A Comparative Geographic Information System (GIS) Analysis to Determine an Optimal Off-Highway Vehicle (OHV) Route in Houston County, Minnesota

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Abstract

Off-highway vehicle (OHV) use has been growing dramatically as a form of recreation. With continuing increases in OHV recreation, it is critical that informed decisions be made when establishing new OHV trail alignments. In order to determine an optimal OHV trail alignment, both ecological and user preference criteria need to be taken into consideration to minimize environmental degradation and maximize user satisfaction. Using Geographic Information Systems (GIS) and a least-cost path suitability model, three separate trail alignments were established in a given study area. A comparative analysis was performed on trail alignment areas to determine most sustainable trails based on input criteria. After careful examination, findings determined it is important to perform multiple analyses to take into consideration various data criteria when utilizing a least-cost path model to establish a new trail that will ensure ecological costs are minimized and user satisfaction is maximized. Moving forward, this study has the potential to assist future trail designers and park managers to make informed decisions when developing new OHV trail alignments.

Introduction

Background

Off-highway vehicle (OHV) use as a form of recreation began in the early 1970's and has since become a growing component of trail related activities (Snyder, Whitmore, Schneider, and Becker, 2008). According to a recent study conducted by Snyder *et al.* (2008) and published in Outdoor Industry Foundation (2006), estimate that 72% of Americans 16 and older outdoor recreate, with recreational motorized trail use growing in popularity. Snyder *et al.* (2008) estimate the number of registered OHV trail users to increase by 39% from 2006 to 2014. As demand for motorized recreation trails continues to increase, the need for creating ecologically sustainable trails has become a critical component to trail management (Albritton and Stein, 2011).

Significance of Study

As a result of the increased use of motorized recreation in recent years, a need to develop more cost effective methods to determine optimal OHV trail alignments has become an important consideration to minimize impacts to potential areas. This dramatic increase in motorized recreation has resulted in the need for a better understanding of the impacts resulting from trail use to develop trail implementation and management practices minimizing environmental

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disruption (Olive and Marion, 2009). In addition to analyzing ecological criteria when developing new trail alignments, it is also critical to assess user preferences to ensure motorized vehicle rider satisfaction. Therefore, trail development requires a carefully thought out process through planning and analysis (Xiang, 1996). In order to effectively and efficiently design a new trail alignment, both ecological and aesthetic criteria must be analyzed using a geographic information system (GIS). The significance of this study will be to determine an optimal trail alignment using a GIS that takes into consideration minimizing ecological degradation and maximizing user experience that will ensure sustainable motorized recreation trails for years to come.

Overview of Study Area

The study area is located in Houston County in south eastern Minnesota as shown in Figure 1.

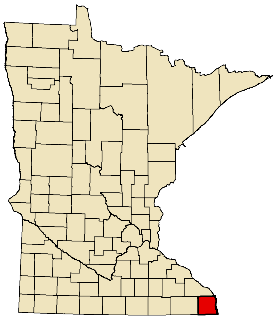

Figure 1. Houston County is located in South Eastern Minnesota.

The diverse landscape of the area poses several ecological challenges. The area consists of potential rare and natural features that must be avoided so as to not disturb their sensitive niche habitats. In addition, the surrounding area is home to many pristine trout stream systems and sedimentation from trail use must be taken into consideration during trail design and development. In addition, the area consists of unique topography with steep hills and varying soil types. Therefore, in order to develop an ecologically sound motorized recreation trail, it is important to use trail design standards in a GIS when analyzing the sensitive areas to determine the optimal trail alignment corridor.

Methods

Data for this analysis were obtained from the Minnesota Department of Natural Resources Data Deli website and the Soil Survey Geographic (SSURGO) Database website. The datasets include: 10m Hillshade Digital Elevations Model (DEM), Minnesota River Centerline dataset, 2006 National Landcover Dataset (NLCD), and the SSURGO Soils dataset. The data were projected in NAD83 Zone 15N Coordinate System. Weighted overlay analysis and suitability modeling were completed using Environmental Systems Research Institute, Inc. (ESRI) ArcGIS 10.2 and the Spatial Analyst Extension. The study area boundary was obtained from the Minnesota Department of Natural Resources and all data were clipped to the study area boundary for analysis.

Off-Highway Vehicle Suitability Model

To determine most suitable locations for an OHV trail alignment, three separate least cost path suitability analyses were performed. The first least cost path analysis took ecological criteria into consideration. The second least cost path analysis took user preference criteria into consideration. Lastly, the third least cost path analysis took both ecological and user preference into consideration. The first step in the process was determining points of interest within the study area to create a loop path. The next step in the process consisted of ranking the data attributes to be used in the analysis. The ranking scale was set from one to three with one being the most suitable and three being the least suitable. Three rank divisions were used to maintain simplicity and consistency among data sets. An overlay analysis was then performed to create a raster data layer that included criteria specific to the model that was used in the Spatial Analyst least-cost path tool.

Site Selection Destination Points

Site destination points were selected based on user preference criteria. A predominant feature motorized recreationists favor are loops. The Management Guidelines for OHV Recreation state that the primary feature motorized recreationists look for when trail riding is a loop (Crimmins, 2006). Another predominant feature trail riders prefer is vistas, so points were selected with high elevations to complete a loop trail. As illustrated in Figure 2, high elevation points were selected to create a loop path.

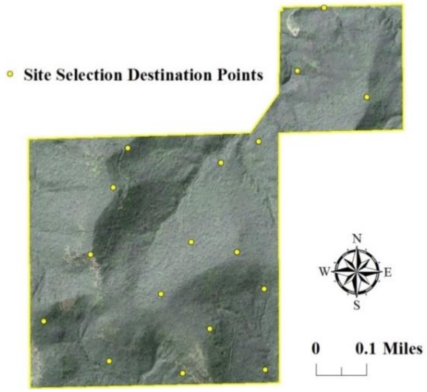

Figure 2. Points were selected based on high elevations to create a loop trail to ensure user preferences were taken into consideration during trail development.

Ecological Data Attributes

Area of Special Concern

In order to ensure long term ecological quality in sensitive areas, the use of buffers around areas of special concern was critical to the trail design (Minnesota Department of Natural Resources, 2007). The study area used for this analysis consists of pristine trout streams and ideal timber rattlesnake habitats. Trail development guidelines suggest a 100 foot minimum buffer is preferred for streams (Minnesota Department of Natural Resources, 2007) Figure 3 and Table 1 illustrate these guidelines and show buffers ranked with respect to distance from streams. A 100 foot buffer was ranked with a value of three, a 200 foot buffer was ranked with a value of two, and a greater than or equal to 300 foot buffer was ranked with a value of one.

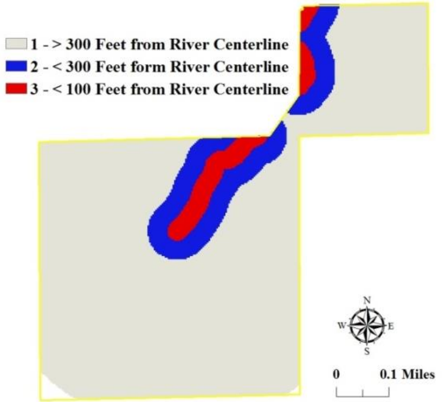

Figure 3. Buffered river centerline data layer based on trail development guidelines. The buffered layers are ranked from 1 to 3, where 1 is the most suitable distance to 3 which is the least suitable distance from river centerlines.

Table 1. River centerline data buffered and ranked from 1 to 3 based on the MN Trail Planning and Development Guidelines, with 1 being most suitable distances to 3 being the least suitable distance from river centerlines.

River Centerline	Ranking
>300 Ft. from Centerline	1
<300 Ft. from Centerline	2
<100 Ft. from Centerline	3

The study site is also home to potential timber rattlesnake habitat. Ideal timber rattlesnake habitat is defined as steep, south facing slopes. In order to avoid these habitats, slope and aspect were derived from the 10m Hillshade DEM. Steep slopes were classified as a slope greater than 45 degrees. The slope was reclassified to exclude anything greater than 45 degrees. Aspect was reclassified to exclude all south facing slopes. South facing slopes greater than 45 degrees were ranked from 1 being most suitable, to 3 being least suitable (Figure 4).

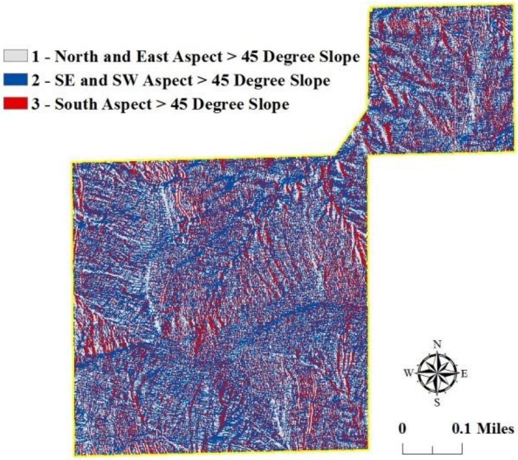

Figure 4. Aspect with greater than 45 degree slopes were ranked from 1 to 3 to avoid potential timber rattlesnake habitat. 1 being the most suitable areas to develop trail and 3 being the least suitable areas to develop trail based on potential timber rattlesnake habitat.

Slope

Slope is an important factor to take into consideration when designing an OHV trail. With steeper slopes comes a greater likelihood of erosion; therefore, in order to minimize trail erosion, slopes were ranked in accordance with standard development guidelines (Minnesota Department of Natural Resources, 2007). Slope was derived from the 10m Hillshade DEM, and reclassified with slopes less than 5% ranked with a value of one, slopes greater than 5% were ranked with a value of two, and slopes greater than 10% were ranked with a value of three. Figure 5 and Table 3 illustrate the ranked raster dataset derived from the 10m Hillshade DEM.

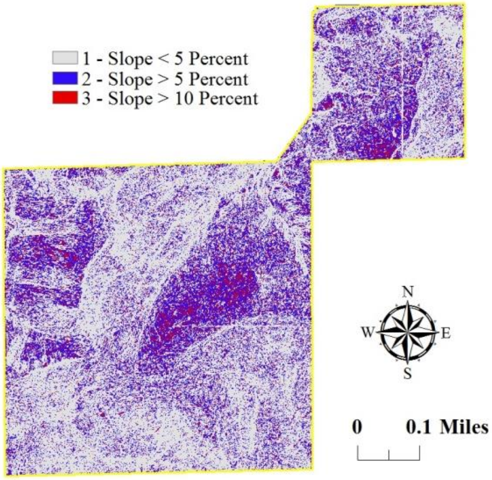

Figure 5. Slope ranked from 1 to 3 based on MN Trail Planning and Development Guidelines with 1 being most suitable, to 3 being the least suitable soil type.

Table 2. Slope ranked from 1 to 3 based on the MN Trail Planning and Development Guidelines. 1 is the most suitable and 3 is the least suitable.

Slope	Ranking
Slope < 5%	1
Slope > 5%	2
Slope > 10%	3

Soils

Understanding how the three main soil types react to motorized recreation trails is important during the trail design phase (Minnesota Department of Natural Resouces, Trails and waterways, 2007). The three types of soil are clay, silt and sand. Loamy soil is a blend of the three. Clay is extremely fine-grained, is strong and resistant to erosion when dry, but when wet becomes slippery and un-compacted (Minnesota Department of Natural Resources, 2007). Silt particles are medium sized, hold less water than clay and have varying levels of resistance to erosion (Minnesota Department of Natural Resources, 2007). Sand is coarse textured, excessively drained and has a high displacement rate when used in trail design (Minnesota Department of Natural Resources, 2007). Loam soil types are a blend of the three soil types and tend to be well drained, have moderate resistance to displacement, and create a firm tread (Minnesota Department of Natural Resources, 2007). According to Snyder *et al.* (2008), well-drained, fine-textured loam or clay loam are the most sustainable soil types for motorized recreation trails. The soil dataset for this analysis was obtained from the SSURGO Soils website which provides a nation-wide soil type dataset that is widely used for determining trail alignment in order to avoid soils that have high displacement rates. For this analysis, soil texture attributes were ranked to reflect these recommendations (Figure 6 and Table 3).

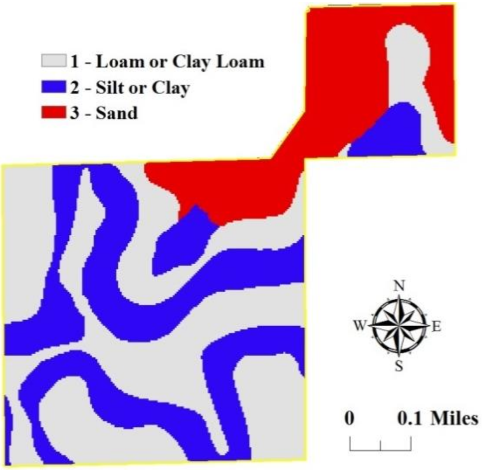

Figure 6. Soil types were ranked from 1 to 3 based on the MN Trail and Development Guidelines. Values of 1 (gray color) represents most suitable, and values of 3 (red color) represents areas least suitable.

Table 3. Soil type ranked from 1 being most suitable to 3 being least suitable.

Soil Type	Ranking
Loam or Clay Loam	1
Silt or Clay	2
Sand	3

User Preference Data Attributes

Viewshed

Accessing scenic vistas is one of the main rider preferences outlined in the Management Guidelines for OHV Management (Crimmins, 2006). Focus groups discussions conducted by Snyder *et al.* (2008) further confirmed rider groups prefer riding on trails with scenic outlooks and vistas. In order to account for scenic vistas and overlooks, viewshed was derived from the 10m Hillshade DEM. The viewshed data was then reclassified and ranked with the longest line of sight with a value of one, mid-range sight with a value of two, and lowest sight distance with a value of three (Figure 7).

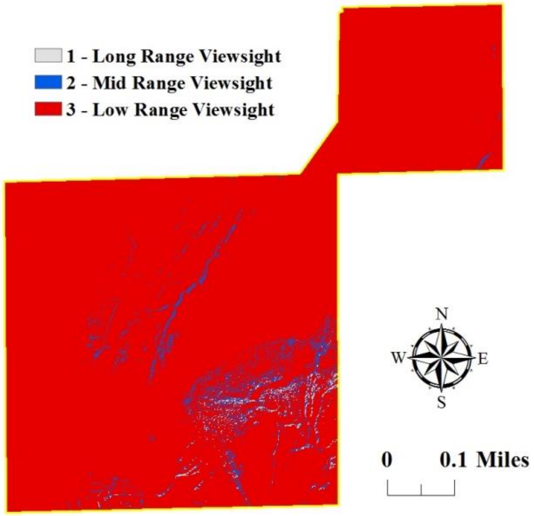

Figure 7. Viewsight was ranked from 1 to 3 based on focus group discussions preference for long range viewsights. 1 represents most favorable viewsight range based on user group preference and 3 represents least favorable viewsight range.

Landcover

Another important factor to take into consideration when determining an optimal OHV trail is landcover type. Focus group discussions conducted by Snyder *et al.* (2008) also concluded the following vegetative cover types were preferred from most to least: deciduous trees, coniferous trees, shrubs/marsh, grasslands, and croplands. The predominant landcover types in the study area consisted of upland deciduous trees, deciduous trees, and coniferous trees. Upland deciduous trees were reclassified and given a rank of one, deciduous trees were reclassified and given a rank of two, and coniferous trees were reclassified and given a rank of three (Figure 8 and Table 4).

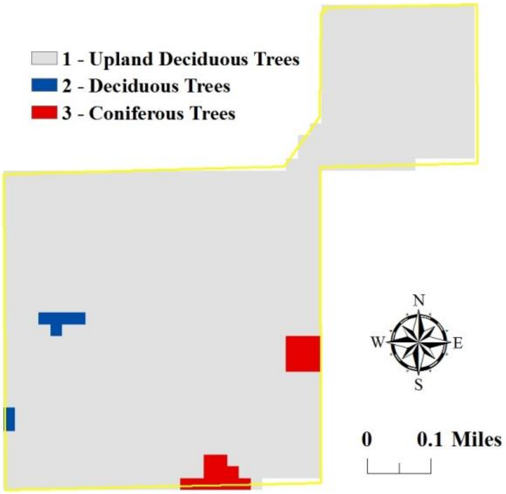

Figure 8. Landcover type was ranked from 1 to 3, with 1 being the most favorable to 3 being the least favorable based on focus group discussion preferences for various landcover types.

Table 4. Landcover types ranked from 1 being the most preferred to 3 being the least preferred.

Landcover	Ranking
Upland Deciduous Trees	1
Deciduous Trees	2
Coniferous Trees	3

Proposed Off-Highway Vehicle Route Based on Ecological Criteria, User Preference, and all Criteria Combined

After data layers were reclassified and ranked, the weighted overlay tool was used to create a suitability model to be input into the least cost-path tool to determine three separate trail alignments. One suitability model was based solely on ecological criteria, another suitability model was based solely on user preference criteria, and the final suitability model included both ecological and user preference criteria. The new data layer created a raster indicating most suitable locations for a new trail alignment (Figure 9).

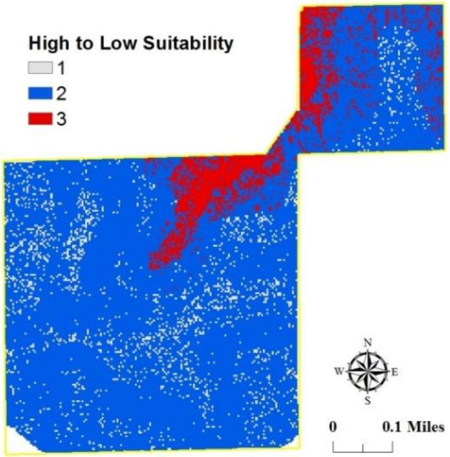

Figure 9. Suitability model from reclassified and ranked data using the ArcGIS weighted overlay geoprocessing tool. The grey areas depict highly suitable areas for trail development, the blue depicts moderately suitable areas for trail development, and red depicts the least suitable areas for trail development.

The suitability data layer was input into the cost-distance tool. The cost-distance tool calculated the least accumulative cost-distance for each raster cell to the nearest source over a cost surface (Figure 10).

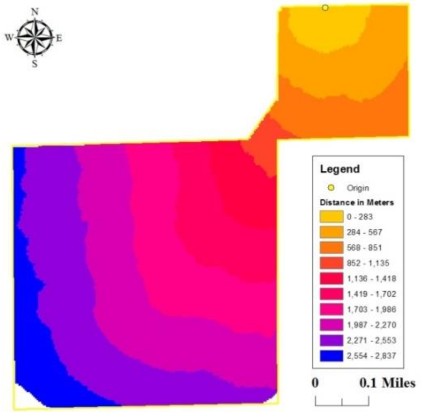

Figure 10. Cost weighted distance grid derived from the suitability model data layer. The cost-distance raster depicts the least accumulative cost shown from light to dark (measured in meters).

Once the cost-distance raster was created, the cost-back link tool was used to define the neighbor next to the cell on the least accumulative cost path to the nearest source (Figure 11).

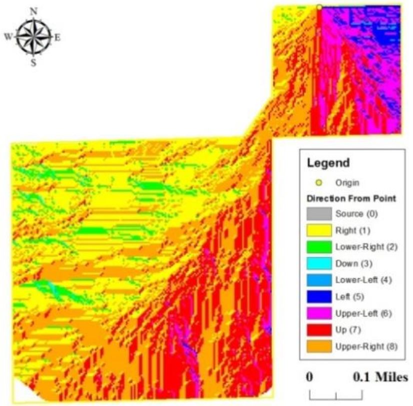

Figure 11. Cost back-link grid derived from the suitability model data layer. The cost back-link raster defines the direction of the neighbor with the least accumulative cost.

Finally, resulting layers from these analyses were input into the least-cost path tool to calculate the least cost-path from source to destination by way of the most cost effective route (Figure 12). This process was repeated from each point to determine the least cost-path resulting in a trail loop based on ecological criteria, user preference criteria, and all criteria.

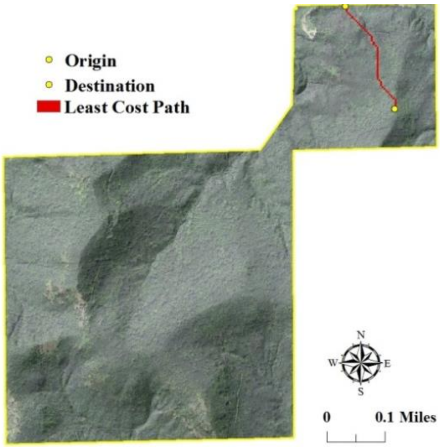

Figure 12. Least cost path from origin to destination within the study area.

Results

This study provided a preliminary analysis for a proposed 5 mile OHV trail alignment in Houston County. The purpose of analysis was to compare a suitable trail alignment using ecological criteria, user preference criteria, and both ecological and user preference criteria to determine the most suitable trail alignment to minimize environmental degradation and maximize user satisfaction.

The results (Figure 13) show the least-cost path trail alignment that included ecological criteria. The ecological datasets in the suitability model included distance from river centerlines, slope, aspect, and soil types.

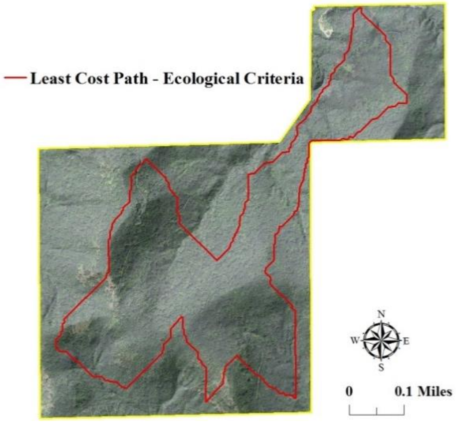

Figure 13. The resulting OHV trail alignment least cost path based solely on ecological criteria.

Results illustrated in Figure 14 show the least-cost path trail alignment that included user preference criteria. The user preference datasets included landcover type and range of viewsight. Loops trails were also a main user preference, so all trails created for the study followed the same loop trail design

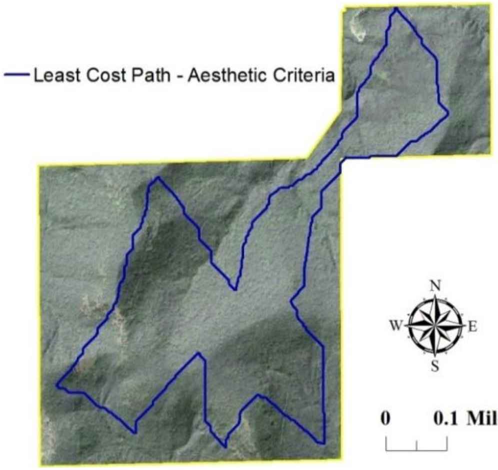

Figure 14. The resulting OHV trail alignment least cost path based solely on aesthetic criteria.

Figure 15 shows the least-cost path that included all data criteria. The suitability model included all ranked data layers that were input into an equal weighted overlay to determine the least-cost path.

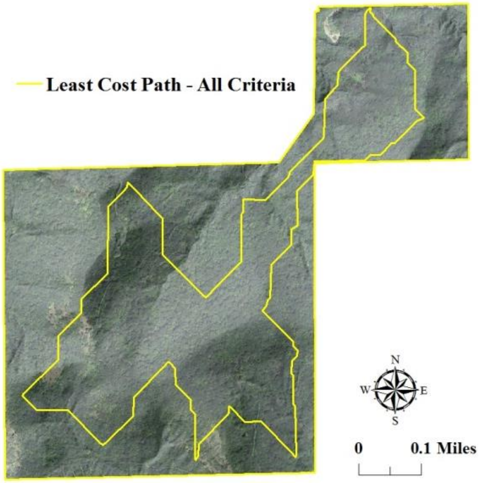

Figure 14. The resulting OHV trail alignment least cost path based on all criteria.

Figure 15 shows all three trail alignments in one map to see variations of different input criteria and least-cost paths that resulted. While the trails are similar in some segments and different in others, planning for a new trail requires careful analysis and evaluation of the study area and features that have the potential to impact the trail.

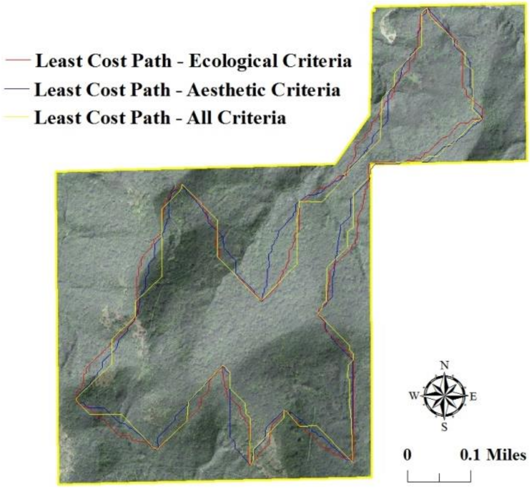

Figure 15. The resulting least-cost paths of all three trail alignments.

Discussion

Interpretation of Results

This purpose of this study was to develop a methodology for a preliminary trail alignment analysis. The findings of this study determine in order to successfully develop a trail, it is critical to take into consideration various data attributes when determining least-cost path trail alignment.

Using GIS as a preliminary analysis to determine trail alignments allows for a more thorough understanding of criteria important when developing new trails. After comparison of the three trail alignments, it was determined that for preliminary trail alignment planning, it was critical to compare the results of the trail alignments to determine the optimal trail based on various input datasets. The trail alignment that included both ecological and user preference criteria was the most suitable trail because it did not compromise any ecological criteria and still maintained user preferences. For this study, the analysis of the trail alignment confirmed that both ecological considerations and user riding preferences can be maximized when taking a holistic approach to trail design.

This study has the potential to be used by trail designers, natural resource managers, park managers or anyone involved in motorized recreation as a preliminary and cost effective analysis to determine suitable and sustainable trail alignments.

Sources of Error

One restriction with the data dealt with the scale of the data layers. The SSURGO Soils data layer provided broad scale mapping of the soil types in the study area. The suitability model may have resulted in a different trail alignment if the soil layer was mapped at a finer resolution. Another similar data limitation was the 2006 NLCD dataset. The landcover type was mapped at a broad scale which may have left out some finer scale landcover classifications. Had the data been mapped at a finer scale, the potential trail may have resulted in a different path.

Another data limitation could have been the raster cell size. The cell size for the study was set to a 30 meter cell size resolution. Since the study area was a small area of land, a smaller cell size resolution may have resulted in different trail alignments.

Recommendations for Future Work

This analysis has the potential to be used for various trail planning applications. The analysis could be applied to other trail use types such as hiking, biking, or horse-back riding trails. In order to customize the model to suit other trail use types, different criteria or datasets could be used in the analysis. One factor that would be critical to apply to different trail analyses would be selecting the appropriate datasets for the area of interest.

Ecological Criteria

Some additional ecological factors that could be included in future trail alignment suitability models could be watershed boundaries to ensure proper run-off during rain events or historical attributes. Other factors that may be considered could be rare plant features or the effect of trail width on adjacent flora and fauna.

User Preference Criteria

Additional user preference criteria that could be included in the suitability model are multiple loop trails or distance from roads. Rider experience depends on trail difficulty, so adding multiple loops of varying rider levels would add another dimension of the analysis. Motorized recreationists ride trails to enjoy the natural environment so taking into consideration line of sight from major surrounding roads could also be a data input for future trail analyses.

Conclusions

This paper provided a methodology that was used to locate a least-cost path OHV trail in Houston County. The study has the potential to assist trail designers make informed decisions when developing new OHV trail alignments.

Using GIS to assist in the preliminary design and analysis of new trails offers a cost effective management tool that has the potential to be used in a variety of suitability trail modeling. The OHV trail analysis outlined in this paper offers a cost effective methodology that can be applied to various preliminary trail design analyses to ensure environmental sustainability while at the same time meeting user expectations.

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