Visualizing Recreational Trails:

Montgomery County, Maryland

A final report submitted at the request of M-NCPPC by:

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Table of Contents

List of Figures

List of Tables

Executive Summary

At the request of the Montgomery County Department of Parks, eight county recreation trails were visualized via 360° photos and video, to help develop a state-of-the-art bike stress index tailored toward mountain bike trails.

Using the Google Street View platform to publish photos online as well as several GIS open-source datasets and analytic tools, approximately 60 miles of trail were successfully visualized, and four mountain biking trails were stress-indexed.

With the images and stress analysis methodology in hand, the department has the opportunity to lead the nation in visualizing recreation trails by integrating the data products into their online trail web-map. The project deliverables also provide a resource for trail planners and managers who strive to convey variable trail conditions to new and local trail users from anywhere in the world.

Project Background and Purpose

People riding bicycles for both recreation and commuting often want to know what to expect on a trail before using it. In recent years, online trail visualization has become a popular way for potential users to get trail information without having to travel to the site. Another way of helping bicyclists determine a bike path's degree of comfort is to quantify its anticipated level of difficulty through a bike stress index.

In Maryland, Montgomery County's Planning Department has created such an index that classifies the level of traffic stress for all streets and paved bike paths within the county. However, there is no stress index for unpaved trails that are primarily traversed by mountain bikers through wooded areas and have no association with traffic. Moreover, these trails are difficult to view online due to their natural concealment away from the viewable streetscape in Google Street View.

Given that unpaved off-street trails do not run parallel to streets, measurable factors other than road traffic conditions must be considered when measuring mountain bike stress. Accordingly, the project team seeks to develop a methodology that quantifies bike stress for unpaved, mountain bike trails using variables that encompass all factors likely to impact bicyclists' comfort on a trail, including fitness levels and perception of safety. With our expertise in GIS, the team intends to digitally visualize several trails in Montgomery County and apply a custom bike stress index in a way that will complement the county's existing online resources.

This project allows Montgomery County to lead the nation in trail visualization and bike stress analytics for natural surface trails. Currently, Philadelphia is the only location in the United States to have a similar strategy to visualize trails with linked 360-degree photos online. Montgomery County will be the first location in the U.S. to create and publish a bike stress methodology for natural-surface mountain biking trails.

Figure 1: Visualizing trails with a 360° camera
https://www.adventuresportsnetwork.com/gear/can-new-360-degree-pov-cameras-revolutionize-action-sports-camera-market/

Objectives

Visualizing Recreational Trails in Montgomery County

The primary objective is to visualize eight popular recreation trails in Montgomery County at the request of the Maryland-National Capital Park and Planning Commission (M-NCPPC). The trail list includes trails with paved and natural surfaces. A combination of 360° photos as well as video is collected from each trail. The 360° photos are linked through the Google Street View platform and the videos are organized, named, and delivered to the M-NCPPC Department of Parks.

Mountain Bike Level of Stress Analysis

The secondary objective is to develop a bike stress index for each of the selected unpaved trails. These trails are only suitable for mountain bikes; therefore, the index will conform to the various skill levels of mountain bicyclists. The proposed methodology is based on existing bicycle traffic stress indexing techniques as well as elements taken from the team's field experience. The final product will include a generic methodology that allows the analysis procedure to be replicated for a larger set of trails, and a color-coded segmented index map that classifies comfort stress parameters into four skill classes.

Literature Review

Essentially, bike stress can be defined as the level of difficulty that a bike trail or path presents to the biker, with trails presenting few barriers to cyclability being low-stress and difficult trails being high-stress. In academic articles, the terminology generally used to describe the traffic stress posed to cyclists is the level of traffic stress (LTS). Currently, studies focus on two aspects: primary factors commonly used to determine traffic stress and various criteria for traffic stress.

Safety is the most important factor influencing LTS for biking. Traffic characteristics, such as speed limit, traffic volume, road width, whether or not independent bike lanes exist, are commonly-used variables. Other variables considered when defining bike stress can range from motor vehicle traffic along the biking path to its terrain (Mekuria, 2012). Standard variables considered in almost every bike suitability study are: roadway geometrics, average daily traffic, posted speed limits, marked bike lanes, quality and maintenance of the path or roadway ("Greenville Bicycle & Pedestrian Master Plan"; Ophardt, 2005). Considering the availability of data, common inputs of LTS for biking are limited to these variables: posted or observed speed limit, presence and width of bikeways, intersection control, proximity to motor vehicle parking, blockage of the bikeway by motor vehicles, traffic volumes and truck route designation, and gaps in the bikeway network.

The Greenville study assigned same weights to each variable, but weighting variables based on their level of impact is an area that could benefit from further research. A variable not found in many cities' plans is the presence of hills. A study in Coimbra, Portugal examined the suitability of hilly areas, and used many variables including acceleration due to gravity, slope, travel time, bicycle velocity, power related to acceleration, power dissipated given the aerodynamic drag. The analysis of LTS for bikeways may also include aerial imagery or biking experiences of people ("Level of Traffic Stress").

Another survey conducted by Meghan W., Gavin D. et al., evaluates 73 motivators and deterrents to cycling, which also show insights into factors that can be used in this project to determine bike stress for trails. Their study shows that three primary motivators for cycling are being away from traffic noise and pollution, beautiful scenery, and biking routes separated from traffic. Along with safety, the comfort of biking, weather, route conditions, and interactions with motor vehicles are factors that highly influence the cycling experience (Meghan et al., 2011).

In their analysis of bikesheds, Iseki and Tingstrom (2014) concluded that street slope and connectivity, distance, and the energy consumption of biking into a single travel impedance factor (measured in watts) should be combined to create more accurate bikeshed analyses. These are variables should also be incorporated into the measurement of bike stress. Bike stress not related to traffic and level-of-comfort on a bike, particularly on unpaved or mountain trails, represents a substantive gap in the literature on bike stress. A more comprehensive approach to measuring bike stress could be particularly helpful in measuring the stress of unpaved trails.

Measures of LTS are generally based on cyclists' tolerance of traffic stress. One classification developed by Geller grouped Portlanders into four categories: "The Strong and the Fearless," "The Enthused and the Confident," "The Interested but Concerned," and "No Way No How." These classifications are popularly used, and based on survey data of people's attitude toward biking and their biking habits. In 2012, the Mineta Transportation Institute (MTI) proposed a new classification scheme of traffic stress based on Geller's work. Other researchers proposed two ways to measure connectivity: "percent trips connected" and "percent nodes connected" derived from the phenomenon that in the U.S. biking networks generally have limited connectivity. Their work on connectivity may not be directly connected to the estimation of traffic stress, but it can contribute because cyclists can endure more stress when detouring too much.

A 2017 MTI report (Mekuria, Bruce, & Nixon, 2017), makes the key point that the LTS of bike lanes is highly influenced by whether there's a parking lane along the bike lanes. The report proposes two criteria for classifying bike lanes based on whether there's a parking lane.

In MWCOG's 2017 report of the TPB Transportation/Land-Use Connections Program, adopts Geller's classification except that LTS 4 is modified as level streets that are suitable for "young, old, and novice cyclists" rather than people who will never bike no matter what kind of street. Arlington County is the study area (as shown below). Corresponding to these four levels of traffic stress, cyclists' tolerance is discussed by traffic characteristics, such as speed limit, traffic volume of low-speed traffic, the interaction of cyclists with vehicles, etc. It also considers barriers, such as rivers, railroad tracks, impassable bridges, and large institutions. Also, it discusses discontinuities, i.e. "weak link" effects. This means that bike lanes are given higher stress scores where they disappear, such as at intersection approaches. In sum, a set of criteria for traffic stress level are proposed for different situations, such as in mixed traffic, for bike lanes and shoulders not alongside a parking lane, etc.

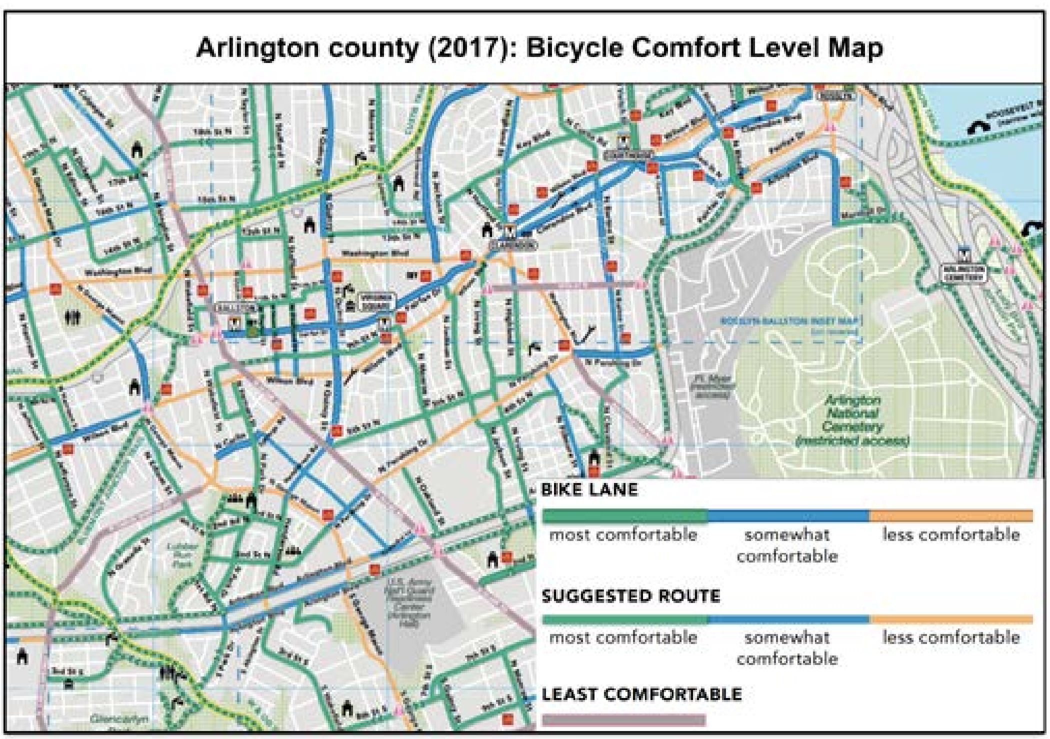

Figure 2: Arlington County Bicycle Comfort Level
(source: MWCOG's 2017 report: Arlington County: Low-Stress Bicycle Network Mapping)

One practical method for scoring bike stress, or biking suitability, is to allow cyclists to report on the perceived bikeability of their area. BikeMaps.org measures biking safety by allowing cyclists to report collisions and near-misses with motor vehicles (Nelson et al, 2015). Each reported incident is then displayed on the map, allowing users to decide for themselves whether or not they believe the trail to be safely bikeable. A major limitation of this measurement is that it doesn't consider a path or trail's terrain and surface type (paved, natural). This method also leads users to operate under the assumption that if no incidents have been reported then a trail is most likely safe and low-stress.

Boston used a similar system of riders scoring roads and paths, resulting in a major city-wide map ("Boston Bikes"). Recently, over 500 cities in Germany combined cyclists' bikeability reports and used a set of criteria evaluated by outside stakeholders to determine the country's most bikeable city. The trails were evaluated to see whether they are frequently cleaned, if there is winter service, if there are traffic lights, as well as trail width, trail surface, ability to transport bikes on public transit, and reported bike thefts (Mispelon, 2017). This comprehensive approach to measuring bikeability was then used to give cities a score ranging from 0-6, with 0 being the most bikeable and 6 being the least. Northwestern Germany was found to be the country's most bikeable region (Mispelon, 2017).

Montgomery County planners applied the methodology developed by the Northeastern University transport scholar Peter Furth and mapped the Traffic Stress Level (TSL) for county streets and bike trails. They quantified the TSL based on "traffic speed and volume, the number and width of car and bike lanes, parking turnover, how easy it is to get through intersections, and other characteristics" (Bliss, 2016). First, segments, intersection approaches, and unsignalized crossings are considered, and criteria for traffic stress of four levels in different situations are proposed. Second, more considerations, such as separated bikeways, the effect of frequently blocked bike lanes, industrial streets, etc. are considered.

Bicycle Stress Map

Figure 3: Traffic Stress Map of Montgomery County
(Source: Montgomery County Maryland Planning Department)

Bike stress, commonly described by level of traffic stress (LTS), is generally measured by people's tolerance of traffic stress, and what concerns cyclists most is safety. People's tolerance is generally linked with traffic characteristics, such as speed limit, traffic volume, and whether or not separated bike lanes exist. Intersections, approaches, and barriers are also frequently applied to estimating traffic stress. Other factors, such as comfort, enjoyment, route condition, and noise and pollution can also influence traffic stress level.

Additionally, processing ratings from users is a popular method for estimating bike stress. Their comments can also be used to calibrate the classification results of traffic stress. Although there are many references about bike stress on general roads, studies about bike stress on natural trials are very limited. Nevertheless, all the investigated studies were helpful in developing our own methodology for estimating bike stress on natural trails.

Visualizing Recreational Trails in Montgomery County

To address the needs of M-NCPPC, the team produced videos and 360° photos for each of the eight assigned trails. The videos provide dynamic trail illustrations and allow viewers to experience some of their natural beauty from anywhere in the world. To further visualize the amenities along each trail, the team took several 360° photos to capture snapshots of trail features. The team used a 2016 model Samsung Gear 360° camera obtained from Google to collect 360° photos, and two Hero GoPro cameras to collect video along each trail.

Before visiting the assigned trails, the team tested the equipment on a trail adjacent to the UMD College Park campus. Photos were collected using the Google Street View phone app, which enables users to immediately view and select photos to publish on Google Maps. Within the app, photos are automatically geotagged, saved to your device, and mapped as red dots on Google Maps within the app—blue dots appear as images are published. Moreover, each photo can be shared with a unique URL link or embedded into a website. The number of times a photo has been viewed is displayed within your Google profile where all pictures are stored once the images have been published. Another benefit of the app is its ability to automatically identify and blur faces and license plates. Unfortunately, no additional edits could be made once the photos were published.

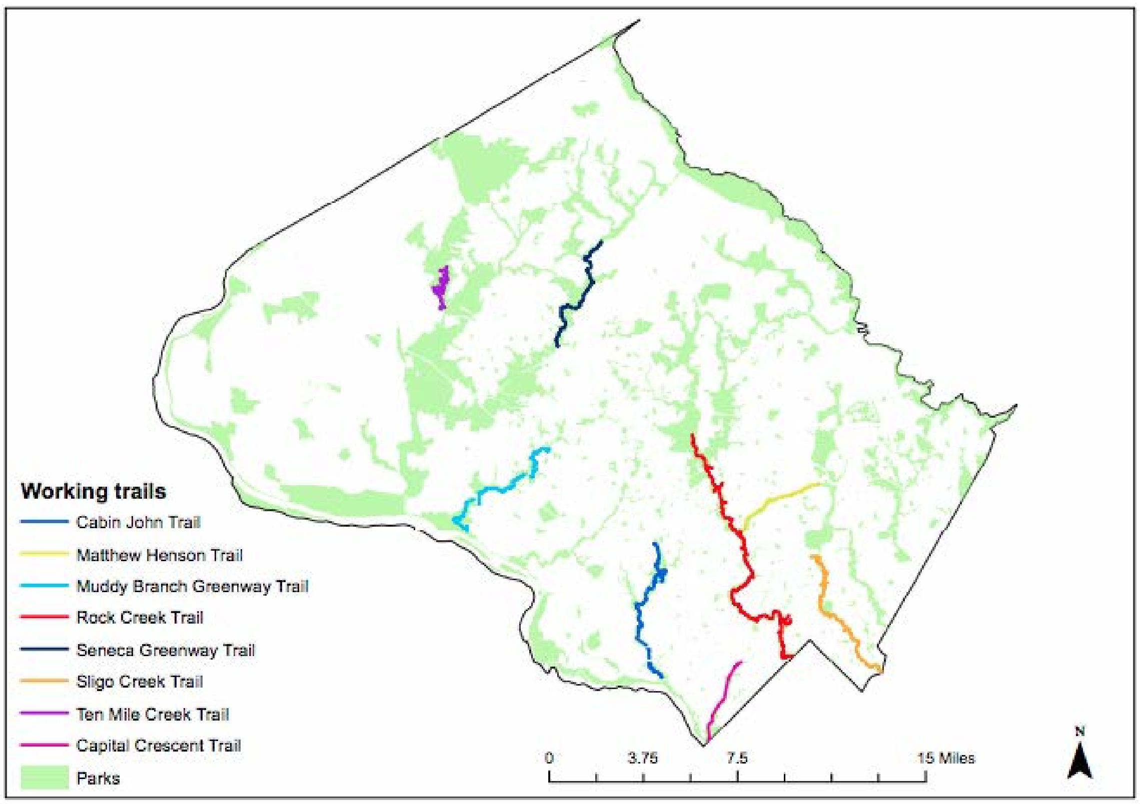

Figure 4: The Eight Visualized Recreation Trails in Montgomery County

The initial plan was to auto-capture photos every few seconds which then could be connected to create a continuous view of the trail—the same view experienced while panning a street in Google Street View. However, the Gear 360° camera's capture interval was too large (~8s) to create a continuous stream of photos when bicycling. Furthermore, the photographer must be a Trusted Google Photographer to take advantage of the auto connect feature.

As an alternative, the team decided to capture 360° photos of features of interest to trail users. Therefore, prior to beginning any trail visualization, various trail features were identified and mapped. Once the locations of the feature points were known, the team's travel lead divided the collection effort over a weeklong period. Photos were taken at features such as:

- Trailheads
- Trail-adjacent parking
- Trail bridges
- Street crossings
- Stream crossings
- Restrooms
- Playgrounds/picnic facilities
- Information kiosks
- Exercise equipment
- Trail junctions

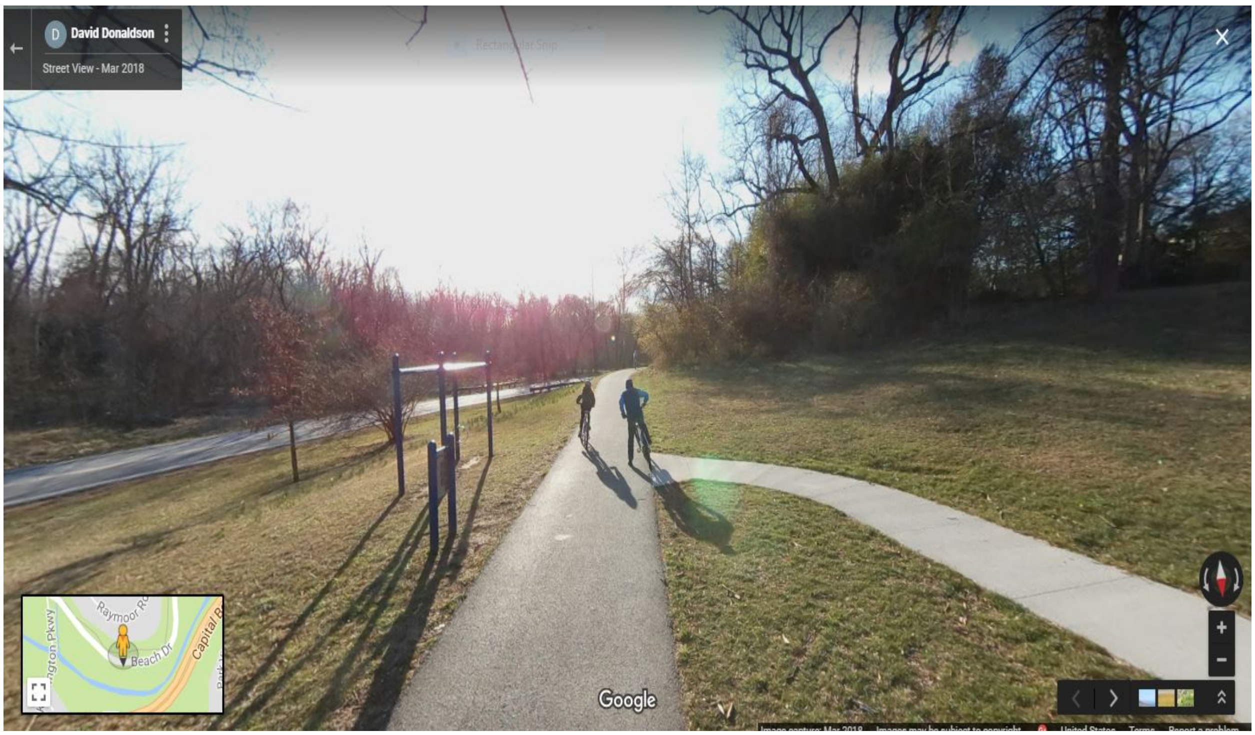

Figure 5: An example of a 360° photo from Rock Creek Trail published to Google Maps

After experimenting with the Gear 360° camera settings, the 360° photos were captured by steadily holding the camera on a handheld monopod or tripod. The GoPro video camera was mounted to the bicycle handlebars or helmet. Videos collected when hiking trails (rather than biking) were captured by holding the GoPro on a monopod. Photos and videos were captured in teams of two, usually with one person biking and the other driving to pick-up/drop-off points. In some instances, the driver concurrently hiked while the other team member biked to increase efficiency, then requested an Uber back to the vehicle.

All photos and videos were collected during the team's spring break, March 18-26. The team needed to collect all field data by March 29th, when the 360° camera lease expired. The group waited as long as possible for spring-like weather but an unseasonably long winter prevented budding of the vegetation. Instead six-inches of snow fell during the middle of the collection period. Therefore, all photos and videos, to the team's dismay, capture a winter landscape with sporadic snow patches instead of the rich greenery one would expect to see along a trail.

Table 1: Summary Table of Visualized Trails

Trail Name	Location	Length	Surface Type	# 360° Photos Captured
Matthew Henson	Wheaton/ Silver Spring	4.2 mi	paved/boardwalk	27
Sligo Creek	Takoma Park/ Silver Spring	10.2 mi	paved	45
Capital Crescent	Bethesda	3.5 mi	paved	22
Rock Creek	Derwood/Rockville/ Silver Spring	14 mi	paved	87
Muddy Branch	Darnestown/ North Potomac	9 mi	natural	29
Seneca Greenway	Gaithersburg/ Damascus	7.8 mi	natural	16
Ten Mile Creek	Boyds	5.7 mi	natural	12
Cabin John	Bethesda/Potomac	8.8 mi	natural	82

Some of the raw video segments suffer from poor horizontal alignment, unwanted obstructions (such as faces and license plates), or overall poor video quality due to walking or biking on uneven, bumpy surfaces. To help the client publish the data on their current trail web-map, the team labeled the videos with quality issues. Links of the 360° photos published to Google street View (which can be customized to reflect any 2D orientation of the 360° view) were gathered in a spreadsheet with the corresponding trail name, feature of interest in the photo, and the location name (or the XY coordinate if no name is available). The video mp4 files were named in a similar way using a standardized naming convention devised by the group. All trails were fully visualized from start to end except the Ten Mile Creek Trail and a small segment of the Muddy Branch Trail.

Mountain Bike Level of Stress Analysis

The team successfully devised a method to model mountain bicycle level of stress based on a categorized stress index ranging from low to high. The stress index focuses on encompassing comfort metrics that include both physical and safety stress. The index is applied to four natural-surface trails in Montgomery County: Muddy Branch, Seneca Greenway, Ten Mile Creek, and Cabin John.

Mountain Bike Levels of Stress

The proposed stress index features four levels designed to address issues of comfort—both physical and safety-related. The first level represents **very low stress** and describes trail sections that suit mountain bicyclists who have a degree of good general health, but are new to the demands of mountain biking. Trail conditions are also comfortable and safe. The second level represents **low stress** and is suitable for novice cyclists who have little experience riding a mountain bicycle. Also, low stress trails present little to no significant hazards to the rider. The third category, **medium stress**, can present a challenge to beginner and even intermediate level mountain bikers. The bicyclist should be physically fit and/or expect at least one moderate safety risk. Finally, a **high stress** level alerts mountain bicyclists that the trail section is suitable only for experienced bikers who can endure physically demanding hill climbs and/or a major hazard such as a dangerous intersection or large stream crossing.

Trail Segments

Instead of generating a stress score for the entire trail, which is the accepted approach among trail managers, this projects spliced each trail into several segments to portray the varying stress levels along the trail. Both the main trail and any spurs or connector trails associated with the main trail were segmented and scored. Segments are defined as starting or ending at either a trail junction, trail-side parking lot, or street crossing. Splicing the trail provides the opportunity to help new riders choose the section of trail that best fits their skill level. It was also determined that the maximum length of any segment should not exceed a half mile.

Street crossing segments are unique because they include the width of the street, any distance a bicyclist may have to walk on a sidewalk or road shoulder (aligned multi-use paths set back from the road are not considered), and an at least 100-foot buffer from the road. This clearly presents the impact of vehicular traffic on a rider’s overall stress level. Due to the presence of vehicles at street crossings, the parameters used to measure traffic stress are different from the parameters that represent stress along off-street bike trails. Therefore, street crossing segments are scored using a separate classification method. A total of 111 trail segments and 13 intersection segments illustrate the four mountain bike trails.

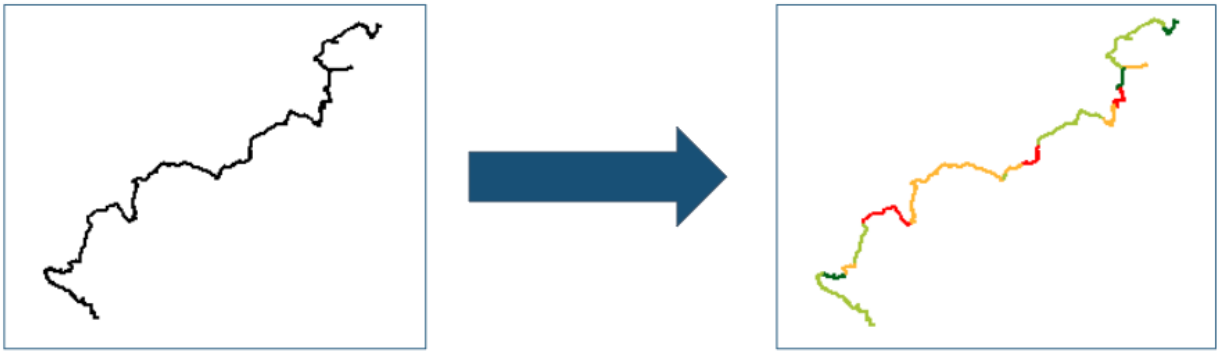

Figure 6: Example of a trail before and after segmentation procedure

Data Collection

Trail line and point feature shapefiles for Montgomery County were provided by the M-NCPPC Department of Parks. The team extracted the detailed information for each of the eight trails. The team also used an open-source Digital Elevation Model (DEM) of Montgomery County provided via the MD iMAP Mapping and GIS Data Portal. Both feature point and elevation data were incorporated into the score calculation for the trail segments.

Data collected for street crossing segments included speed limits, number of lanes, intersection devices and traffic volume. The team used Average Annual Daily Traffic (AADT) collected from MDOT SHA AADT Locator ArcGIS Online application. All other street information was collected from Google Street View.

Level of Stress Analysis - Trail Segments

A generic algorithm was formulated to calculate the total bike stress for any given trail segment. The formula incorporated weighted coefficients and two types of variables: continuous and discrete. The continuous variables represent elevation and trail egress distance datasets that produce a unique value for each segment. Z-scores are calculated for the continuous datasets to normalize the scores. Discrete variables usually comprise five or fewer categories. Normally a discrete variable such as the size of a stream crossing does not apply to every trail segment. Therefore, the raw stress score is added directly to the summation of Z-scores. This approach worked due to the small sample size of segments with discrete stress data. The Z-scores would actually inflate the impact of these discrete data types. However, if more trails are added to the model, the number of segments with discrete data may increase, thus, potentially making the Z-score normalization procedure applicable for all variables

$$Total\ Stress = \sum_i \alpha_i Z(X)_i + \sum_j \beta_j Y_j \quad for\ all\ i,j$$

$$where: \alpha_i + \beta_j = 1$$

X = Continuous Variable (i.e. elevation, distance) ---> Z_X = Z-score of X variable
Y = Discrete Choice Variable (i.e. stream present)
α, β = Weight coefficients
i = set of all X variables
j = set of all Y variables

With the algorithm in place, the team identified several potential stress-measuring weighted parameters to estimate mountain bike stress for all trail segments. Originally several stress-inducing factors were considered in the analysis. However, due to the limited availability of stress data and the goal of creating a generic, easy-to-replicate stress model, a list of approximately 20 variables was narrowed to four:

1) Trail Gradient
2) Trail Obstacles
3) Trail Emergency Egress
4) Type of Users

A digital elevation model (DEM) enabled the calculation of several elevation parameters for all trail segments including minimum elevation, maximum elevation, average slope and maximum slope. This task was completed by running the Add Surface tool accessed within the ESRI ArcGIS 3D Analyst toolbox. Since a DEM models the true surface elevation and does not measure man-made bridges, many of the calculations were believed to have misrepresented the true surface conditions where bridges were present. Where the model would compute a steep slope to indicate a drop-off, in reality, a bridge would provide a significantly shallower grade not captured by the DEM. To minimize this error, only the average slope was included in the analysis.

Another source of bicycle stress is natural and man-made obstacles. Anything from rocks, roots, and streams to construction zones can induce stress in a bicyclist. However, the only measured parameter used in this analysis was the presence and size of stream crossings. Although all obstacle types require extensive field measurements to calculate the item's stress impact, stream crossings were the easiest to categorize due to the readily available location and visual data provided in the trail feature point shapefile and 360° pictures.

The remaining variables in the model include the average distance from any point along a trail segment to the nearest trail exit, and the type of user allowed on the trail. Trail exits include neighborhood access points, street crossings, and parking lots. The lengths of adjacent connector trails were included in the distance calculation. The allowed user variable refers specifically to horseback riding and whether horses are allowed on the stretch of trail. Horseback riders are thought to have less of an impact on bicycle stress than the obstacle variables.

It's important to note that only four unpaved mountain biking trails were evaluated using these four variables. Therefore, variables such as the trail surface type and width are withheld from the analysis due to the assumption that all the evaluated trails are single-track and natural-surfaced.

Level of Stress Analysis - Street Crossing Segments

Intersections along the trails were stress-indexed separately since the rider's perceived comfort and safety depend on traffic-related variables. For instance, when the speed limit is high, the crossing is perceived to be more dangerous, thus, it creates a more stressful environment for cyclists. The same principle is applied to the number of lanes and the average annual daily traffic volume of vehicles at the street crossing. An increase in number of lanes and in traffic volume will both increase a cyclist's stress level. A more important traffic condition is the presence of a traffic control device. While most crossings have at least one device, some street crossings have no signals, crosswalks, stop signs or warning signs. These situations are particularly hazardous for cyclists because vehicles are not expecting pedestrians or cyclists to cross at the location. In total, five traffic stress parameters are considered: number of lanes, speed limit, distance walking along the street, traffic volume, and the presence of traffic control devices. To summarize and evaluate the bicycle stress level at street crossings, the team implemented a rule-based classification methodology that scores each parameter from 1 (very low stress) to 4 (high stress). The classification rules are summarized in the Street Crossing Scorecard (Table 2).

Table 2: Street crossing scorecard

Score Level	Posted Speed Limit (mph)	Volume (AADT)	Distance Walking on Sidewalk (ft)	# of Lanes	Intersection Devices
1	≤25	≤2000 Or local streets	[0, 49.9]	1 or 2 through lanes	Signals/Stop signs
2	30	[2000, 5000]	[50, 299.9]	4 lanes including 2 shoulder lanes	Warning signs AND crosswalk
3	35/40	[5000, 20000]	[300, 1320]	4 lanes without shoulders	Warning signs OR crosswalk
4	≥45	≥20,000	>1320	6 or more lanes	No Warning Devices

There are a few features to note on the scorecard. The AADT data source did not provide counts for local streets, therefore, they were assumed to average less than 2,000 vehicles a day. Furthermore, the sidewalk walking distance parameter is based on the distance a person has to walk parallel to the road before arriving at the trailhead. The distance intervals are based on natural breaks in the data distribution for the 13 street crossings analyzed. Any distance over a quarter of a mile (1,320 feet) was assigned the highest stress score. Finally, the number of shoulder lanes were considered when assigning a score based on the total number of lanes.

One feature not shown in the scorecard involves the intersection traffic-control devices. If a signal or stop sign is present at an intersection, the volume and number of lanes are not factored into the stress score. No matter how many vehicles or number of lanes exist, all vehicles are expected to fully stop at the crossing location. The speed score is also lowered by one level unless the bicyclist is required to ride with traffic to reach the trailhead because no sidewalk is present.

After all parameters are individually scored by segment, the average score value is calculated, and in some cases, penalties are assigned. For example, if a guardrail along the street blocks the path and forces a bicyclist to lift their bike over the obstacle, if the majority of the path along the street has no sidewalk, or it is difficult to locate the trail-head from either direction, the score was increased by **0.5** per item. The average score plus the penalty gives the intersection's final score. The assigned scores for each parameter, average scores, associated penalties, and final scores for each of the 13 street crossings are shown in Table B in the Appendix.

Mountain Bike Trail Stress Analysis Results

Trail Segments

For this research purposes, the final mountain bike stress score was calculated according to the formula:

*Mtn Bike Stress Score = 0.5*Z-score (Average Slope %) + 0.35*Stream crossing + 0.1*Z-score (Egress Distance) + 0.05*Horseback riding permitted*

The score's formula is generic and may be changed to meet the needs of trail planners and data availability. Different weights were applied based on the level of each variable's perceived effect on the total bike stress score. The resulting weights were finalized through trial and error. Figure 7 shows the obtained mountain bike stress total score for four natural-surface trails in Montgomery County. Four categories of stress are labeled from "very low stress" (dark green) to "high stress" (red). Segments specific to Cabin John Trail that cater to pedestrians only are colored black.

Three of the four trails have high stress segments. The Muddy Branch trail contains three red segments with orange segments (medium stress) between them. The same trail has almost no "very low stress" segments, making this trail the most challenging for beginners. The Ten Mile Creek trail has two red segments, not surprising, since the newly constructed trail is designed specifically to challenge mountain bikers. The Cabin John trail shows the variety of different segment's scores and, for beginners, may be attractive mainly in its southern part. The Seneca Greenway trail looks to be the simplest among the four and may be a good start for beginners, especially in its middle part. These results seem reasonable based on team's hiking and riding experience; however, the findings are field-verified, which should be done in future work.

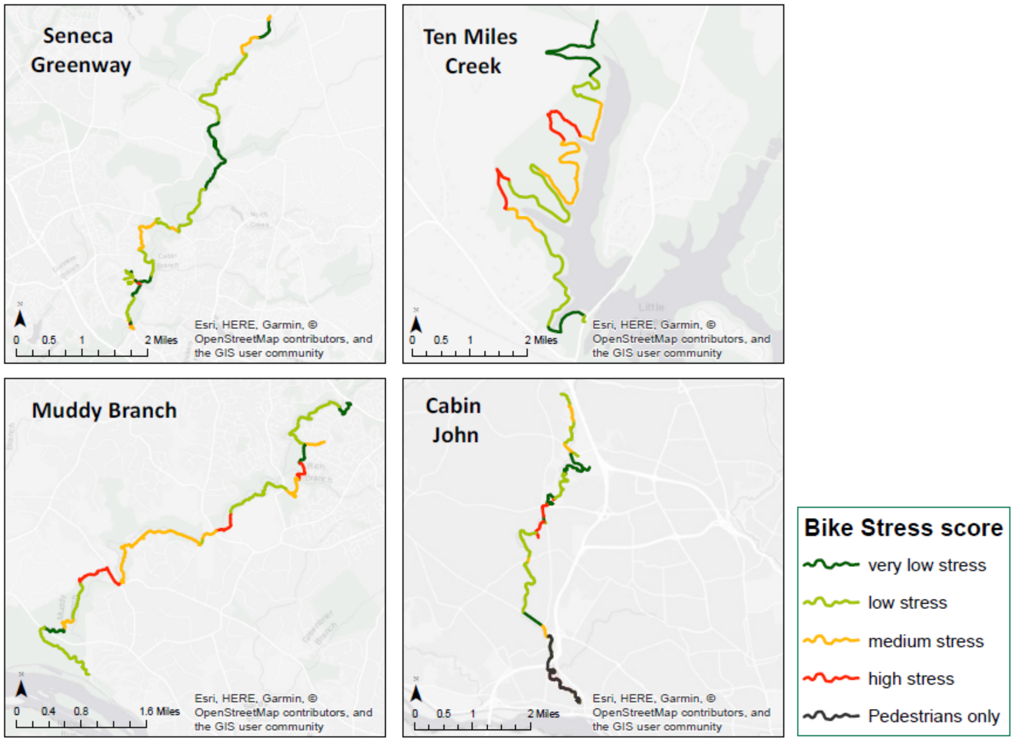

Figure 7: Composite bike stress score for four natural surface trails in Montgomery County, 2018

Table 3: The range of bike stress score's components

Level of bicycle stress	Composite scores range	Average elevation (ft)	Stream crossing	Egress distance (ft)
Very low	-1.03...-0.32	1.5...5.36	No crossing	0...1,371
Low	-0.32...-0.24	5.36...7.75	Minor	1,371...5,352
Medium	-0.24...0.82	7.75...11.11	Moderate	5,352...9,716
High	0.82...1.58	11.11...15.61	Major	9,716...15,488

Figures 8 through 11 are maps of the components of the composite Bike Stress score, and the Table 3 shows the range of scores for different levels of stress. The map of the average slope scores shows only one steep slope segment on the trail, in the middle of the Ten Mile Creek trail. The average elevation difference on this segment is up to 15.61 feet. Muddy Branch and Cabin John also have some steep segments that are shown in orange.

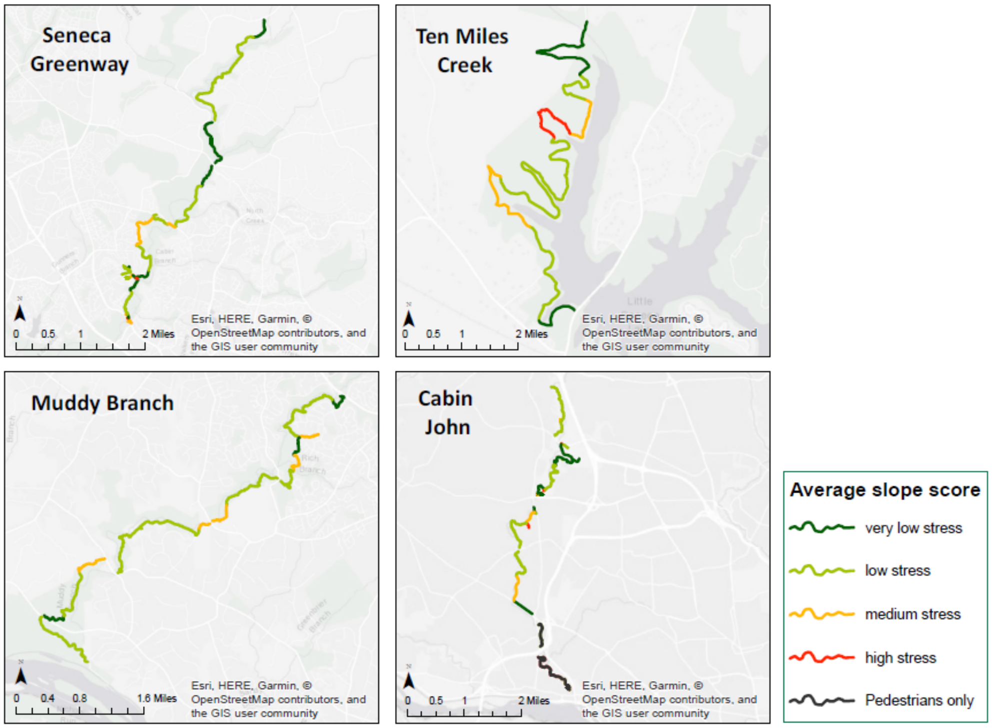

Figure 8: Average slope score for four natural surface trails in Montgomery County, 2018

For stream crossings, the team specified the categories shown in Table 4. Trail segments without stream crossings were considered "very low stress." If the stream was small, not deep, and did not have rocks, it received a score of "1" and was considered "low stress." Medium stress streams were wider, deeper, and might contain rocks. The bicyclists may need to walk the bicycle through this type of stream. Medium stress streams received score of "2." The highest level of stress (score "3") was assigned to streams that were especially hard to ride over or to walk through. There was only one stream at this level, on the north of the Seneca Greenway.

Figure 9 shows the scoring for stream crossings. In addition to the high stress stream crossing on the Seneca Greenway trail, there are a lot of segments with medium stress stream crossings on the Muddy Branch Trail and numerous segments with the low stress streams on the other trails. The Ten Mile Creek Trail does not contain any stream crossings, to the best of our knowledge.

Table 4: Stream crossing categories

Class	Description	Example	Location
1 - Minor	- Normally little or no water flow in stream. - Rider can ride through the stream without getting wet.		Muddy Branch Trail
2 - Moderate	- Water flow at a shallow depth - Width of water flow about the length of a bicycle or less - Some rocks me be present - The approach can have a moderate grade at either end.		Muddy Branch Trail
3 - Major	- Exceptionally wide and/or deep water flow which may require a person to dismount the bike. - OR a sudden extreme hillclimb to exit stream with rocks is present		Seneca Greenway

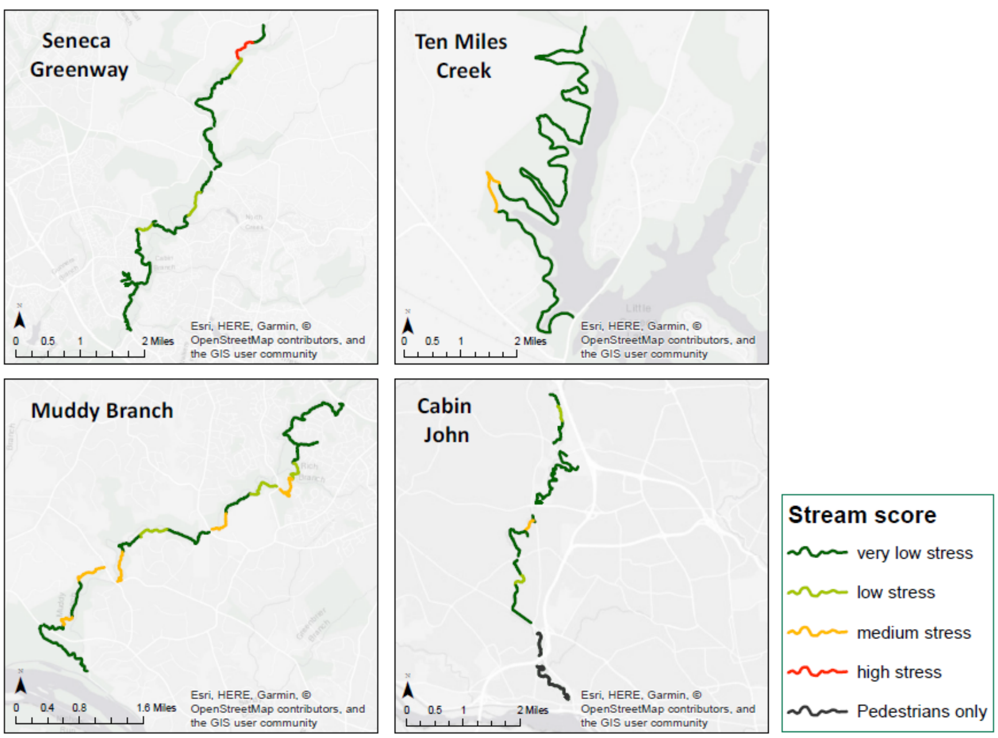

Figure 9: Streams crossing score for four natural surface trails in Montgomery County, 2018

Egress distance was another variable in the composite bike stress score. This is the distance to the closest junction that leads to a road or urban area. Figure 10 shows that the Ten Mile Creek and Muddy Branch trails have long segments without junctions in the middle, which is why these segments received a "high stress" score. However, this score does not influence the final result too much because it is weighted only by 10 percent.

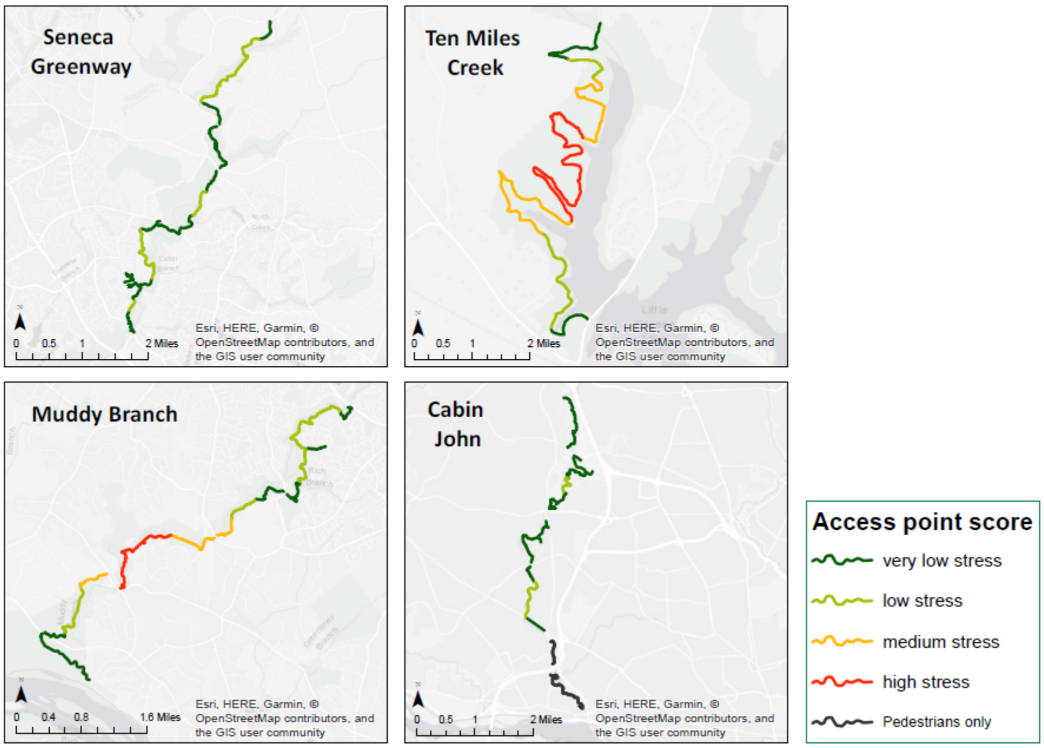

Figure 10: Egress distance score for four natural surface trails in Montgomery County, 2018

The fourth component of the composite Bike Stress score is horseback riding. Figure 11 shows the segments where the horseback riding is allowed (in red) and not allowed (in green). The team retrieved this data from the Montgomery County Parks website. It sometimes did not coincide with the signs on the trails and may need to be updated. However, because of this score's low weight, only 5 percent, it did not influence the final score too much.

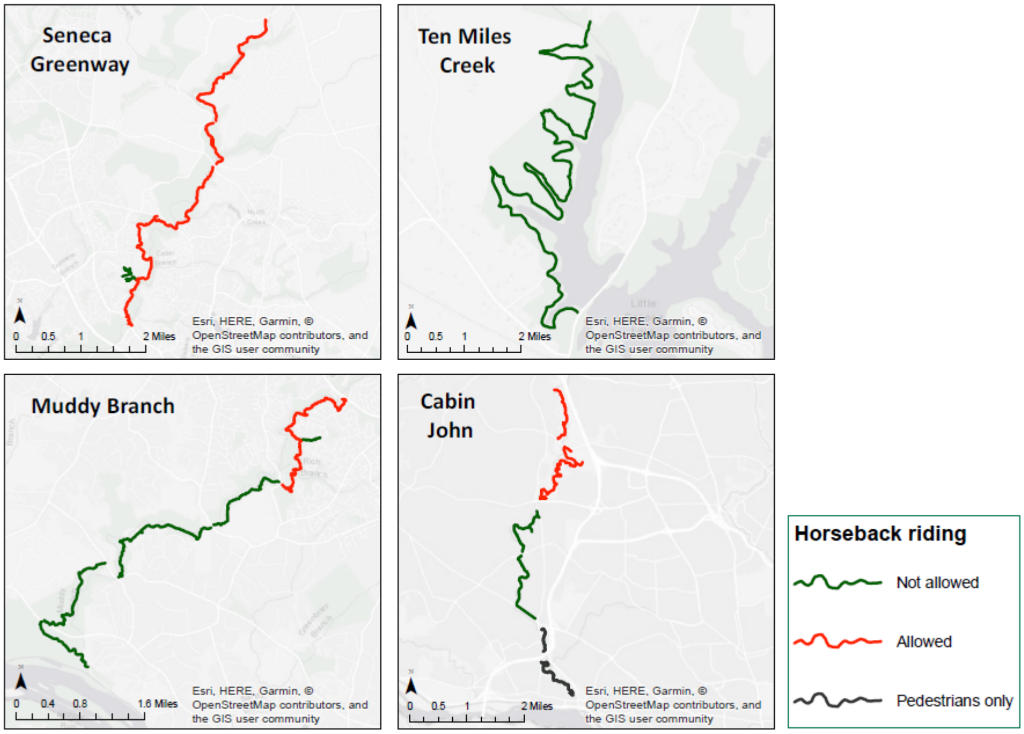

Figure 11: Horseback riding on four natural surface trails in Montgomery County, 2018

According to the team members' experience, the final Bike Stress Score reflected the difficulty of the trails in most cases and, therefore, may be used as a tool for attracting new riders to the suitable trail segments.

Street Crossing Segments

The stress level results for street crossing segments are shown in Figures 12 and 13.

The first intersection, at Wightman and Brink Roads, has a very low stress level since the road's speed limit is very low, the number of lanes and AADT are small, the intersection has stop sign and crosswalk which provide safety for the cyclist, cyclists do not need to walk along the street, and there are no other penalties. This intersection has the lowest stress level and provides comfort and safety for cyclists.

The second intersection, at Clarksburg Road, has higher score and is low stress level. Though the speed limit, number of lanes and volume are small, there are no intersection devices there and cyclists need to cross the street during the gap interval. This provides less travel safety and comfort compared with the first intersection that has a very low stress level.

For the third case, an example of the intersection with moderate stress level is shown. Though the number of lanes and the volume are low, the speed limit is high and the intersection devices are poor. Furthermore, the cyclists must walk a long distance along the road.

The last intersection, a crossing at Tuckerman Lane, has the highest stress level. Though the intersection has signal and crosswalk, the speed limit is high and the volume is much higher than the others. Moreover, the intersection has three penalties: a guardrail blocking the path at the southern entrance, no sidewalk along a significant portion of the road, and it is very difficult to locate the southern trail-head since no trail signs are present. These factors give this intersection highest stress level since safety and travel comfort are poor.

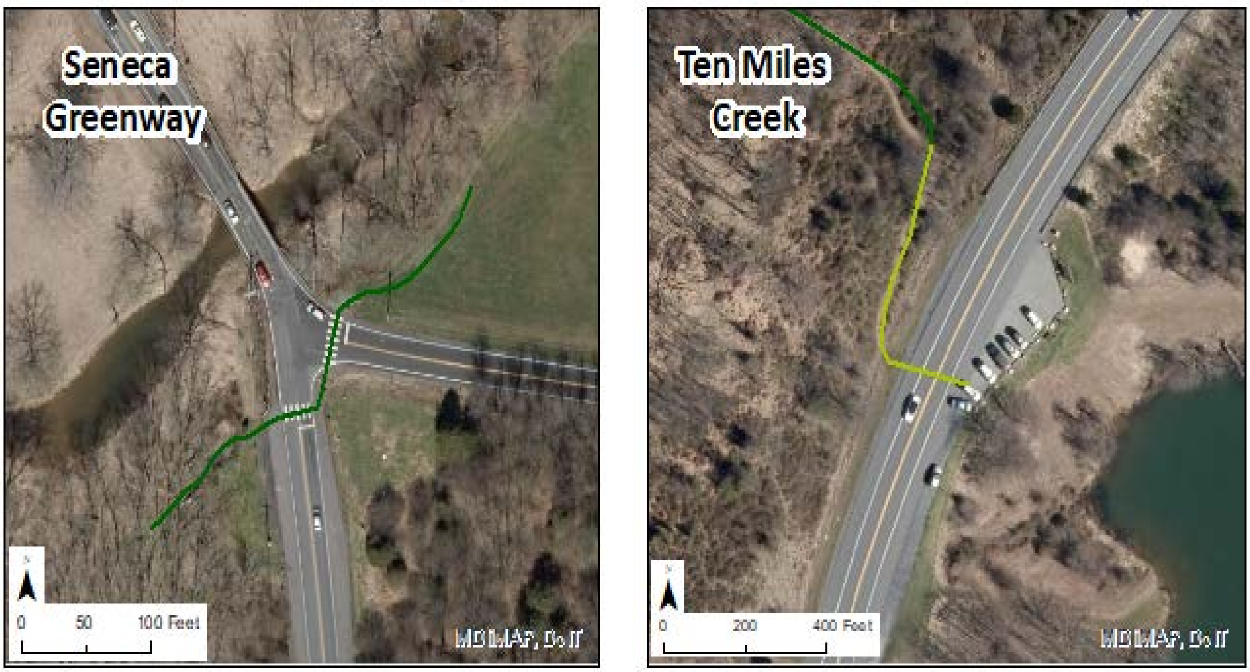

Figure 12: “Very Low Stress” street crossing at Wightman and Brink Roads (left) “Low Stress” crossing at Clarksburg Road (right)

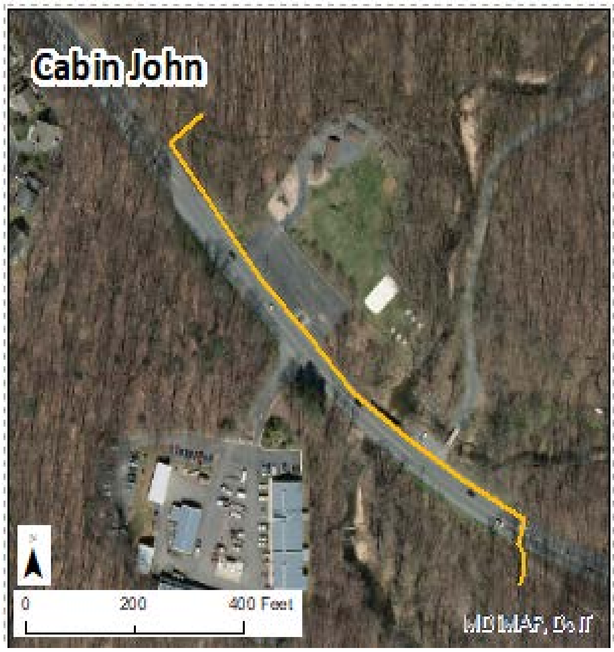

Figure 13: “Moderate Stress” crossing at Tuckerman Lane (left); “High Stress” crossing at Democracy Boulevard and Seven Locks Road

Recommendations

The main recommendation is to integrate some form of the bike stress methodology into the Montgomery County online trails web-map. Not only will trail users be able to interpret the difficulty of the trail online, but the County will likely be the first region to implement a mountain bike stress index that covers a county-wide trail network. The completed product will inform users about the stress levels of each trail segment, which will allow bicyclists to make rational route-choice decisions before arriving at a trail.

Second, it is recommended the Montgomery County Department of Parks obtain their own 360° camera and video equipment if they wish to continue visualizing the park trails. Owning a 360° camera would give the department the option to select a camera that best meets their needs and allows for the trails to be visualized during more visually appealing times of the year. To create more steady and clear videos using GoPro devices, we recommended using a handheld monopod rather than mounting the camera on a bike or helmet. For paved trails, mounting the GoPro on top of a motor vehicle could also be effective.

It is also recommended that Montgomery County incorporate variables that were not captured in the stress analysis, such as the trail condition (i.e. rocks, roots, width) and the presence of wayfinding signage. Including these variables could produce more accurate bike stress score results. Incorporating STRAVA data, which tracks the routes of bicyclists, would also contribute to an overall improved stress score because the number of people using the trail correlates with the level of stress.

For more statistically reliable results, the number of trails in the bike stress analysis should be expanded to eventually include all the trails in Montgomery County. Because this analysis uses data from only four trails, the resulting stress scores are based on a small sample of segments, and therefore, may not represent the entire trail network.

Finally, the team also recommends eliminating some physical obstacles on the trails. Some trail improvement suggestions include: creating a gap in any guardrails that block trailheads at street crossings, installing a bridge over significant stream crossings, and installing more wayfinding signage. These improvements could significantly reduce the stress level in several locations along the trail. In general, eliminating high stress features could entice less-skilled bicyclists to ride the County’s natural surface trails.

Future Work

The trail videos collected with the GoPro camera will need to be post-processed, then integrated into the trails web-map. The videos have several unwanted obstructions such as faces, license plates, and short sequences of uncontrollable quivering. Therefore, it will take time to cut-out the undesirable material, stitch the videos together, and join them with the corresponding trail segment on the web-map. Integrating the 360° photo URLs into the trail lines shapefile also requires additional work. Here, the hope is ArcGIS Online can display the Google Street View URLs within the web-map's attribute table.

The bike stress analysis results should be verified by input from frequent trail users. Since the stress level of discrete variables, and weights of all variables, were determined by young, healthy adults, it is important to get feedback from trail users across a spectrum of ages and ability, then potentially adjust the formula or weights, depending on feedback. After results are verified, trail improvements should be made in locations determined to be high-stress.

During the analysis, the team faced questions that may require further research. First, there were challenges in identifying the project's target audience. Who are the bicyclists in Montgomery County? How often do they ride? Why do they use bicycles (commuting, recreational)? Which trails do they prefer? What are their skill levels? Answering these questions would not only help create a suitable mapping product like the bike stress analysis but might also be helpful for other uses by the County's transportation team. Second, it would be helpful to analyze the behavior of current trail users: bicyclists, pedestrians, and horseback riders. What would they like changed on the trails? Which obstacles are real "obstacles" for them, and which are not (elevation, streams crossings, road crossings)? How do they feel about sharing the trail with other users? What kind of trail facilities do they need, and where? To answer these questions, qualitative methods of research would be helpful, including interviewing, focus groups, and surveys.

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Appendix

Table A: Literature Review Summary

Authors / Organization	Title	Case study	Contributions
Geller R. / Portland Office of Transportation (updated in 2009)	Four Types of Cyclists	NA	1. Comprehensive surveys about Portlanders' attitudes toward biking 2. Classification of Portlanders into four types ● The Strong and the fearless ● The Enthused and the confident ● The interested but concerned ● No way no how
Mineta Transportation Institute (2012)	Low-stress bicycling and network connectivity.	San Jose, CA	1. A new scheme of classification of traffic stress ● LTS 1: most children can tolerate ● LTS 2: the mainstream adult population ● LTS 3: "enthused and confident" but still prefer having their own dedicated space for riding ● LTS 4: "strong and fearless." 2. Two way of measuring connectivity · "percent trips connected", · "percent nodes connected"
Arlington county (2017)	Arlington County: Low-Stress Bicycle Network Mapping	Arlington county, VA	1. Four levels of traffic stress ● LTS 1: Suitable for young, old, and novice cyclists, ● LTS 2: "The mainstream adult population" -- "Interested but concerned" ● LTS 3: "Enthused and confident" ● LTS 4: "Strong and fearless" 2. Traffic stress criteria in different situations ● In mixed traffic ● For bike lanes and shoulders not alongside a parking lane, etc. 3. Barriers and discontinuities are considered ● Rivers, railroads, impassable bridges, large institutions, etc. ● "weak link" effect: bike lanes will be given higher scores if they disappear when approaching intersections

Delaware Department of Transportation (2015)	The Low-Stress Bikeability Assessment Tool	Statewide	1. Scheme of traffic stress level ● LTS 1 & 2: relatively safe and bikeable, ● LTS 3 & 4: more challenging and less accessible to the "interested but concerned" cyclist. 2. Data inputs are traffic, lane width, traffic speed, traffic volume, the availability of shoulders and / or separate cycling facilities, and safety.
City of Greenville and the Greenville Urban Area Metropolitan Planning Organization (MPO) (2011)	Greenville Bicycle & Pedestrian Master Plan	Greenville urban area	1. The bicycle conditions (such as facilities and barriers) in Greenville urban area were manually examined, documented, and photo inventoried, 2. Bicycle crashing map was included, 3. Public comments & feedback, such as ● the top deterrents of bicycling (i.e. difficult intersections, uncomfortable traffic conditions, long-path connection ● Factors discouraging cycling (i.e. lack of bicycle lanes, shoulder, or paths) 4. Bicyclists' behaviors were observed and analyzed.E.g., common problems are biking against traffic or on the sidewalk, not wearing helmets.
Tralhao, L., Sousa, N., Ribeiro, N., & Coutinho-Rodrigues, J. (2015)	Design of bicycling suitability maps for hilly cities	City of Coimbra, Portugal	1. A hilly city of Coimbra's suitability for cycling is analyzed based on the relationship between slope and desirable length, 2. Approximate arc slope is conducted because of insufficient data collection, 3. Mapping is based on arc value, and strictly (arc <= 5%) / weakly cyclable (short length, wavy, etc.) zones are detected.
Meghan W., Gavin D., Diana K., Kay T. (2011).	Motivators and deterrents of bicycling: comparing influences on decisions to ride	Metro Vancouver	1. Top motivators: away from traffic noise and pollution, beautiful scenery, paths separated from traffic. 2. Top deterrents: ice and snow, streets with a lot of traffic, streets with glass/debris, streets with high speed traffic, and risk from motorists. 3. Factor analysis: safety, ease of cycling, weather conditions, route conditions, and intersections with motor vehicles.

Table B: Street crossing scoring index calculations

Shapefile FID	Trail	Traffic Control Devices	# of Lanes	AADT	Speed Original	Speed Reduced	Sidewalk Distance	Avg Score	Guardrail	Sidewalk Unavailable	Difficulty locating trailhead	Total Raw Score	Total Score
0	Seneca Greenway	2	1	1	1		1	**1.2**				1.2	**1**
1	Seneca Greenway	2	2	3	3		1	**2.2**				2.2	**2**
2	Seneca Greenway	1	2	3	3	2	1	**1.3**				1.3	**1**
3	Seneca Greenway	3	1	2	3		2	**2.2**		+0.5		2.7	**3**
4	10 Mile Creek	4	2	2	3		1	**2.4**				2.4	**2**
5	Muddy Branch	4	1	2	2		4	**2.6**		+0.5	+0.5	3.6	**4**
6	Muddy Branch	4	1	2	2		1	**2.0**	+0.5			2.5	**3**
7	Muddy Branch	3	1	3	2		1	**2.0**				2.0	**2**
8	Muddy Branch	4	1	2	4		1	**2.4**				2.4	**2**
9	Cabin John	4	2	3	3		1	**2.6**	+0.5			3.1	**3**
10	Cabin John	1	4	4	4	3	4	**3.0**	+0.5	+0.5	+0.5	4.5	**4**
11	Cabin John	1	3	4	3	2	4	**2.3**			+0.5	2.8	**3**
12	Cabin John	4	2	3	3		3	**3.3**				3.3	**3**
[grey]	- # of lanes & AADT both voided if signal or stop sign present												
[yellow]	- Speed score is reduced by point if signal or stop sign is present												
[green]	- Original speed score used if cyclist required to bike on road at grade with traffic												

Table C: Team member responsibilities

Team Member	Role	Responsibilities
David Donaldson	Team Lead	Managed the data collection, data analysis, & reporting for the project. Acted as liaison between the team, instructor, and Montgomery County Dept. of Parks
Lauren Pepe	Data Lead	Managed the data for the selected trails. Also responsible for segmenting all the trails.
Weiyi Zhou	Data Lead	Managed the data for the selected trails. Developed Stress Index methodology for street crossing intersections
Hunter Gibson	Mapping Lead	Oversaw the mapping of the bike stress index for the bike trails.
Jane Sun	Policy Lead	Reviewed relevant literature on previous efforts to create bike stress indexes
Iryna Bondarenko	Travel Lead	Created travel plans for trail data collection. Also produced stress scores for all 8 trails.