributes. Recent survey research among registered ATV riders in MN identified salient desired trail attributes and experiences (Schneider & Schoenecker, 2006; Schoenecker, 2006). Specifically, respondents indicated a variety of scenery, maps at the trailhead, signs showing all users allowed in an area, routes connecting to other riding areas, and signs indicating length of trail were important for an enjoyable riding experience. While these results provide broad direction to help managers and planners in designing trail systems, additional information was needed to fully illuminate riders' opinions and preferences for trail attributes and experiences. To address this, five focus groups were conducted among ATV riders.

Focus group discussions conducted during spring 2007 identified details of preferred trail attributes across three rider experience levels (novice, intermediate and advanced) in a university-based focus group facility. Focus group participants were selected from questionnaire respondents (Schoenecker, 2006) and supplemented through the snowball sampling technique. As such, respondents had a range of ATV riding experiences throughout Minnesota. A nominal cash incentive ($20) was offered to participants. A total of 27 recreational ATV riders participated in 5 focused discussions on recreational ATV riding (novice $n = 7$; intermediate $n = 6$, advanced $n = 14$). The focus group goal was to explore the meanings and perceptions associated with optimal ATV rides and trails. The focus group script followed a funnel sequence to ease participants into the focus group setting and then narrow in on areas of research interest. The discussion focused on gaining a better understanding of the experience attributes related to variety of terrain, exhilarating scenery and exciting experiences. Each focused discussion was recorded and textual data were organized in categories and sub-categories by three independent parties associated with the project.

Results of the focus groups indicated that riders of all skill levels have an interest in riding on trails with scenic overlooks and vistas. Second, riders expressed preferences for certain types of land cover and vegetation viewed when riding. Given a choice among agricultural land, meadows and forests, the ATV riders expressed strong preference for riding in forest land, followed by meadows and agricultural land. Riders also expressed a preference for seeing deciduous (hardwood) trees versus spruce or pine vegetation. Finally, trails with loops are desirable to many riders (Robert Potts, Santa Fe National Forest, personal communication on 7/28/2006) because they provide more opportunity to see a variety of features than a dead-end trail.

Trail criteria

A discussion of the trail elements and design criteria incorporated into the GIS trail generation method follows. Specifics on the data elements and databases utilized in the case study application are discussed in the Data section to follow. Following recommendations of the DNR, 10% was chosen as the upper bound on acceptable slope for ATV trail segments (MN DNR, 2004, p. 10). Thirty-meter (100-feet) buffers were placed around all permanent water bodies in an effort to reduce the likelihood of trail segments in these areas and their associated riparian impacts. It is important to note that the buffered areas were not removed from consideration as eligible regions for trail segments, but rather given a much less-desirable weighting in the GIS classification system.

To address the safety issue associated with road crossings and trails, 30-m buffers were placed around public roads except around potential trail access points. As with the water buffers, pixels in the road buffers were not excluded from consideration but given undesirable weights in the GIS classification that would make them less likely to be selected for trail segments.

The method allowed the inclusion of multiple land ownership categories and the ability to weight them differentially in locating trail segments. In terms of land ownership classes, state, county, tax-forfeiture lands and private land in-holdings were considered. In most cases, a public land manager would avoid the placement of a trail through any privately held in-holdings within the administrative boundaries of public land. However, in the event that private land owners might be willing to grant right-of-way access on their private lands for riders, our method has the flexibility to consider these other classes of landownership in locating trails.

Given that noise issues are often cited as a concern or source of conflict with other users, and given inherent safety issues associated with keeping motorized and non-motorized trails separate (Vail & Heldt, 2004), a 1-km (0.6 mile) buffer around existing cross-country skiing, snowmobile and walking trails in our study area was enforced.

Based upon findings from the rider focus groups, several rider-specified trail attributes were considered. To address the importance of views from trails, a 'viewshed' was computed for each pixel in the landscape. This was an enumeration of the total number of pixels that were 'visible' from each pixel in the landscape. Using a 30-m digital elevation model (DEM), we calculated that a pixel could be 'seen' from another if a straight line could be constructed to connect the two without any intervening pixels. Viewsheds were calculated using the centroid of each 30-m raster cell to a radius of 1000 m at an observation height of 1 m. The observation height of the algorithm was set at 1-m as this approximates the view of the landscape an ATV rider might experience while riding. This calculation gives a numerical estimate of the extent of the vista or view from any point in the study area.[5] Pixels that had larger viewsheds were considered more desirable for trail location than those with smaller viewsheds, or fewer visible pixels. Lee and Stucky (1998) also integrated viewshed analysis with least-cost path modeling, although their application was for a hiking trail alignment study.

Also based upon the focus group findings, the following hierarchy of cover types was specified with declining rider preference: deciduous trees, coniferous trees, shrubs/marsh, grasslands, and croplands. GAP land cover data were used to identify these major vegetation cover types in the study area. Finally, since trail loops are desirable to many riders, we sought to generate trail alternatives which contained a loop.

All of the data layers were subsequently processed within the ArcGIS® environment, and a model was created allowing for differential weighting of the layers and generation of optimal trail location.

GIS Least-Cost Path algorithm

Many GIS software packages have the capability to generate optimal or 'least-cost' paths between specified origin and destination points. Within the ArcGIS® environment, the Spatial Analyst extension and the least-cost path application can be used to generate desirable paths (ESRI, 2005, 2006a, 2006b). The Least-Cost Path algorithm within a GIS framework has been used in a wide variety of applications, including: assessing habitat connectivity in protected reserves (Adriansen et al., 2003; Rothley & Rae, 2005), designing habitat corridors (Beazley et al., 2005; Kautz et al., 2006; Rouget, Cowling, Lombard, Knight, & Kerley, 2006), locating hiking trails (Lee & Stucky, 1998; Xiang, 1996), selecting pipeline routes (Feldman, Pelletier, Walser, Smoot, & Ahl, 1996), and optimizing road layout (Atkinson, Deadman, Dudycha, & Traynor, 2005; Collischonn & Pilar, 2000; Yu, Lee, & Munro-Stasiuk, 2003). To date, however, applications of the Least-Cost Path algorithm to motorized recreational trail location and design have not been discussed in the literature.

[5] A customized AML ArcScript was developed that operated within the ArcINFO® environment to compute these values. The script was customized from one developed by Hannes Reuter for calculating viewsheds called 'manyviewsheds2.aml.' His original script is available online at: http://arcscripts.esri.com/details.asp?dbid=13500.

The Least-Cost Path algorithm works by identifying a connected path of pixels in a discretized landscape that minimizes the ‘cost’ of moving through the landscape from a specified origin to a destination. In this application, ‘cost’ refers to the degree of suitability of a pixel for an ATV trail segment, where lower values indicate greater suitability. The least-cost path for the ATV trail application is the one that results in the highest level of suitability, where suitability is a weighted function of desirable trail attributes. Four steps are involved in the least-cost path computation in ArcGIS®. First, ‘resistance values’ are calculated for each pixel in the landscape for each trail attribute criteria. The resistance value may represent time, distance, difficulty, risk, or some combination thereof, to move across a pixel. This is the ‘cost’ to cross the cell, or in our example, the degree of suitability of placing an ATV trail segment through that cell. Next, the resistance values for each criterion are weighted and combined to create an aggregate resistance value for each pixel, or a resistance surface for the landscape. Third, Dijkstra’s shortest path algorithm (Dijkstra, 1959) is initiated through the COSTDISTANCE function to calculate total ‘costs,’ or the sum of the total resistance values, to move between a specified origin pixel and each pixel in the landscape.[6] This creates an accumulated or total cost surface. The final step is to utilize the COSTPATH function and identify the path between a specified destination and origin through this accumulated cost surface which minimizes the sum of the resistance values included in the path. Conversely, this function maximizes the suitability of a set of connected cells in forming an ATV trail. In this application, smaller resistance values indicate more desirable, suitable or favorable trail conditions.

Data

The method is illustrated with an application to a case study site on a state forest in Minnesota.[7] Data for the case study area were obtained from several sources. While soil type is an important attribute to consider in ATV trail location, an evaluation of USDA STATSGO data of the study area revealed little variability in soil type (e.g., the study area was largely sandy loam). As a result, soils were not considered in the case study application, although the method could readily incorporate soils data. Elevation information was derived from DEM data of Minnesota (LMIC, 2006) and used to estimate slope. The slope value was computed as the maximum rate of change between a pixel and its neighbors. Viewshed data were calculated from the LMIC DEM as well (LMIC, 2006). The location of wetlands and other water bodies was identified from the National Wetlands Inventory (NWI) (Cowardin, Carter, Golet, & LaRoe, 1979; US Fish and Wildlife Service, 2006). USGS level-3 GAP Analysis data of land cover were retrieved from the Minnesota DNR and used to identify desired vegetation and land covers.[8] An inventory of existing motorized and non-motorized trails, roads, and entry points in the study area was obtained from DNR. The entry points were used as potential origin/destination points for the trail optimization algorithm. The GIS department in the case study county provided land ownership data. All data used the North American Datum 1983 (NAD83) and were projected to the UTM coordinate system Zone 15N.

The slope, water, land ownership, roads, viewsheds, land cover, and trails layers were transformed into GIS shapefiles for initial processing. Subsequently, these layers were converted to raster format at 30 m cell resolution prior to calculation in the COSTDISTANCE algorithm. Vector data were converted to raster format with a cell size of 30 m.

Values for each of the data layers were specified on a 5-point scale based upon an equal interval classification with 5 as the most costly (e.g., least suitable) and 1 as least costly (most suitable). See Table 1. For instance, all ‘buffer’ pixels for roads, trails, and water were assigned a value of 5. Non-buffer parcels were assigned a value of 1 in this data layer. Any pixel with a slope greater than or equal to10% was assigned a value of 5, and those less than 10% a value of 1. Pixels in private land within our study area were assigned a value of 5, while public land (e.g., state, county or tax-forfeiture land) was given a value of 1. The vegetation layer was scaled as follows: deciduous trees were assigned a value of 1, coniferous a value of 2, shrubs/marsh a value of 3, grasslands a value of 4, and agricultural land a value of 5. Values for the viewsheds, which ranged from approximately 0 to 3000 pixels, were partitioned into a 5-point scale. Trail origin and destination points were identified, as well as two intermediate points to facilitate the creation of a loop trail.

An important feature of this trail optimization approach is that different assumptions about the importance of or preferences for the trail attributes can readily be incorporated, allowing for comparative analysis of alternate trails. Varying the relative weights assigned to each data attribute results in the computation of a new resistance layer or cost surface upon which the Least-Cost Path algorithm operates. Two different cost surface layers were generated in our application. In the first, all of the data layers were weighted equally. In the second cost surface, the vegetation layer was weighted 10 times

[6] Dijkstra’s algorithm (Dijkstra, 1959) is a classic technique from graph theory for solving network problems and finding a shortest path between specified nodes. The algorithm works by fanning out from the origin and successively computing the total resistance cost from the origin to each cell in network. The cost to move between two adjacent cells is computed as the cumulative cost to reach the first plus the average cost to move through the two cells. In the case of diagonal moves, the cost is multiplied by the square root of 2 to account for the longer distance. The algorithm guarantees an optimal solution if there is a single destination point and if all of the resistance values are non-negative.

[7] The state forest is not currently considering the designation of new ATV routes in the forest but provides a hypothetical case study with a realistic setting to illustrate the capability of the approach for generating new ATV trail segments. More detailed information about the study site is available from the author upon request.

[8] Available from the Minnesota Data Deli: (http://deli.dnr.state.mn.us/).

Table 1
Summary of values for the data elements

Data element	Reclassified values
Buffer pixels	5
Non-buffer pixels	1
Pixels with slope ⩾10%	5
Pixels with slope <10%	1
Private land ownership	5
Public land ownership	1
Deciduous vegetation	1
Coniferous vegetation	2
Shrub/marsh vegetation	3
Grassland vegetation	4
Agricultural vegetation	5
Viewshed values	1–5

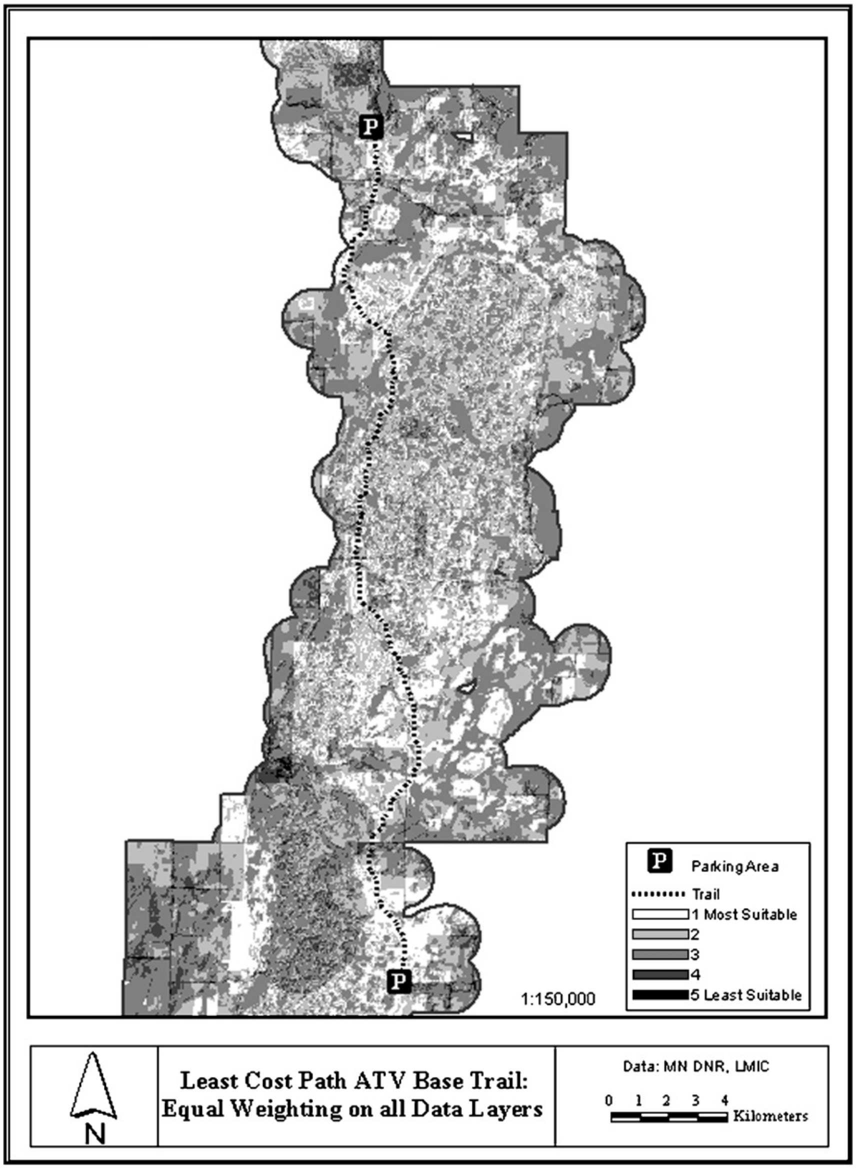

Fig. 1. Map showing optimal trail location for the ‘Baseline’ case where all data layers were weighted equally.

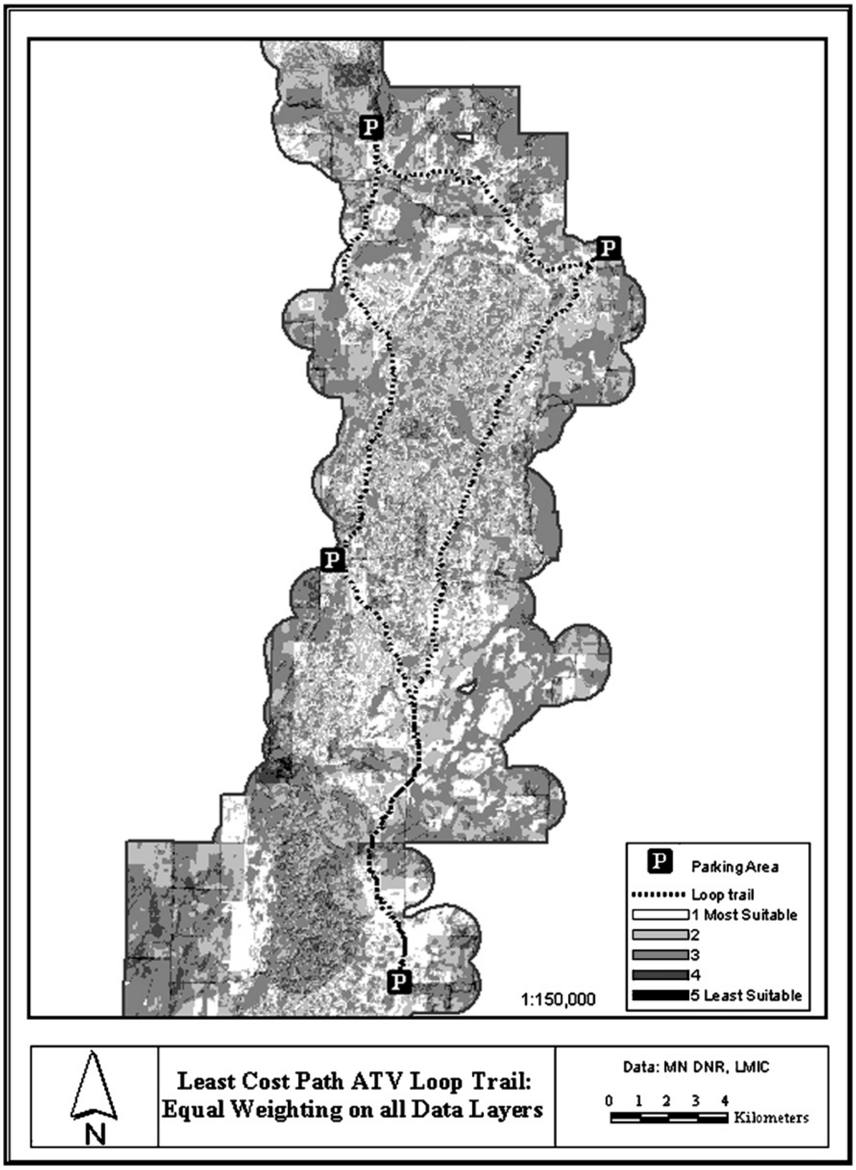

Fig. 2. Map showing optimal loop trail location.

higher and the viewshed layer 25 times higher than the rest of the data layers. This second cost surface was computed to illustrate how higher priority on rider preferences influences the optimal location of the trail.[9]

Results

Three trails were generated with the Least-Cost Path algorithm, one for each of the two weighting scenarios described above and one loop trail that corresponds to the first weighting scenario. Fig. 1 illustrates the optimal 'baseline' trail for a situation in which all of the data layers are weighted equally. The origin and destination points for the trail; e.g., the two parking areas in the figure, were specified a priori. The background layer of the figure is the resistance surface for this combination of data values, weights and classification. The white areas in the figure are the most suitable for trail segments, with the degree of suitability declining in successively darker areas. The resulting optimal path displayed in this figure was clearly located so as to avoid some of the less desirable, darker regions of the resistance layer. For example, in the

[9] While the two sets of weighting factors were chosen for purposes of illustration, more rigorous and analytical methods, such as the Delphi method or multiattribute utility theory, could be utilized to determine scale values and weights which correspond to users' preferences.

region just west and north of the southern parking terminus, the trail is avoiding a non-motorized recreation area. The trail layout is also influenced by the location of some roads and snowmobile trails and is curving west in the central part of the trail to avoid these areas.

Since the results of the rider focus groups indicated that loop trails are important, the Least-Cost Path algorithm was used to generate an optimal loop trail again based upon equal weighting of the data layers. The loop trail was generated by utilizing the same two parking access areas as in Fig. 1, and then adding in two intermediate points that the trail was required to access (Fig. 2). The two intermediate points were chosen because they represent existing parking facilities in the case study area, and as such, reasonable entry/exit points for the creation of a new trail. Generating the loop trail required the generation of four separate least-cost paths between each pair of the four trail points. In the loop application, the generation of the least-cost paths progressed counter-clockwise beginning from the southern parking terminus. Aspect did not factor into our trail algorithm, that is, a pixel's resistance value did not vary depending upon direction. As such, the same optimal loop trail would have been generated irrespective of which of the parking areas was chosen as the loop path origin.

The resulting location of the western side of the loop trail (Fig. 2) is very similar to that of the baseline trail in Fig. 1. This was the case since the western parking area is not far off of the optimal baseline trail in Fig. 1. The loop trail only had to deviate a small amount from the optimal baseline trail to accommodate this intermediate trail point. The eastern segment of the loop trail, particularly the northeastern segment, was influenced by the presence of private land in-holdings in the

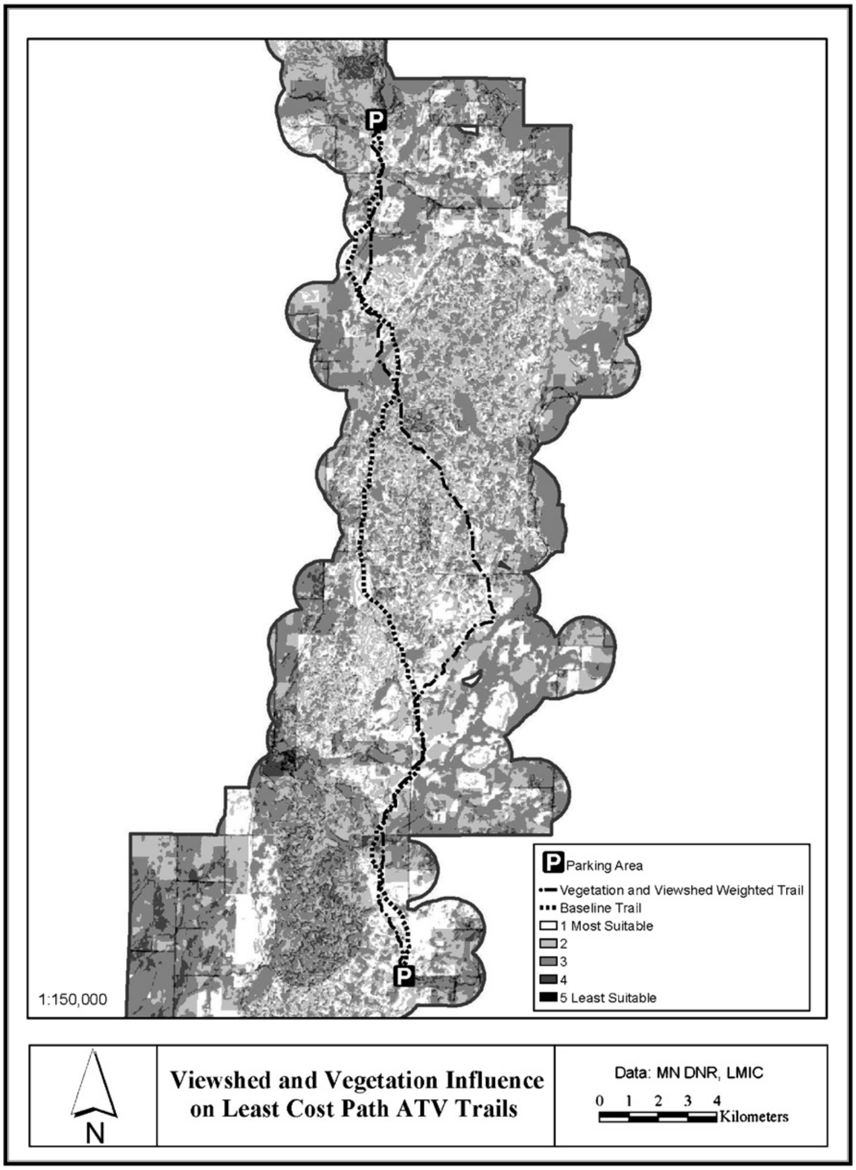

Fig. 3. Map showing optimal trail location when views and vegetation are weighted more heavily than the other data layers.

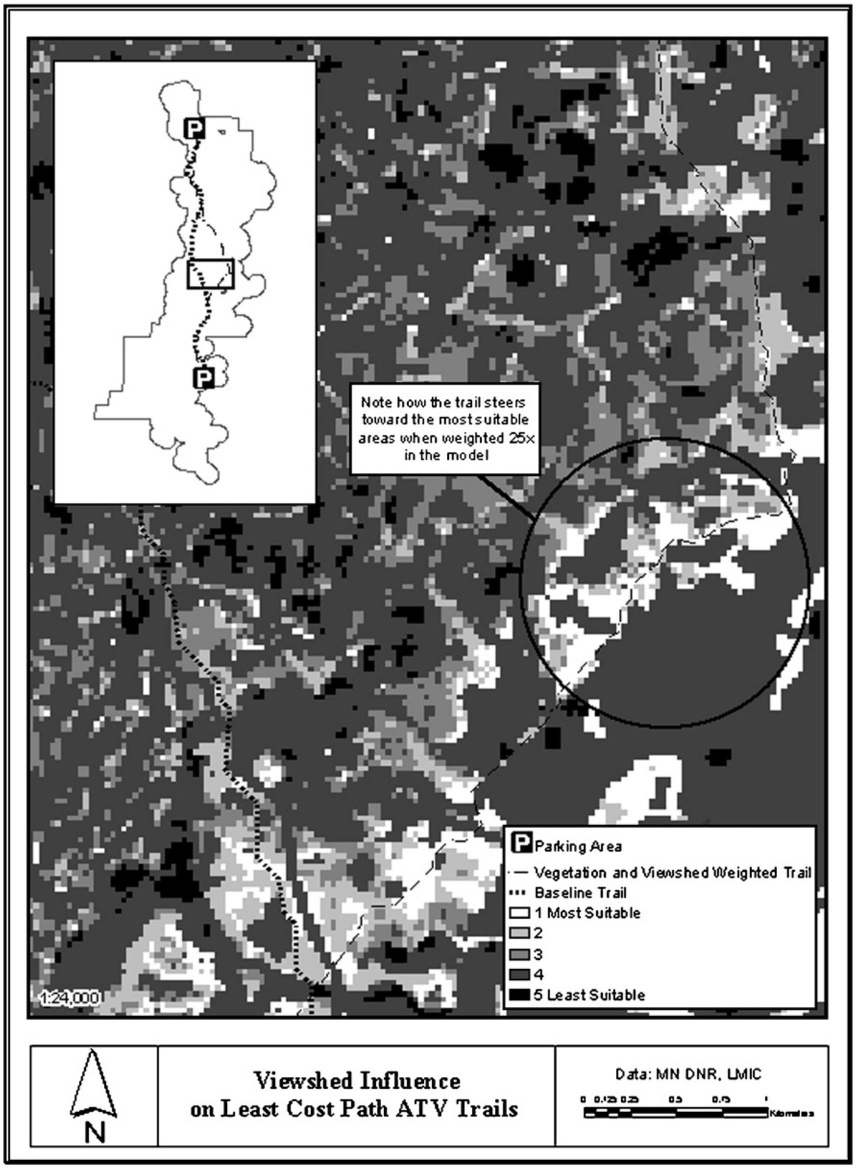

Fig. 4. Map showing close-up of region of view and vegetation weighted optimal trail.

study area. The trail was located so as to avoid these private lands to the greatest extent possible, as well as avoiding some roads and snowmobile trails.

To illustrate the influence that differential weighting on the trail attributes has on the optimal path that is generated, a new cost surface was computed with higher weights on the vegetation (10 times higher) and viewshed (25 times higher) data layers. The Least-Cost Path algorithm was run on this new cost surface, and a new optimal path with the same origin and destination points as the baseline trail in Fig. 1 was generated. Fig. 3 displays the baseline trail and new vegetation-and-viewshed enhanced trail on the original cost surface layer. Deviations between these two trails are substantial, particularly in the central section of the trails. To gain a better understanding of why the new trail location deviates so significantly from the baseline, it is useful to view a small segment of the trail at a higher resolution and with the just the viewshed data layer as the background layer (Fig. 4). In Fig. 4, it becomes apparent that in this section of the trail, the new trail deviates to the east in order to access an area of the highest scenic value, or highest viewshed suitability.

Discussion

In the case study application, rider preferences for trail attributes associated with views and desired vegetation were incorporated into the trail selection algorithm. The inclusion and preferential weighting of these rider preferences had an impact on the resulting optimal trail that was generated when compared to the trail generated with equal priority given to all of the trail attributes, as would be expected. This suggests that trails designed without explicit consideration of rider preferences may not meet rider's expectations and needs, which in turn, may lead to a greater propensity of riders to veer off of established paths in search of trail attributes and experiences that they desire.

A variety of applications and extensions to this trail location optimization method are possible. First, the method could be used to identify desirable (or undesirable) *regions* of the landscape to consider for trail location without actually running the Least-Cost Path algorithm. That is, if a planner were interested in using the GIS to identify suitable areas of the landscape in which to locate a trail rather than using it to explicitly generate an optimal trail layout, the data layers could be combined and weighted within the GIS framework to identify high, medium, or low quality regions of the landscape to locate trails. This is what the method is doing when generating the resistance values and cost-of-passage surface described earlier in the text. Suitability of *existing* trail systems could also be evaluated in this manner by overlaying them on the resistance surface map.

The trail location method could also be used to design connections between existing trail systems. Results of the focus groups indicate that riders desire connected trail systems that allow for long-distance riding. While our application focused on designing a new trail system within one administrative region, this method could readily be extended to consider how to connect existing trails or locations of interest.

The framework and method could also readily incorporate additional trail attribute and preference data if available in a GIS format. As an example, DNR guidelines (MN DNR, 2004) also recommend that ATV trails avoid areas with endangered, threatened and special concern species; cultural and historical features; as well as old growth forest stands. If spatial data on the location of these features were available in GIS format, then these design criteria could also be incorporated into this trail generation method. Additionally, if more were known about preferences for trail attributes and experiences by skill level of riders, then trails with differing degrees of difficulty or challenge could also be specified to meet different rider skill levels. While the trail generation method was illustrated by an application to ATV trail planning, it is readily adaptable to recreational trail planning for other recreation modes or segments, including hiking, biking or snowmobiling trails.

Conclusions

The use of a GIS and the Least-Cost Path algorithm offers a structured but flexible approach to ATV trail location that helps to automate the process of generating candidate paths for consideration in trail planning decisions. This method shows promise for the generation and evaluation of candidate ATV trail segments in a variety of planning settings, as well for other modes of recreational trail planning. The method allows for the incorporation and consideration of all of the standard ATV trail design criteria, as well as the ability to incorporate new, rider-specified attributes. Additionally, the method readily allows for the incorporation of preferences and priorities for the data attributes as reflected in the relative weights that can be assigned to each.

On a final note, we are not suggesting that a GIS algorithm can replace the role of decision-makers and the public in the process of locating ATV trails. However, we do suggest that a GIS approach can be used to provide structure and rigor to the process and to generate a variety of alternatives that reflect different priorities and assumptions for further consideration and discussion by agencies, riders and the public.

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References

Adriansen, F., Chardon, J. P., DeBlust, G., Swinnen, E., Villalba, S., Gulinck, G., et al. (2003). The application of 'least-cost' modeling as a functional landscape model. *Landscape and Urban Planning*, *64*, 233–247.

Atkinson, D. M., Deadman, P., Dudycha, D., & Traynor, S. (2005). Multi-criteria evaluation and least cost path analysis for an arctic all-weather road. *Applied Geography*, *25*, 287–307.

Beazley, K., Smandych, L., Snaith, R., MacKinnon, F., Austen-Smith, P., Jr., & Duinker, P. (2005). Biodiversity considerations in conservation system planning: Map-based approach for Nova Scotia, Canada. *Ecological Applications*, *15*(6), 2192–2208.

Collischonn, W., & Pilar, J. V. (2000). A direction dependent least-cost path algorithm for roads and canals. *International Journal of Geographical Information Science*, *14*(4), 397–406.

Cordell, H. K., Betz, C. J., Green, G., & Owens, M. (2005). *Off-highway vehicle recreation in the United States, regions and states: A national report from the National Survey of Recreation and the Environment (NSRE) (off-highway vehicle recreation statistics from NSRE)*. Asheville, NC: USDA Forest Service, Southern Research Station January 19, 2006.

Cowardin, L. M., Carter, V., Golet, F. C., & LaRoe, E. T. (1979). *Classification of wetlands and deep water habitats of the United States*. Washington, DC: US Department of the Interior, US Fish and Wildlife Service, Office of Biological Services FWS/OBS-79/31.

Dijkstra, E. W. (1959). A note on two problems in connection with graphs. *Numerische Mathematik*, *1*, 269–271.

Dolesh, R. J. (2004). Tough terrain: The conflicts associated with multi-use trails. *Parks & Recreation*, 57–63 October 2004.
ESRI (Environmental Services Research Incorporated). (2005). ArcGIS® v. 9.1. Redlands, CA.
ESRI (Environmental Services Research Incorporated). (2006a). ArcGIS® v. 9.2. Redlands, CA.
ESRI (Environmental Services Research Incorporated). (2006b). ArcINFO® v. 9.2. Redlands, CA.
Feldman, S. C., Pelletier, R. E., Walser, E., Smoot, J. C., & Ahl, D. (1996). GIS, remote sensing analysis used to select potential route. *Pipe Line and Gas Industry*, 52–55.
Groom, J. D., McKinney, L. B., Ball, L. C., & Winchell, C. S. (2007). Quantifying off-highway vehicle impacts on density and survival of a threatened dune-endemic plant. *Biological Conservation*, *13*, 119–134.
Hastings, A. L., Fleming, G. G., & Lee, C. S. Y. (2006). *Modeling sound due to over-snow vehicles in Yellowstone and Grand Teton National Parks*. US Department of the Interior, National Park Service NPS-D-1201. DOT-VNTSC-NPS-06-06.
Heath, R. (1974). *The environmental consequences of the off-road vehicle* (36p). Washington, DC: Defenders of Wildlife.
Kautz, R., Kawula, R., Hoctor, T., Comiskey, J., Jansen, D., Jennings, D., et al. (2006). How much is enough? Landscape-scale conservation for the Florida panther. *Biological Conservation*, *130*, 118–133.
Kilgore, M. A., & MacKay, D. G. (2007). Trends in Minnesota's forest land real estate market: Implications for forest management. *Northern Journal of Applied Forestry*, *24*(1), 37–42.
Lee, J., & Stucky, D. (1998). On applying viewshed analysis for determining least-cost paths on Digital Elevation Models. *International Journal of Geographical Information Science*, *12*(8), 891–905.
LMIC (Land Management Information Center). (2006). Digital Elevation Model (DEM) of Minnesota. Available online from: http://www.lmic.state.mn.us/. (ftp://ftp.lmic.state.mn.us/pub/data/phys_biol/elevation/demarc.zip) [Last accessed 10/2006].
Meersman, T. (2006). Trouble on the trails. Minneapolis Star Tribune newspaper, A1 and A21. December 10, 2006.
Minnesota DNR, Division of Trails & Waterways. (2003). Off-highway Vehicle Route Designation/Trail Decommissioning Trail Evaluation Policy, Process, Criteria and Outcomes. St. Paul, MN (7pp).
Minnesota DNR, Division of Trails & Waterways. (2004). OHV Trail Designation Rapid Environmental Assessment Checklist. St. Paul, MN, March 30, 2004 (10pp).
Outdoor Industry Foundation. (2006). Outdoor Recreation Participation Study. Eighth edition for year 2005. Outdoor Industry Foundation, Boulder, CO 〈http://www.outdoorindustry.org/images/researchfiles/ParticipationStudy2006.pdf?27〉.
Preisler, H. K., Ager, A. A., & Wisdom, M. J. (2006). Statistical methods for analyzing responses of wildlife of human disturbance. *Journal of Applied Ecology*, *43*, 164–172.
Rothley, K. D., & Rae, C. (2005). Working backwards to move forwards: Graph-based connectivity metrics for reserve network selection. *Environmental Modeling and Assessment*, *10*, 107–113.
Rouget, M., Cowling, R. M., Lombard, A. T., Knight, A. T., & Kerley, G. I. H. (2006). Designing large-scale conservation corridors for pattern and process. *Conservation Biology*, *20*(2), 549–561.
Schneider, I. E., & Schoenecker, A. H. (2006). All-terrain vehicles in Minnesota: Economic impact and consumer profile. UMN Technical Report.
Schoenecker, A. H. (2006). Describing and Differentiating Recreational ATV Rider Preferences. Unpublished Master's of Science Degree in Natural Resource Science and Management, College of Food, Agriculture, and Natural Resource Sciences, University of Minnesota. December 14, 2006.
Specialty Vehicle Institute of America. (2006). *Specialty Vehicle Institute of America: Special report 2006* (ATV statistics). Irvine, CA: Specialty Vehicle Institute of America. Retrieved November 8, 2006 from 〈http://www.atvsafety.org/sviapressreleases/SVIA_A2_Final_Low.pdf〉.
Tuttle, M., & Griggs, G. (1987). Soil erosion and management recommendations at three state vehicular recreation areas, California. *Environmental Geology and Water Sciences*, *10*(2), 111–123.
USDA Forest Service. (2004). R5 OHV route designation guidebook. National Forests in California, USDA Forest Service. 〈http://www.fs.fed.us/r5/routedesignation/pdfs/rd-guidebook.pdf〉.
USDA Forest Service. (2005). Motor vehicle route and area designation guide. National OHV Implementation Team, v.111705, Pacific Southwest Region. Washington, DC (82pp).
US Fish and Wildlife Service. (2006). National Wetlands Inventory data. Available online from: 〈http://wetlandsfws.er.usgs.gov/NWI/products.html〉. [Last accessed 10/2006].
Vail, D., & Heldt, T. (2004). Governing snowmobilers in multiple-use landscapes: Swedish and Maine (USA) cases. *Ecological Economics*, *48*, 469–483.
Webb, R. H., & Wilshire, H. G. (1983). *Environmental effects of off-road vehicles*. New York: Springer.
Xiang, W.-N. (1996). A GIS based method for trail alignment planning. *Landscape and Urban Planning*, 11–23.
Yu, C., Lee, J., & Munro-Stasiuk, M. (2003). Extensions to least-cost path algorithms for roadway planning. *International Journal of Geographical Information Science*, *17*(4), 361–376.