Impact of eBike Usage on the Carriage Roads in Acadia National Park

An Interactive Qualifying Project Report
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Abstract

Our goal was to identify and predict population trends of the Carriage Roads, in Acadia National Park, with a focus on the eBike user group. Using a trail camera and big-data, a mathematical model was established to estimate the daily population on the Carriage Roads. Additionally, data loggers and surveys were used to gain a stronger understanding of the mobility patterns of eBikes. A manual count of bikes was also conducted to determine the ratio of eBikes to traditional bikes.

Executive Summary

Impact of eBikes Usage on the Carriage Roads in Acadia National Park

Our research addressed the growing population of visitors on Acadia National Park's Carriage Roads. The park has seen an increase of 1.2 million visitors between 2015 and 2021 (U.S. Department of Interior, 2021 b). Due to the popularity of the Carriage Roads, overcrowding is an urgent concern.

Electric bikes, a relatively new group on the Carriage Roads, are an efficient alternative to traditional bikes that make it easier to travel farther (Electric Bicycles, 2020). eBikes have a motor that provides varying levels of assistance. This assistance can be accessed when the rider actively pedals or uses a throttle depending on the classification.

From this, our goal was to identify and predict population trends of the Carriage Roads with a focus on the eBike user group. We broke this goal into these three objectives:

1. Estimate the daily population on the Carriage Roads.
2. Determine the percentage of eBikes compared to traditional bikes on the Carriage Roads.
3. Compare the mobility patterns of eBikes to those of traditional bikes.

Our group carried out various methods to collect the necessary data. To address objective one, we have expanded on past research by the park to estimate the total population on the Carriage Roads. Charles Jacobi, a natural resource specialist, was previously head of this research, which began in the late 1990s and has been periodically updated through 2015 (Jacobi, 2015). This process involved creating a regression equation from a graph of an automated counter at one location and an in-person census at multiple other locations. Regression analysis involves creating a line of best fit for a scatter plot that can then be used to estimate additional data points.

To replicate the automated counter, we set up a motion-activated trail camera at the same location. Our count from the trail camera was used in tandem with big-data to create the scatter plot used in the regression analysis. The big data used came from Streetlight Data, a company that uses cell phone pings to track traffic patterns. Using Streetlight Data, we were able to examine the daily total population on the Carriage Roads without requiring the manpower of an in-person census. We selected 13 locations on the Carriage Roads to record percent distributions from Streetlight Data. Using the numbers acquired from the trail camera and the distribution from the 13 percentages, we were able to create estimates of the population on the Carriage Roads.

Objective two was also an expansion of past work. This work was done by the 2020 WPI IQP research team. They counted eBikes and traditional bikes via trail cameras located at different locations along the Carriage Roads. We were able to complete in-person counts at multiple locations.

For objective three, the group handed out data loggers to cyclists on the Carriage Roads. The data loggers were used to record the GPS coordinates of riders along with their average speed, top speed, elevation change, time of ride, route taken and distance traveled. This information was used to compare the mobility patterns of traditional bikes and eBikes.

After compiling and analyzing all of our data, the group came up with three key findings. The first finding was a new equation to estimate the total number of people on the Carriage Roads.

$$y = 6.89x + 146.77$$

This equation was based on linear regression, meaning as the trail camera count (x) increases, the total population estimation (y) increases a proportional amount. For this equation, if the trail camera counted zero people, then the total population would be estimated at approximately 147 people. However, it should be noted that our model range did not go below a trail camera count of 300 as we collected data during peak season. Therefore, trail counts lower than 300 should be considered less reliable.

The second finding was that eBikes make up 21.9% of all bikes on the Carriage Roads. We counted 7,597 bikes in total, of which 1,662 were eBikes. This was an increase of 18.4 percentage points from two years ago. Bike rental companies in Bar Harbor stated they had increased their eBike inventory to accommodate demand. To help predict the future trend in eBike usage, our survey included the question "would you ride an eBike here in the future?" Of the eighty-nine respondents, 79.8% of them answered yes.

The third finding was that eBike users traveled more miles and stayed on the Carriage Roads longer than traditional bike users. Traditional bikes were found to go 12.0 miles per ride, whereas eBikes tended to travel 19.6 miles. Additionally, eBikes were shown to stay on the Carriage Roads forty-five minutes longer than traditional bikes. eBikes tended to frequent the Around the Mountain, Amphitheater and Day Mountain Loops more than traditional bikes, as shown in our heat maps below. These loops were not commonly traveled as their elevation could pose a challenge to many riders. The pedal assist on eBikes was likely providing more accessibility to those trails. eBikes were also traveling faster than traditional bikes on average. We looked at average moving speed, preventing stopping time from impacting speed calculations. eBikes averaged 9.23 mph whereas traditional bikes averaged 7.59 mph, meaning eBikes traveled 21.6% faster than traditional bikes on average. We believe this has to do with the speeds eBikes can achieve going up hills with the pedal assist.

Figure A: Map of the Carriage Roads

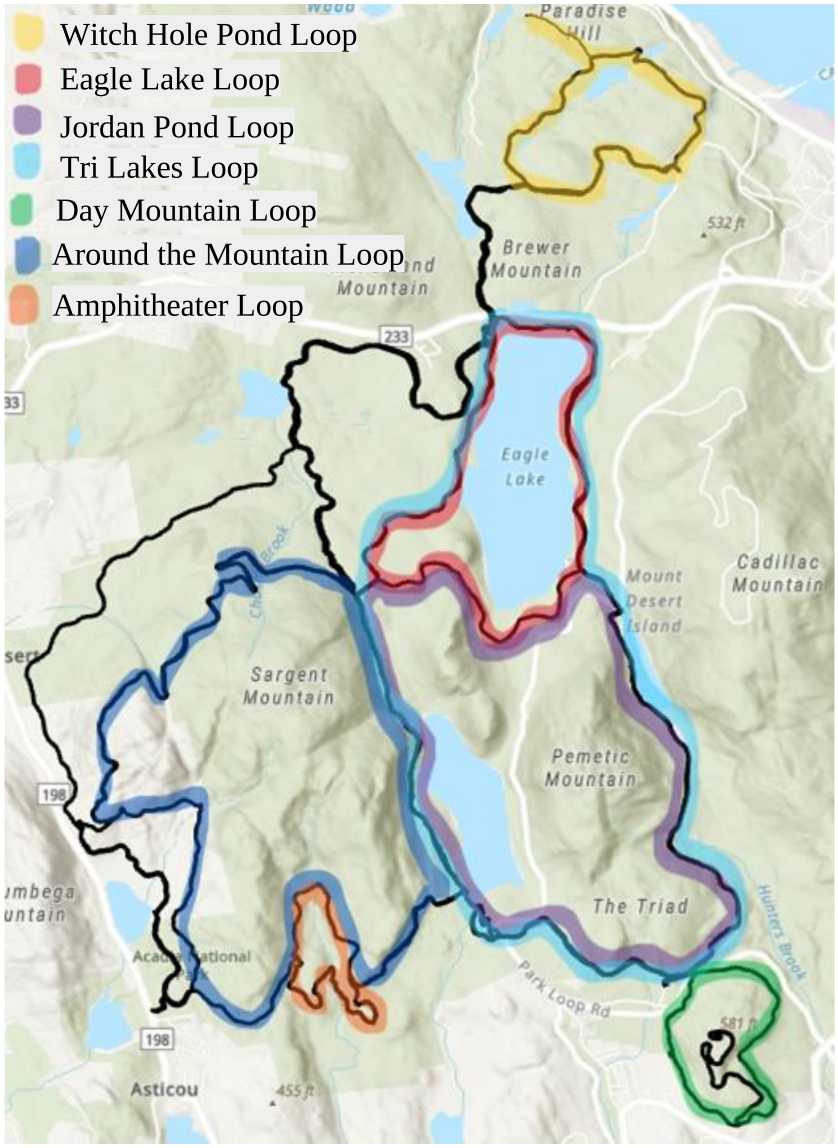


Figure B: Traditional Bike Heat Map

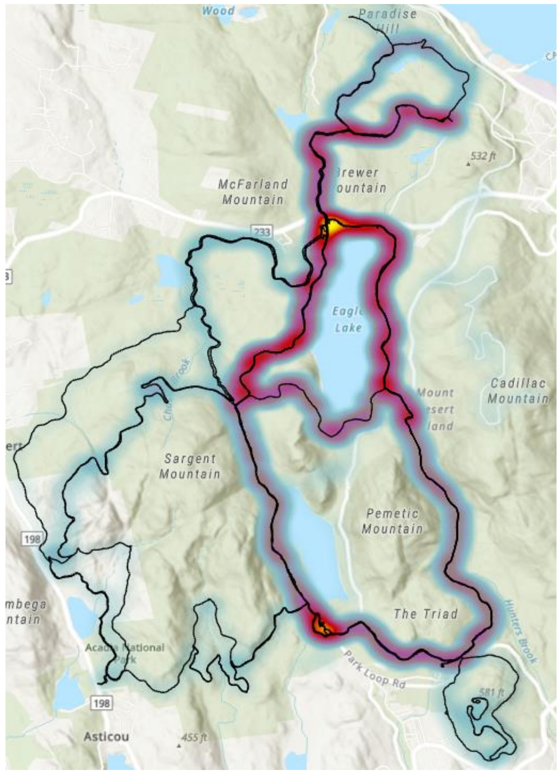
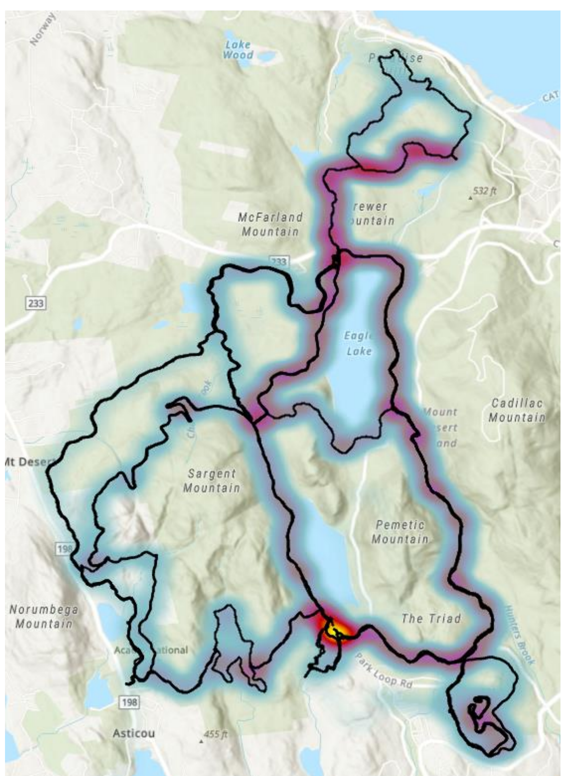


Figure C: eBike Heat Map



These findings guided us to conclusions that we formulated into recommendations for the park and future research groups.

1. Investigate the Around the Mountain, Amphitheater and Day Mountain Loops for increased wear
    - eBikes brought new attention to the Around the Mountain, Amphitheater and Day Mountain Loops
    - Acadia National Park should utilize this data to improve maintenance plans
2. Verify that the permanent automated counter works with our regression equation
    - Update regression model after gathering more data points
3. Investigate the carrying capacity of the Carriage Roads
    - Determine whether the Carriage Roads are overcrowded, to the point of affecting safety and visitor experience.
4. Continue monitoring the percentage of eBikes vs. traditional bikes on the Carriage Roads
    - Gather more data points in the following years
    - Predict the future trend of eBikes on the Carriage Roads

The number of visitors to Acadia will likely continue to increase in the following years. The heat maps and distance information has brought up more specific eBike questions. For example, does the increased weight and tread impact the Carriage Roads? This work has provided an even stronger baseline for future research and has supplied enough data to expand into more specific research. The tools and methods established during our research will help the park combat this increase and make the Carriage Roads a safe and enjoyable experience for all users.

Acknowledgments

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1.0 Introduction

Every year, visitation to National Parks have drastically increased. From 2009 to 2019, the number of yearly visitors at the National Parks has risen by nearly 42 million (U.S. Department of the Interior, 2022 e). This increase created overcrowding issues and detracts from the visitor experience. However, through data collection and analysis, parks can develop better management strategies. Having a greater comprehension of user groups can greatly improve the quality of the park. In 2019 Interior Secretary David Bernhardt announced that eBikes would be allowed the same access as traditional bikes on the trails in the National Park System (Repanshek, 2019). Since this announcement, eBikes have become the newest user group parks must manage.

For National Parks, the main user groups to examine include pedestrians, hikers, motorists, traditional bike riders and eBike riders. Each user group presents different challenges when managing parks. Typically, more motorists introduce road congestion and parking issues, while pedestrians and hikers tend to congest trails. eBikes presented a new issue at most National Parks since they were a fairly new technology and forced on some parks in 2019 with government mandates.

With 4 million visitors in 2021, Acadia National Park was listed in the top 25 most popular National Parks (U.S. Department of the Interior, 2022 d). The park's popularity has grown by more than 50% from 2019 to 2021 (Schreiber, 2021). The Acadia National Park Service (NPS) has struggled with the increase in visitation, in particular on the Carriage Roads. These trails are one of Acadia National Park’s main historic attractions, guaranteeing a large number of visitors in this area. Over the years, many studies have been done on the Carriage Roads to better understand visitor usage. As the trail usage changed, it was necessary to repeat these studies to update the information. There was a specific need to examine the new and growing eBike population on the Carriage Roads.

The goal of the Worcester Polytechnic Institute’s (WPI) Acadia 2022 eBikes group was to identify and predict population trends of the Carriage Roads, with a focus on the eBike user group. We have established a system to continuously provide Acadia NPS with accurate visitor rates. Our team also gathered data on eBike usage. We specifically examined the mobility patterns and ratio of eBikes to traditional bikes on the Carriage Roads.

2.0 Background

The following background sections described relevant information to conduct a study of the population of Acadia National Park's Carriage Roads. This section discusses Acadia National Park, the Carriage Roads, population issues and eBikes. Instruments pertinent to the project include data loggers, a permanent automated counter and Streetlight Data. Finally, summaries of past studies of the Carriage Roads are provided.

2.1 Acadia National Park

Acadia National Park, established in 1919, was the first National Park created east of the Mississippi River (U.S. Department of the Interior, 2018). The foundation of Acadia began with reservation groups formed by several wealthy landowners. These groups worked to build trails, hold cultural events as well as prevent the villages from falling into disrepair. As their efforts continued, they began gaining support from full-time residents(U.S. Department of the Interior, 2022 b).

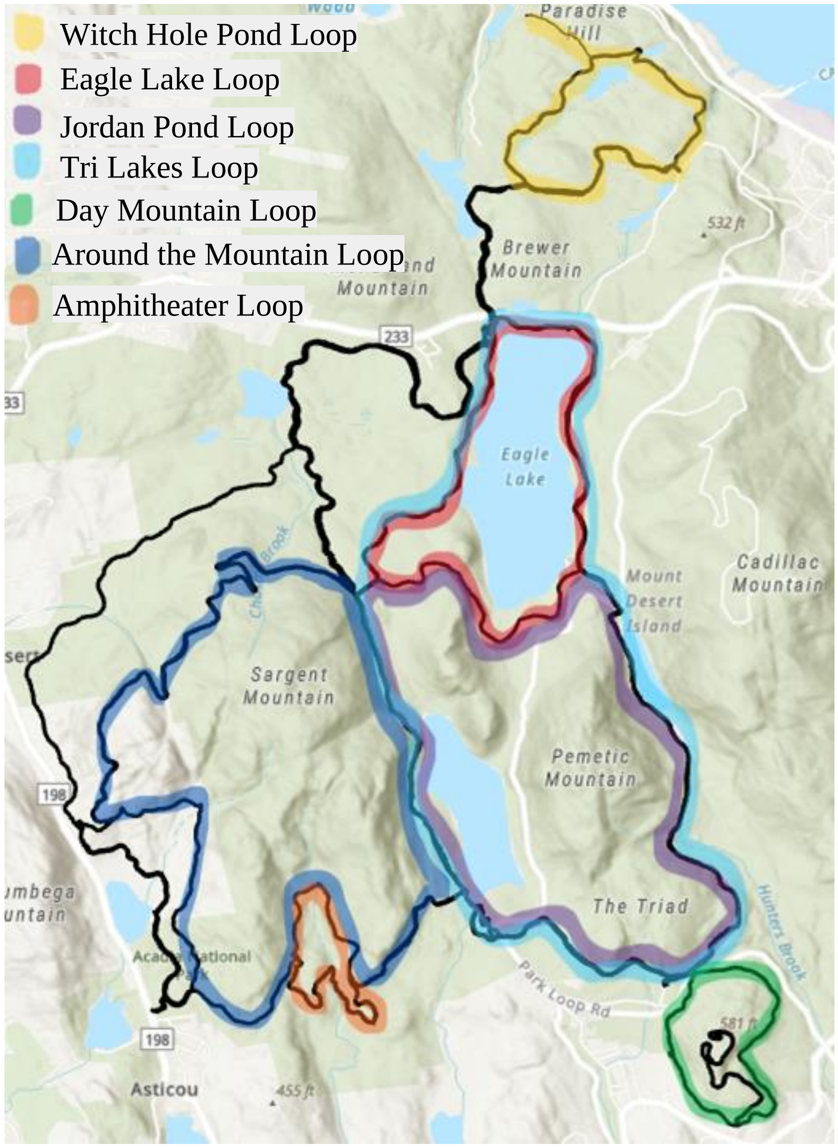
Throughout its history, the popularity of Acadia National Park has continued to grow. Over the past 7 years, Acadia has seen an increase of 1.2 million visitors (U.S. Department of the Interior, 2021 b). This escalation put more wear on the park. In turn, more care was required to combat the increase in visitors. Acadia received some of that care from groups outside the government.

A group called the Friends of Acadia, a local nonprofit organization that helps maintain the park has been supporting Acadia since 1986. They are committed to aiding the park with maintenance to protect the outstanding natural beauty, ecological vitality, and cultural distinctiveness of Acadia (U.S. Department of the Interior, 2021 a). Their active support was instrumental in organizing efforts to preserve the integrity of the park. One aspect of the park they help maintain is the Carriage Roads, a prominent attraction of the park (Friends of Acadia, 2022).

2.2 Acadia's Historic Carriage Roads

Acadia National Park's historic Carriage Roads have been a notable feature of the region since their construction in 1913. The Carriage Roads are forty-five miles of historic broken stone roads and scenic views (U.S. Department of the Interior, 2021 a). They have been a major feature of the park since their restoration in the 1990s (Friends of Acadia, 2022). These trails allow access to pedestrians, horses, bicycles and electric bikes (U.S. Department of the Interior, 2021 a). Carriage Roads consist of many loops and connecting trails as exhibited below in figure 1. Some scenic locations accessible from the Carriage Road loops include Eagle Lake and Jordan Pond. Over the years, these popular areas within the Carriage Roads have experienced an increased number of visitors (Jacobi, 2015).

Figure 1: Map of Carriage Road Loops



2.3 Population Problems at Acadia

Overall, National Parks have been dealing with overpopulation and crowding issues caused by a significant uptick in visitation. At Acadia National Park specifically, there have been groups working to analyze the population of the Carriage Roads dating back as early as 1995 (Jacobi, 2016). To combat the overcrowding issue, many National Parks have been working to set up reservation systems to protect both visitor experience and the environment of popular locations. At Acadia specifically, NPS has recently implemented a vehicle reservation system on Cadillac Mountain. According to the park's superintendent, the park has been happy with the success of the reservation system (Schreiber, 2021).

Despite recent success with the reservation system, several issues related to the popularity of Acadia National Park remain. The open borders of the park are a major contributing factor to this issue. There is no controlled point of entry for the park, making it impossible to properly count the number of people in the park on any given day. The same issue applies to the Carriage Roads. The expansive and intertwining nature of the roads presente major difficulty in gathering an accurate count of people. The recent introduction of eBikes to the Carriage Roads added to the difficulty of accurately counting people.

2.4 eBikes

Electric bikes, a relatively new group on the Carriage Roads, are an efficient alternative to traditional bikes that make it easier to travel farther (Electric Bicycles, 2020). eBikes have a motor that provides varying levels of assistance. This assistance can be accessed when the rider actively pedals or uses a throttle depending on the classification. They recently became more common, both in cities as an alternate way to commute and on trails for help getting up hills. The 2019-2020 year saw a 145% gain in the number of eBike sales (Surico, 2021), while the 12 months leading up to October 2021 saw a 47% increase in revenue generation (Sorenson, 2021). Transport officials became increasingly interested in eBikes as a way to reduce congestion which could also promote future purchases of eBikes (Plazier, 2017). To better regulate eBike usage, most states recognized the following classifications for eBikes.

> Class 1: eBikes that are pedal-assist only, with no throttle, and have a maximum assisted speed of 20 mph.
>
> Class 2: eBikes that also have a maximum speed of 20 mph, but are throttle-assisted
>
> Class 3: eBikes that are pedal-assist only, with no throttle, and a maximum assisted speed of 28 mph (Repanshek, 2019).

As their popularity increases, more policies need to be enacted to help them integrate with other modes of transportation.

2.5 eBike Usage

One component that made transportation methods difficult to monitor was the new addition of eBikes. eBikes had only been allowed the same access to National Parks as traditional bikes for three years. According to the Senior Vice President of Government Affairs at the National Parks Conservation Association (NPCA), a large part of implementing the eBike policy in the National Park System was to improve the public's experiences while visiting a park. However, the implementation of this policy was rushed, with Interior Secretary David Bernhardt giving parks just 30 days to create an eBike policy. Initially, in response to this policy, the staff at Acadia National Park decided "motorized bikes couldn't travel the park's iconic Carriage Roads" with a potential fine of $130 (Repanshek, 2019). Eventually, in September of 2019, the park updated its policy to allow class one eBikes on the Carriage Roads (Acadia National Park 2019).

Since the revised policy, eBikes were allowed into Acadia National Park. Because of eBikes' new appearance in the park, Acadia officials want to know how visitors are using them. Understanding where eBike users were going provided a more complete picture of the eBike population.

2.6 Permanent Automated Counter

Acadia National Park recently purchased a permanent automated counter. Once installed, the counter will monitor visitors passing through one of the trails on the Carriage Roads. The model of counter the park has purchased (an Eco-Counter) uses a pair of sensors to count pedestrians, cyclists, horses and all-terrain vehicles. It can distinguish between these groups as well as which direction individuals are traveling.

2.7 Streetlight Data

Streetlight Data is a company that can "measure vehicle transit, bike, and foot traffic" (Transportation Analytics On Demand, 2022). The information provided can determine general behaviors in regard to the types of transit. Due to the nature of collecting the data, this was not accurate for determining the actual numbers of people. The data was collected through cell phone pings, only counting individuals with cell service. However, the data was useful for generating comparisons between groups (Transportation Analytics On Demand, 2022).

2.8 Past Studies of Carriage Road User Groups

In the late 1990s, there was a major research project aimed at estimating the population on the Carriage Roads (Jacobi, 2016). The project's intent was to create a standard for crowding on the Carriage Roads. As part of the research, there was an effort to model the Carriage Road use so that park personnel could estimate the population. A specific mathematical equation, known as regression, was employed to estimate crowding on the trails. The regression equation was used to take data from an electronic counter at a fixed location, then estimate the total population on the trails. To formulate the equation, an in-person census was conducted with ten people spread across the Carriage Roads, as seen in figure 2. This count provided values for the total population and showed how that population was distributed. They also installed an automated counter on the west side of Eagle Lake, as seen in figure 3. The goal was to compare the distribution of the total population with the results from the automated counter. These results were then compared to create the mathematical model. This equation has been adjusted throughout the 2000s, with the most recent update in 2015.

In addition to estimating the total population of the Carriage Roads, the 2015 study described the carrying capacity of the Carriage Roads. It stated the carrying capacity was violated after a 3,000-visitor limit was exceeded 15 times during the 150-days between May 15th and October 15th. The model used to estimate the total population was used in conjunction with this carrying capacity to monitor the use of the Carriage Roads (Jacobi, 2016).

Figure 2: Jacobi's Counting Locations

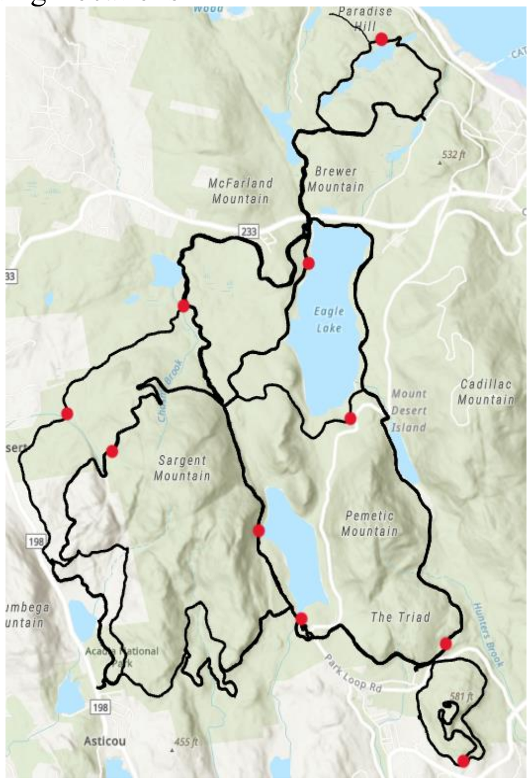
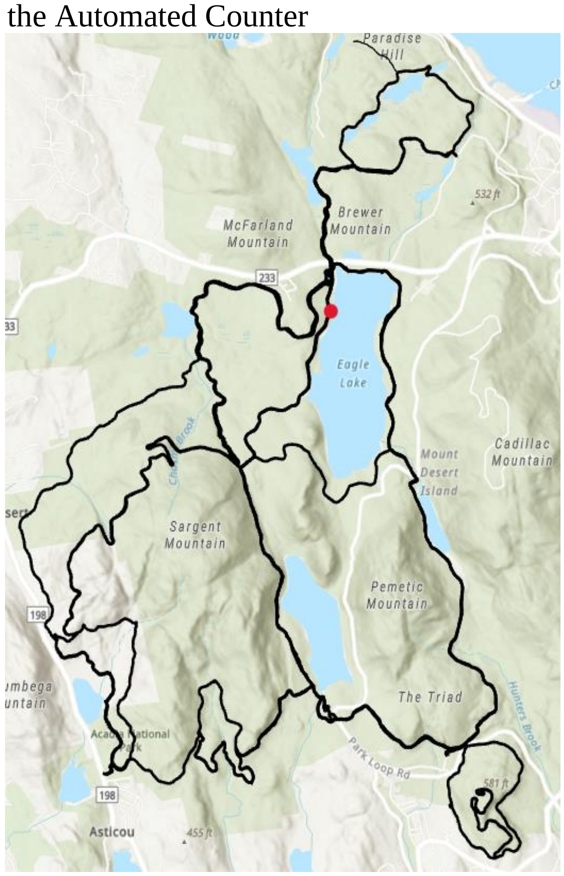


Figure 3: Placement of the Automated Counter



2.9 Past WPI eBike Research

WPI IQP teams have conducted studies on eBikes for the past three years. In 2020 the focus was on the emergence of eBikes on the Carriage Roads and how their behavior related to traditional bike users. The 2021 project used Streetlight Data to analyze the percentage of people traveling through a given location. These past studies can be used to create trends on the changing eBike population specific to the Carriage Roads. The 2021 group also handed out and collected data loggers from eBike users during their rides. Data loggers are devices with multiple sensors designed to track and gather GPS and motion data. They used this data to look at speeding, specifically down hills to see if there were differences in the safety of eBikes compared with traditional bikes.

Acadia's increase in popularity, along with the acquisition of the permanent automated counter, created a need for a more recent comparison of these past studies to current data. Furthermore, the addition of eBikes to the Carriage Roads presented a new group that should be accounted for in further research into the population of the roads.

3.0 Methodology

The methodology describes the procedure for gathering and examining information needed to understand the population of the Carriage Roads. Information has been collected on both the behavior of user groups as well as the daily population of visitors. This data was gathered by breaking down the research into the following process:

1. Estimate the daily population on the Carriage Roads.
2. Determine the percentage of eBikes compared to traditional bikes on the Carriage Roads.
3. Compare the mobility patterns of eBikes to those of traditional bikes.

These objectives will provide valuable information on the Carriage Roads users. The information provided to Acadia National Park will help them manage the Carriage Roads more effectively.

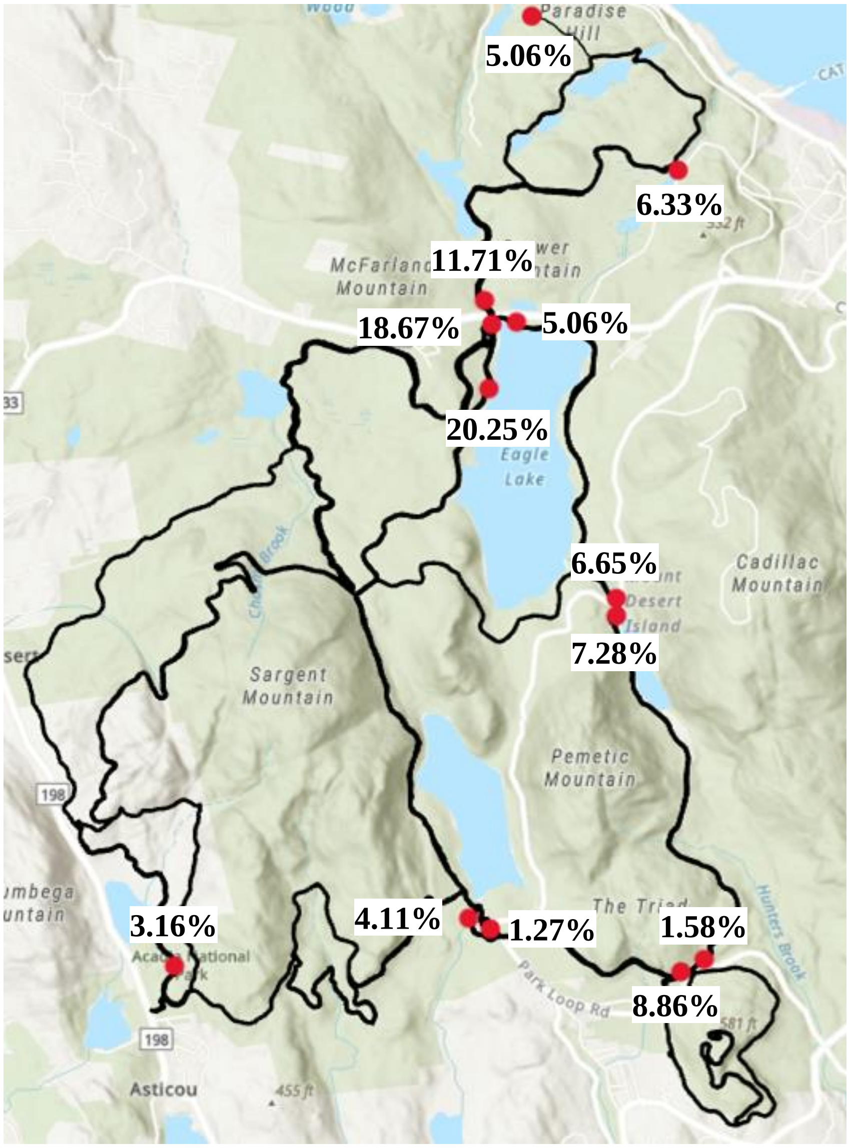
3.1 Regression

To better understand the total population on the Carriage Roads, our team set out to remake and improve the equation previously used to estimate the population. Acadia intends to install a permanent automated counter on the west side of Eagle Lake. This would be the same location as the automated counter from the previous Jacobi studies. We placed a temporary trail camera at the same location to simulate the automated counter. The camera was set up to take pictures when a pedestrian or cyclist passed in front of it. The images were periodically collected and manually counted.

We interpreted the images similar to how the permanent automated counter would record people passing by it. This was done so that the park can still utilize our research once the counter is installed. For pedestrians, we counted all individuals who walked by the trail camera in either direction with two exceptions: If the individual was a child in a stroller or a child being carried by a parent, they were not counted. For cyclists, we counted them when a singular bike frame went by in either direction. For example, if the bike was a tandem bike or had a trailer behind it was still counted as one bike. In the event an individual was walking a bike past the camera, they were counted as a bike. eBikes and traditional bikes were tallied together because the counter cannot distinguish between the two.

Using Streetlight Data, we were able to examine the daily total population on the Carriage Roads without requiring the manpower of an in-person census. We selected 13 locations on the Carriage Roads to record percent distributions from Streetlight Data. Figure 4 below shows an example map that demonstrates what one percent distribution looked like. Many versions of these distributions were required to create an accurate regression equation. Most of the 13 locations selected were near entrances to the Carriage Roads. The exception was the inclusion of the trail camera location. Using the numbers acquired from the trail camera and the distribution from the 13 percentages, we were able to create estimates of the population on the Carriage Roads.

Figure 4: Percent Distributions



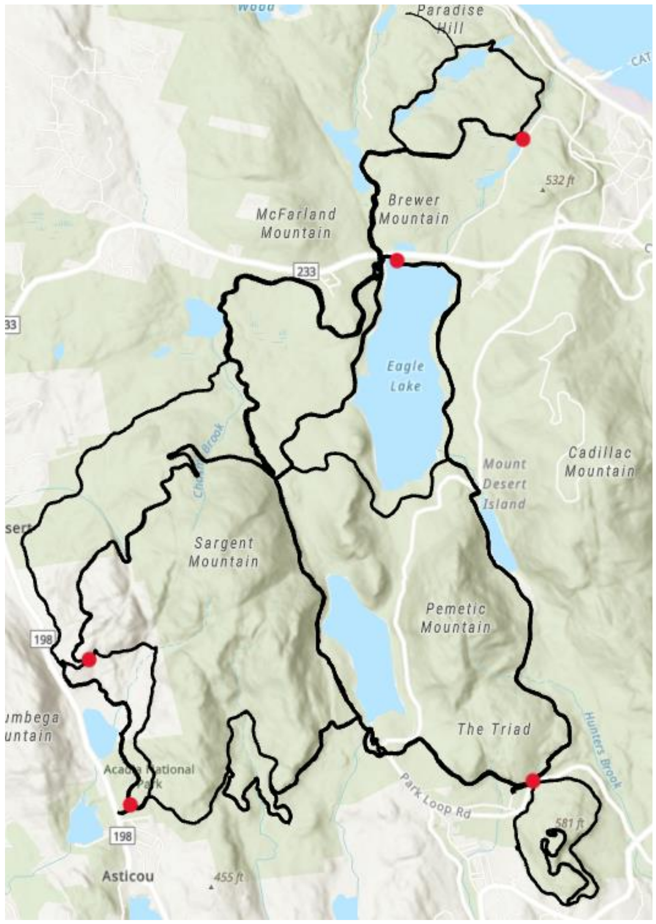
By repeating this process multiple times, a scatter plot was made from the points generated which can be seen in Appendix D. This graph provided a basis for the derivation of the regression equation. The regression equation is essentially a line of best fit or trendline generated from the scatter plot. It takes a count from the trail camera location as the input and then outputs the estimation for the total population of the Carriage Roads.

3.2 Counting eBikes and Traditional Bikes on the Carriage Roads

To accurately assess the ratio of traditional bikes to eBikes on the Carriage Roads a visual count was performed. Counts were tracked with a mobile application meant to log tallies. The counts were conducted at the following locations: the Duck Brook Bridge, the Eagle Lake boat launch, the Hadlock Loop parking lots and the Triad-Day Mountain Bridge. Figure 5 displays these locations. Most of our data came from the Duck Brook and Eagle Lake locations because they allowed us to optimize data collection and gather from a favorable sample size. The

Hadlock and Day Mountain areas were initially chosen to cover a more diverse selection of the Carriage Roads. However, counting did not occur at these locations during the latter half of our study. Those locations did not provide a large enough sample size to be significant within the scope of the project.

Figure 5: Our bike counting locations



When counting, we classified cyclists as either eBikes or traditional bikes. Our concern was not with the number of people for this count. Therefore, tandem bikes and bikes towing a trailer containing children were counted as a singular bike. Based on our knowledge of the difference between traditional bikes and eBikes, they were visually distinguished by the person counting. Figures 6 and 7 below show the difference in the appearance of eBikes and traditional bikes. Figure 6 depicts an eBike that has a significantly larger crossbar containing the battery. We recognize that there may be some error in the ability to make this distinction, however, we assumed the potential error was insignificant.

Figure 6: eBike (Pedego, n.d.)

Figure 7: Traditional Bike

For the Hadlock parking lots and the Duck Brook Bridge, we counted individuals as they left the site to prevent as many double-counted riders as possible. The count at the Eagle Lake boat launch included bike traffic in both directions. The counting occurred during the following shifts: 9:00 am to 12:00 pm and 12:00 pm to 3:00 pm. This resulted in separate counts for the morning and afternoon. These numbers were summed together to give us a total count of eBikes and traditional bikes. The percentage of eBikes versus traditional bikes was then derived from these numbers.

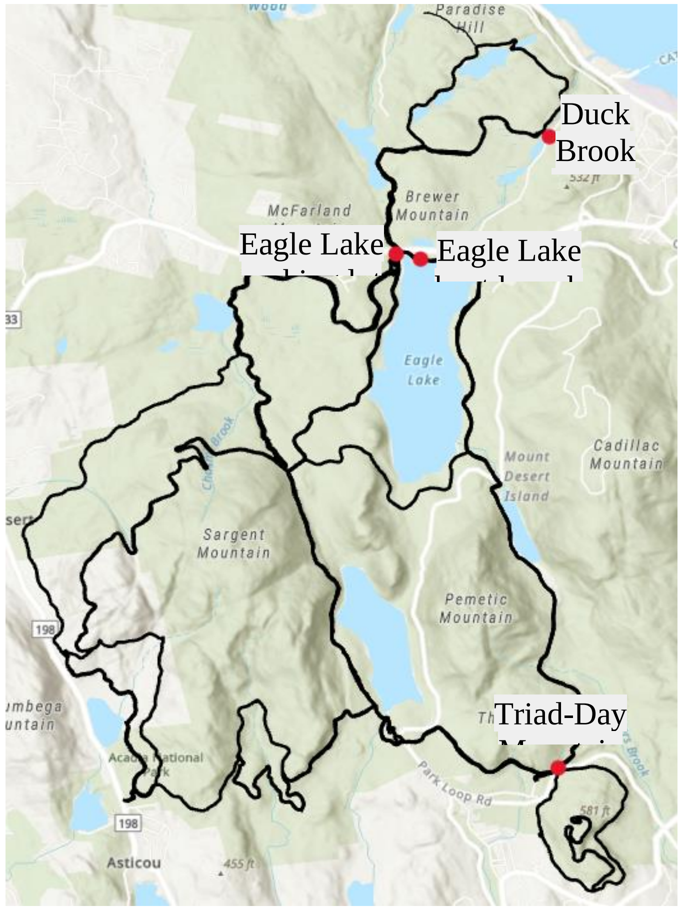
3.3 Data Loggers

To determine where bikes are traveling on the Carriage Roads, we handed out data loggers to both eBike and traditional bike riders. Figure 8 shows a data logger which is roughly two inches in length. We configured the data logger to record its GPS location at one-second intervals. The GPS coordinates recorded can be processed to gather information such as average speed, top speed, elevation, time of ride, route taken and distance traveled. This information was used to compare the trips of cyclists.

Figure 8: Data Logger

We distributed the data loggers at four distinct locations: the Duck Brook Bridge; the Eagle Lake boat launch; the Eagle Lake parking lot; and the Triad-Day Mountain Bridge. Figure 9 shows where we were stationed.

Figure 9: Map of Data Logger Distribution Locations



We chose these locations through informal interviews, observation and the need for a broad scope of the Carriage Roads. The Duck Brook Bridge was chosen because it was the most direct route from Bar Harbor to the Carriage Roads, and most rental companies recommend this route. The second location, Eagle Lake boat launch, was a high-traffic section with a parking lot, an Island Explorer (a bus service) stop and two gates that funnel traffic. Our third location was near the entrance to the Eagle Lake Loop where people tend to stop and plan their rides. We found this area to be good for handing out data loggers and conducting surveys. The Triad-Day Mountain Bridge was chosen to isolate the speed and elevation relationship for both cyclist groups. However, our software was unable to extract these comparisons.

We waited at the distribution sites until all data loggers were collected to reduce the responsibility on users and reduce the likelihood of losing data loggers. In the event the data logger was not handed back, they were in pre-addressed envelopes to make the return process straightforward.

Once the data loggers were returned, the information on the data loggers would be downloaded, compiled and analyzed. Files were evaluated using softwares called Canway and Garmin BaseCamp to extract specific data from rides and compare them. Examples of both softwares can be seen below in figures 10 and 11.

Figure 10: Canway Software

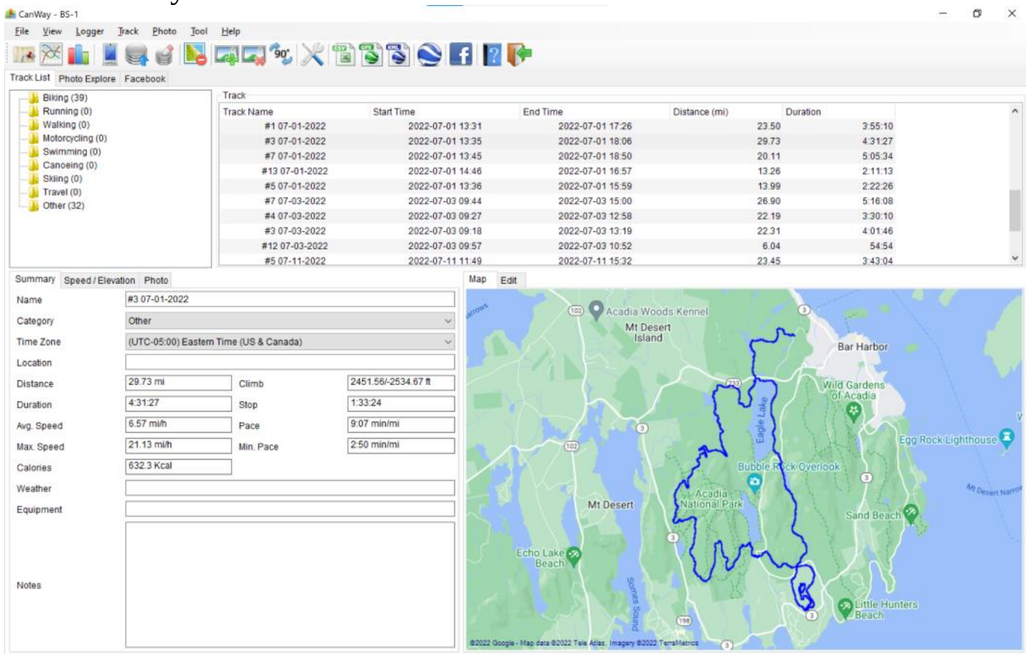
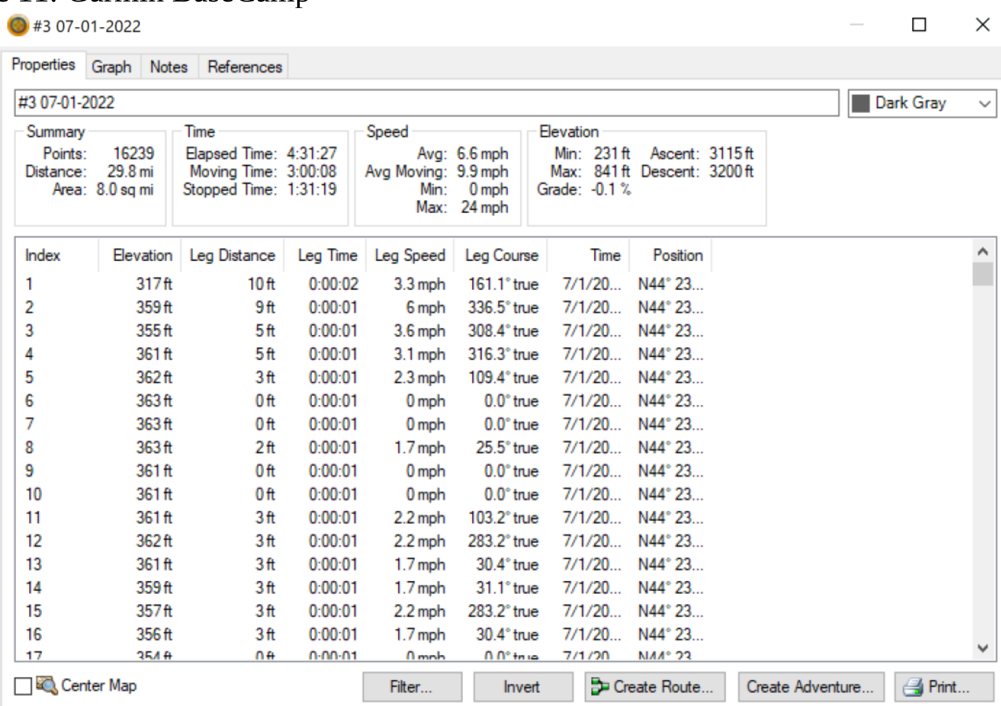


Figure 11: Garmin BaseCamp



3.4 Surveys

Carriage Road user experience was assessed via survey. Appendix A shows the survey script used in the field. The responses were used to bolster information collected from data loggers and in conjunction with cyclist ratios to help make predictions. For example, the surveyed perceptions of eBike speeds were compared to the actual speeds of eBikes to see if eBikes and traditional bikes should have the same policies.

3.5 Ethics

This project was conducted under the advice of WPI. All information gathered from surveys, data loggers and other sources is anonymous and confidential unless stated otherwise. Participants were allowed to skip any questions they did not wish to answer. The opinions shared were our own and do not reflect those of WPI. All information gathered was used for research purposes as part of our Interactive Qualifying Project.

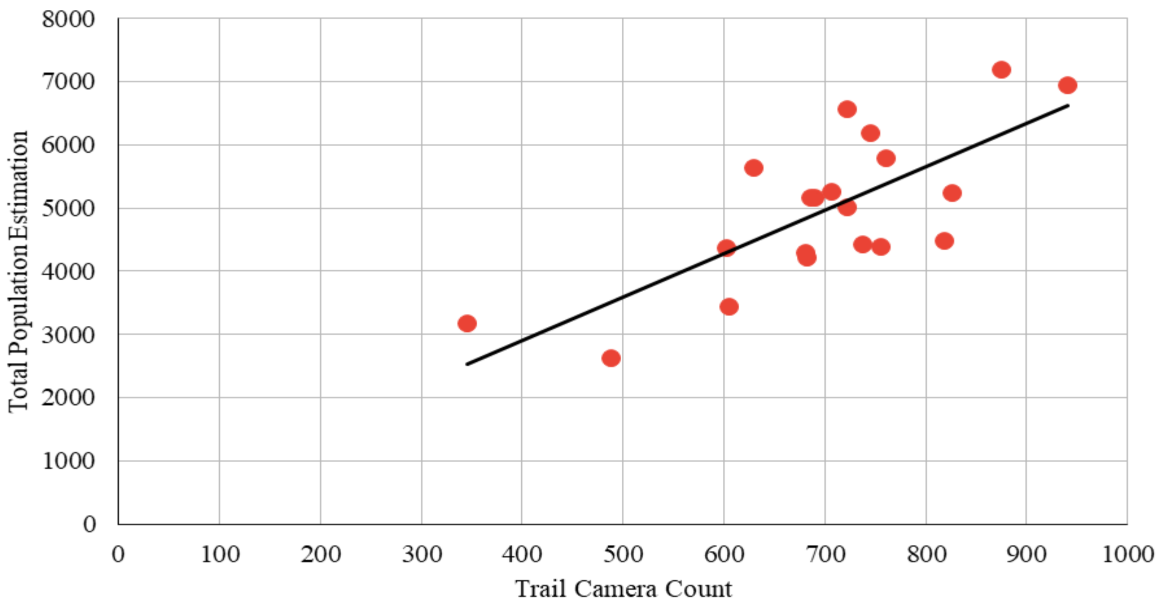
4.0 Findings and Discussion

This section discusses what we derived from our methods. These include the regression analysis, ratio of bikes, mileage of bike rides, ride duration and bike speeds. Building from that data, our team will go over our findings and discussions.

4.1: Our regression model can estimate the population on the Carriage Roads

The count from the trail camera and Streetlight Data were combined to create an accurate regression model. Figure 12 below shows the regression model of our data. Our data points are shown in red while the black line is the trendline used to make the estimations. The regression equation we constructed had a slope of 6.89 and a y-intercept of 146.77. While our r^2 value of 0.56 was not particularly high, our regression equation was still proven accurate by the F statistic. The F statistic derived from the equation was 0.0117.

Figure 12: Scatter Plot with Trendline of 2022 Data



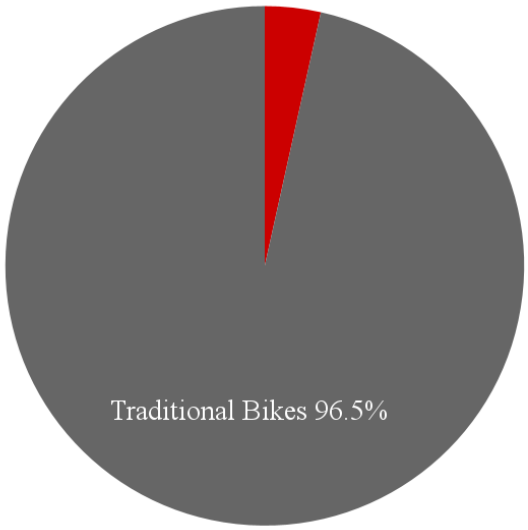
The equation is most accurate when counts from the trail camera fall between the lowest and highest volume days recorded. The confidence interval will widen if you stray from this range. Meaning that estimation for values outside the range of our data will be less accurate. We had no counts that were under 300 people, therefore estimations based on counts lower than this will be less accurate.

The data points created using the trail camera, in conjunction with the big-data, demonstrate that the carrying capacity established by Jacobi has been violated. On 19 of the 20 days the trail camera recorded, the estimated population on the Carriage Roads exceeded 3,000. This surpassed the 15-day allowance provided in the carrying capacity. Based on this, the population on the Carriage Roads has reached a point of concern.

4.2: eBikes make up 21.9% of all bikes on the Carriage Roads

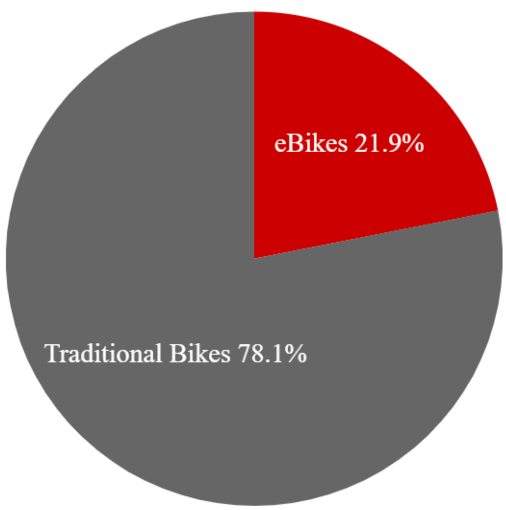
We conducted a manual count that can be used to find the percent of bikes on the Carriage Roads that are electric. This count was broken up into two sections: eBikes and traditional bikes. The 2020 eBike IQP team created a baseline for the ratio of eBikes to traditional bikes through their research. They found that of 3,310 bikes recorded, only 3.5% were eBikes, as seen in figure 13.

Figure 13: eBikes vs. Traditional Bikes 2020



Our team in 2022 recorded 7,597 bikes, with 21.9% of them being eBikes, as shown in figure 14. This is an increase of 18.4 percentage points in just two years.

Figure 14: eBikes vs. Traditional Bikes 2022



Rental companies in Bar Harbor have been expanding their inventory of eBikes. Acadia Bikes began renting eBikes in 2020, but 2022 was their first year with a significant inventory of 24 eBikes (G. Tucker, personal communication, July 20, 2022). Pedego Bar Harbor had a similar story with an addition of ten eBikes this year (S. Dunbar, personal communication, July 18, 2022).

One of the questions on our survey was “would you ride an eBike here in the future?” 79.8% of the 89 respondents said they would. Based on the results of the manual count, the rental shops increased inventory, and the interest in riding eBikes on the Carriage Roads in the future, we believe the percentage of eBikes on the Carriage Roads will continue to increase.

4.3: eBike riders traveled more miles and stayed on the Carriage Roads longer than traditional bike riders

To further recognize the impact of eBikes on the Carriage Roads, it was important to know where the eBikes are regularly traveling. Understanding how the Carriage Roads were being utilized was important to maintain such a large space. Heat maps, as seen in figures 15 and 16, were created from the data logger information. They show the heavily trafficked areas for both types of bikes.

Figure 15: Traditional Bike Heat Map

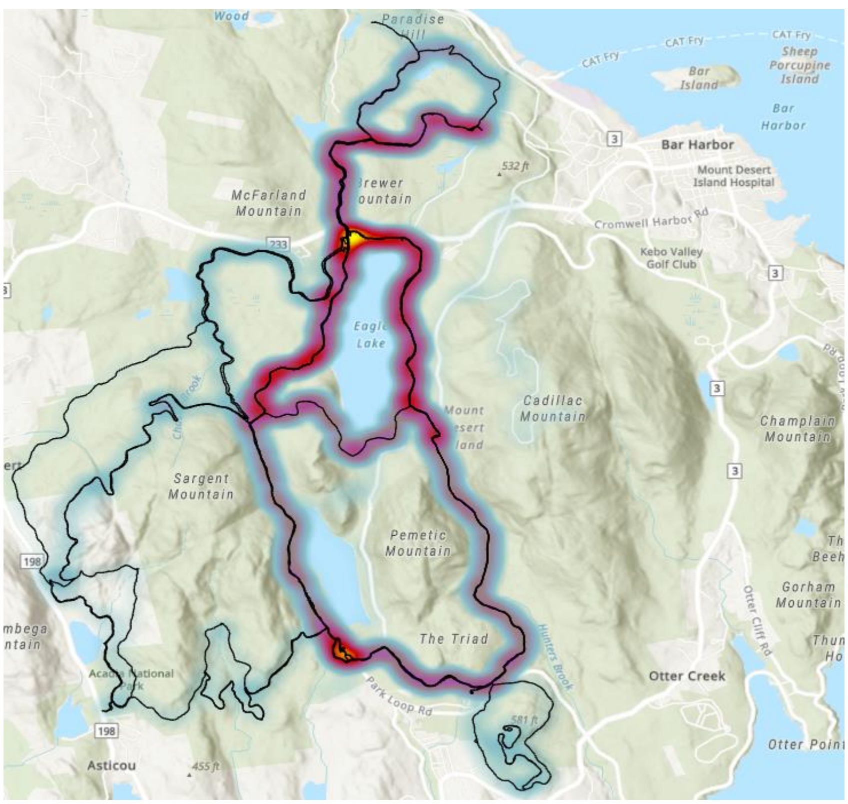
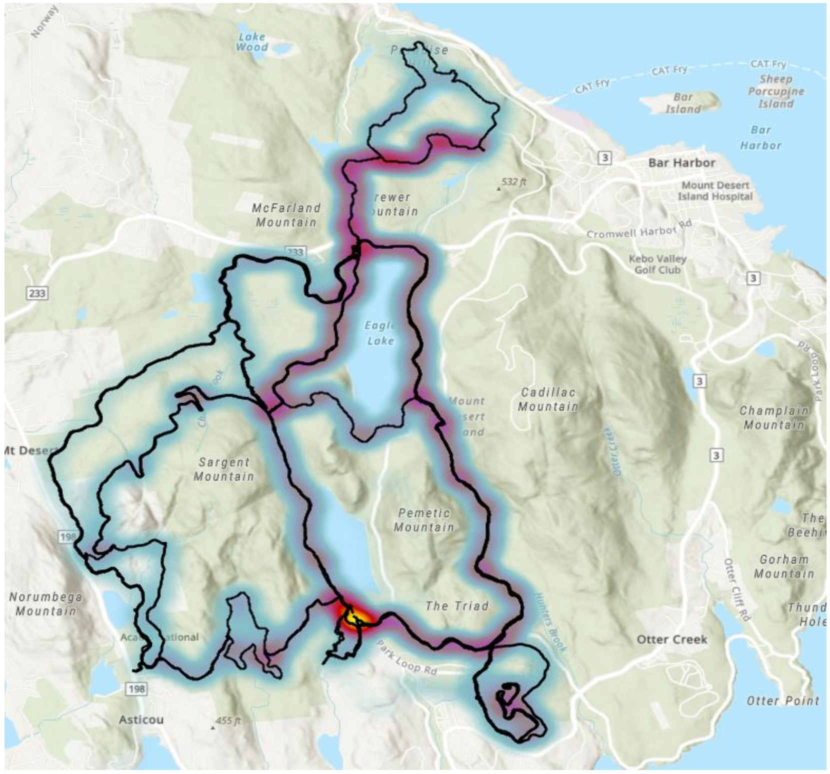


Figure 16: eBike Heat Map



The areas in red are more heavily traveled sections, while sections in blue are traveled less. eBikes and traditional bikes shared many similar paths on the Carriage Roads, but also favored different sections while traveling on them. Both groups frequented the Witch Hole Pond Loop, the Eagle Lake Loop, the Jordan Pond Loop and the Tri-Lakes Loop, as outlined in figure 1. Most traditional bikes remained within loops closer to main entrances shown in figure 15. eBikes often traveled in more remote sections with higher elevations such as the Around the Mountain Loop, the Amphitheater Loop and the Day Mountain Loop, as seen in figure 16. Traditional bikes traveled these routes, but with less frequency than eBikes did.

Supporting the information our heat maps present, we found eBikes had a greater total mileage than traditional bikes. Figure 17 shows that traditional bikes traveled 12.0 miles on average. eBikes traveled 19.6 miles, extending the range by 63.3%. In addition to the total mileage, eBikes are staying out on the Carriage Roads longer. Figure 18 shows that traditional bikes spent an average of 2 hours and 36 minutes on the Roads, whereas eBikes averaged 3 hours and 23 minutes, an increase of 30.3%.

Figure 17: Average Mileage of eBikes vs. Traditional Bikes on the Carriage Roads

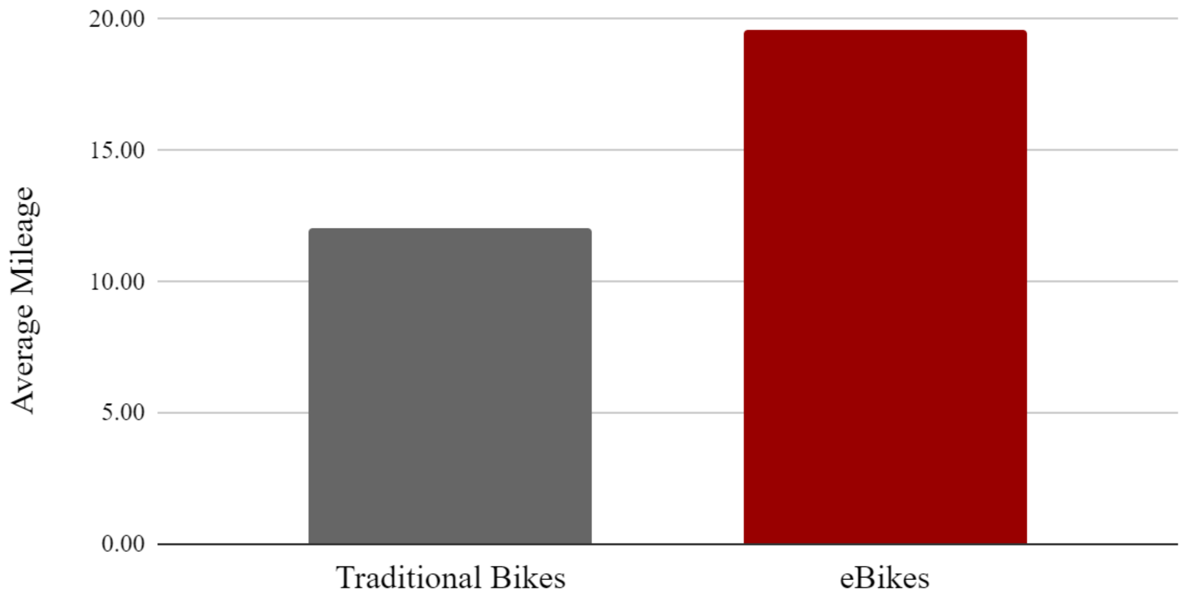
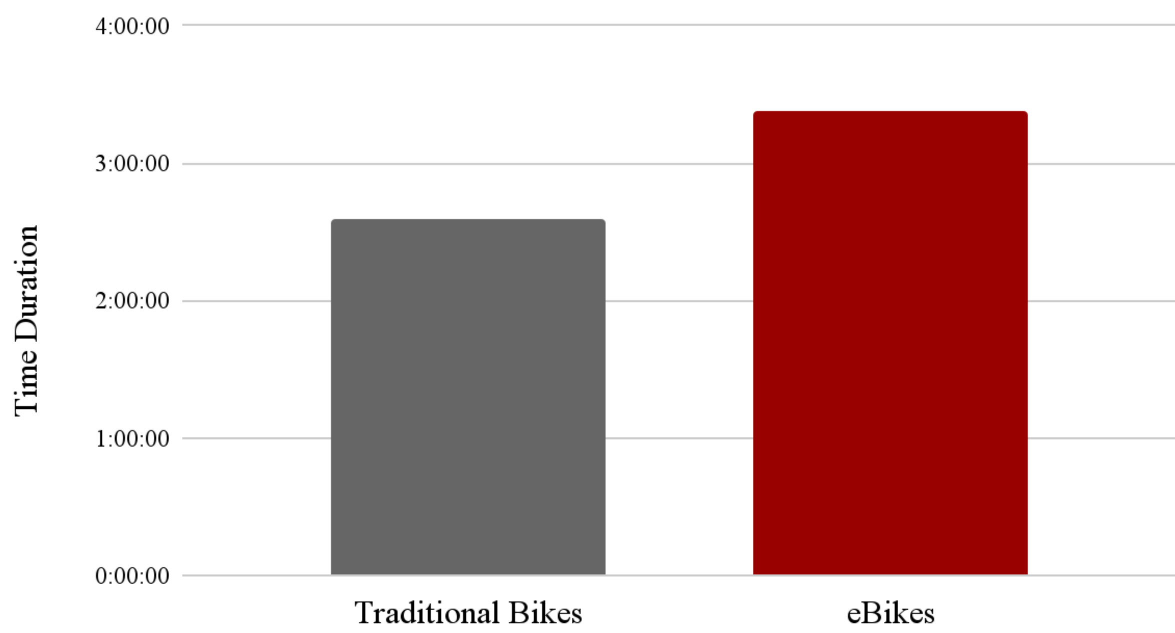


Figure 18: Time Duration of eBikes vs. Traditional Bikes on the Carriage Roads



Because eBike riders stay on trails longer and travel significantly farther, we expect more bikes to be on the Carriage Roads at one time. This will impact the carrying capacity and in turn affect the visitor experience.

eBikes also had an average moving speed significantly higher than that of traditional bikes. We eliminated the time the rider spent stationary by looking at the average moving speed instead of the average speed. The average moving speed of traditional bikes was 7.59 whereas eBikes averaged 9.23. This leaves a difference of 1.64 mph, shown in figure 19. We suspect this difference was attributed to eBike riders traveling faster uphills. The average top speeds of the two groups were nearly identical, with a 0.88 mph difference between the two, as seen in figure 20.

Figure 19: Average Moving Speed of eBikes vs. Traditional Bikes on the Carriage Roads

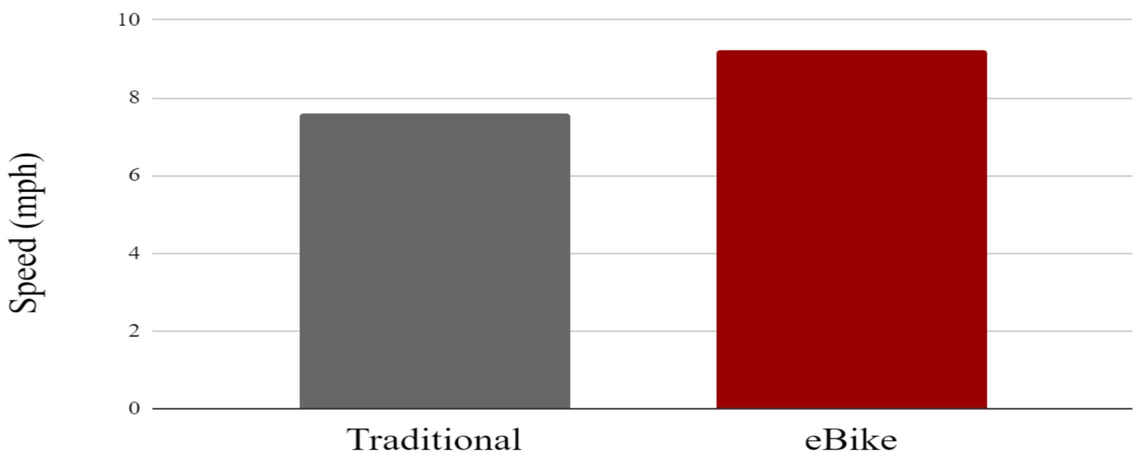
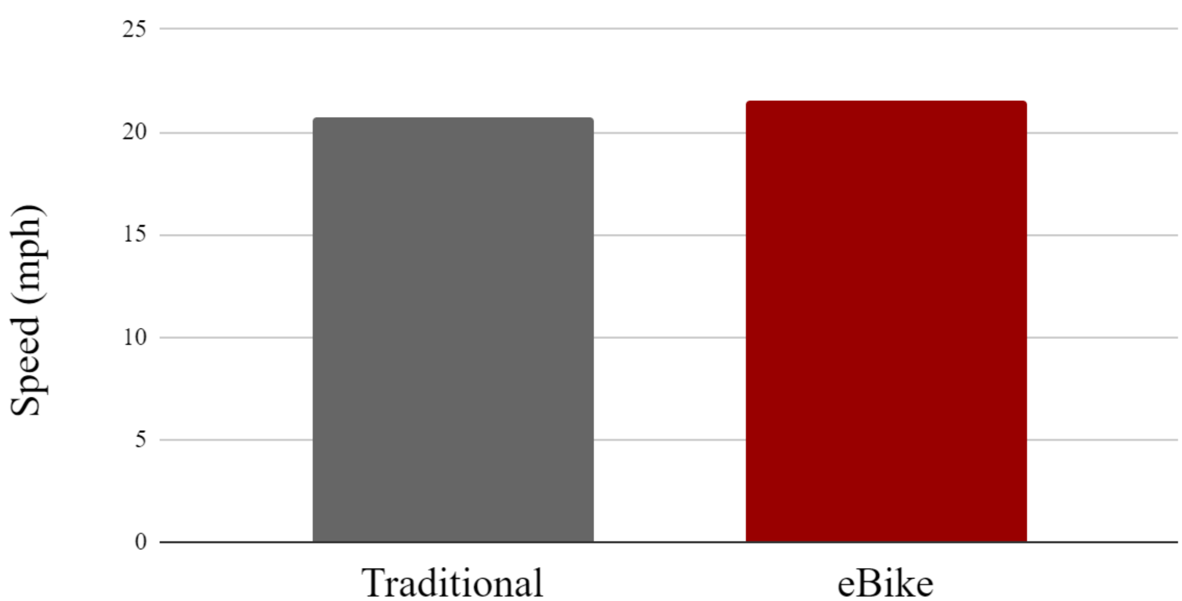


Figure 20: Average Top Speed of eBike vs. Traditional Bikes on the Carriage Roads



On top of this, the survey result shows that when assessing the safety perception of eBikes, there was no significant difference when compared to traditional bikes. Due to this, we concluded that eBikes and traditional bikes should be treated the same when creating policies.

5.0 Recommendations

After a thorough analysis of this information, we established several recommendations. These recommendations shall provide insight to Acadia National Park on how to monitor and maintain the Carriage Roads. They will also inform future research teams on which aspects of the Carriage Roads to focus on.

5.1: Investigate the Around the Mountain, Amphitheater and Day Mountain Loops for increased wear

Our analysis of the heat maps, the mileage and time data, as well as the increase in eBike proportions, showed that eBikes are on the Carriage Roads for longer and are traveling to more remote sections than traditional bikes. These remote sections include the Around the Mountain Loop, the Amphitheater Loop and the Day Mountain Loop. We recommend Acadia NPS investigate these loops for increased wear.

5.2: Verify that the permanent automated counter works well with our regression equation

Our regression equation was created to use a permanent automated counter that the park plans to install on the west side of Eagle Lake. The equation allows the park to take the number from the counter and produce an approximation of the total number of people on the Carriage Roads. To verify this process results in an accurate approximation, the park should compare the output of the equation to an in-person census.

5.3: Investigate the carrying capacity of the Carriage Roads

With the increase of visitors in Acadia, a reevaluation of the Carriage Roads' carrying capacity might be beneficial for the future. We have found that eBike users are traveling further and staying longer on the roads than traditional bike users. This will likely lead to more bikes on the roads at one time, threatening the safety of riders as well as the integrity of the roads. Additionally, we have found that the current carrying capacity has been violated. These problems would be detrimental to the visitor experience. We recommend looking into both carrying capacity and visitor experience.

5.4: Continue monitoring the percentage of eBikes vs. traditional bikes on the Carriage Roads

The ratio of eBikes versus traditional bikes from 2020 and 2022 was useful, but cannot accurately predict future eBike percentages. To properly make this prediction, more than two data points are required. We recommend that counts continue to be taken from the same locations in the following years. This will allow the park to find a trend in the percentage of eBikes on the Carriage Roads.

6.0 Conclusion

Our goal was to help Acadia National Park obtain a greater comprehension of the Carriage Road user groups, including the newest one, eBikes. To gather data, GPS trackers and surveys were distributed to eBike and traditional bike riders while simultaneously conducting counts of all user groups on the Carriage Roads. From these methods, we established an equation to estimate the daily population. Additionally, we determined the percentage of eBike users, and their general behavior when compared to traditional bikes on the Carriage Roads. Four recommendations were derived from these findings for the park and future research teams. The recommendations can be summarized as follows: investigate specific Carriage Roads loops for wear, verify and improve our regression equation, look at carrying capacity for the Carriage Roads and continue to monitor the percentage of eBikes.

The number of visitors to Acadia will likely continue to increase in the following years. Our heat maps and distance information has generated discussions of more specific eBike questions, such as whether increased weight and tread affect the Carriage Roads. We have provided an even stronger baseline for future research with enough data to expand into more specific projects. The tools and methods we established will help the park combat this increase and make the Carriage Roads safe and enjoyable for all users.

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Appendix A: Survey for Carriage Road Users

Hello, we are students from Worcester Polytechnic Institute in Massachusetts working on a research project. Our project is focused on examining how eBikes are being used on the Carriage Roads. We are looking for people to complete a survey. Would you mind helping us? This survey is confidential. Feel free to skip a question or opt-out at any time during this survey. If you would like to contact us, our team email is gr-eBikes@wpi.edu, and our project advisor's email is wpi.bianchi@gmail.com.

Date: **Time:** **:** (am) (pm) eBike traditional pedestrian
Location: Duck Brook Eagle Lake: BL Intersection Hadlock: U L Day Mt.
Age Range: Kid Teen YA MA Senior

Past use of eBikes

- Have you ridden an eBike before?
  Yes No

- Rented or own?

How eBikes impact accessibility

- On a scale from 1 to 5 (1 being inhibited and 5 being aided), how much have eBikes impacted your ability to travel?
  1 2 3 4 5
- Can you elaborate on your rating?

Speed of bikes/eBikes

- On a scale from 1 to 5 (1 being least confident and 5 being most confident), rate your confidence in your ability to distinguish between bikes and eBikes.
  1 2 3 4 5
- On a scale from 1 to 5 (1 being safe and 5 being unsafe), did you feel unsafe with the speed at which the eBikes were traveling?
  1 2 3 4 5
- On a scale from 1 to 5 (1 being safe and 5 being unsafe), did you feel unsafe with the speed at which the traditional bikes were traveling?
  1 2 3 4 5

Future use of eBikes

- Would you ride an eBike here in the future?
  Yes No
- Any particular reason?

Appendix B: Trail Camera Counts

Date	Pedestrians Counted	Bikes Counted	Total Count
06/25/2022	76	412	488
06/26/2022	116	486	602
06/27/2022	124	222	346
06/28/2022	176	764	940
06/29/2022	149	670	819
06/30/2022	181	541	722
07/03/2022	128	594	722
07/04/2022	166	524	690
07/05/2022	216	529	745
07/06/2022	214	612	826
07/07/2022	153	476	629
07/08/2022	172	510	682
07/09/2022	159	522	681
07/10/2022	159	601	760
07/11/2022	167	540	707
07/12/2022	246	629	875
07/13/2022	160	596	756
07/14/2022	114	572	686
07/15/2022	154	584	738
07/16/2022	109	496	605

Appendix C: Data Logger Data

Traditional Bike			
Time Duration (Hours:Minutes:Seconds)	Mileage	Max Speed (mph)	Avg. Moving Speed (mph)
1:38:41	3.88	18.02	5.5
1:41:55	10.93	14.29	9.2
5:46:15	19.11	22.99	6.4
3:43:02	18.41	17.4	6.2
3:14:18	19.42	19.26	7.5
3:05:18	11.86	21.75	7.7
1:11:38	6.16	19.26	6.9
1:31:20	6.09	16.16	6.3
1:24:04	6.55	21.13	6.5
0:59:06	6.04	12.43	7.4
0:46:55	5.85	21.75	9.7
0:59:45	6.1	14.91	8.4
3:22:26	13.36	21.13	6.4
6:00:12	27.45	26.72	7.3
0:44:54	6.03	21.75	11.4
0:43:00	2.93	13.05	6.6
5:15:54	12.24	15.53	4.1
2:17:22	5.52	13.05	4.1
2:22:51	20.99	25.48	11.1
1:35:13	16.64	30.45	13.6
0:15:29	1.81	18.02	7.9
1:34:59	15.32	21.13	10.8
1:14:17	5.68	21.13	7.2
4:39:27	16.3	21.13	8.3
4:55:59	12.16	29.83	7.1
2:22:31	12.11	16.78	6.9
6:59:38	20.39	41.63	6.8
2:02:05	7.16	14.91	7.0
2:13:05	11.65	22.99	7.7

1:58:14	6.09	19.88	5.7
4:28:16	12.84	22.99	5.8
1:06:10	7.13	20.51	8.4
3:06:48	17.93	26.1	7.2
2:57:58	18.5	20.51	7.6
3:29:32	11.92	24.85	6.8
2:09:28	10.7	11.81	6.8
2:46:14	7.42	14.91	5.2
2:00:07	14.6	28.58	11.1
3:21:00	16.8	16.16	6.3
1:45:08	6.09	18.02	8.3
1:44:36	17.85	21.75	10.3
5:10:08	16.64	19.88	5.5
2:41:58	11.51	14.91	7
2:37:49	11.72	17.4	6.9
1:00:28	6.15	21.13	7.6
3:47:45	15.69	24.85	5.4
2:45:04	13.47	23.61	7.7
3:32:42	20.54	24.85	8.5
0:49:10	6	22.99	8.8
2:45:41	6.81	15.53	7.4
2:51:28	11.63	14.91	7
1:13:44	6.03	14.91	7
0:58:48	11.2	24.23	11.6
0:55:50	4.7	17.4	7
1:43:36	12.56	21.13	7.9
4:27:30	20.06	22.99	7.5
1:11:22	3.65	14.91	5.7
0:29:55	6.03	24.85	12.5
3:51:33	19.27	19.88	7.8
1:48:06	7.08	16.78	6.6
3:47:03	24.57	27.96	8.9
1:50:20	11.07	20.51	8.1
4:02:10	19.16	19.88	7.1

6:05:25	18.42	24.85	7.2
2:07:01	14.69	29.83	8.1
0:35:13	1.45	9.94	4.7
1:54:57	12.88	24.23	8.9
5:00:29	18.45	23.61	5.8
3:06:05	16.88	23.61	8.3
2:47:52	16.48	26.72	7.6

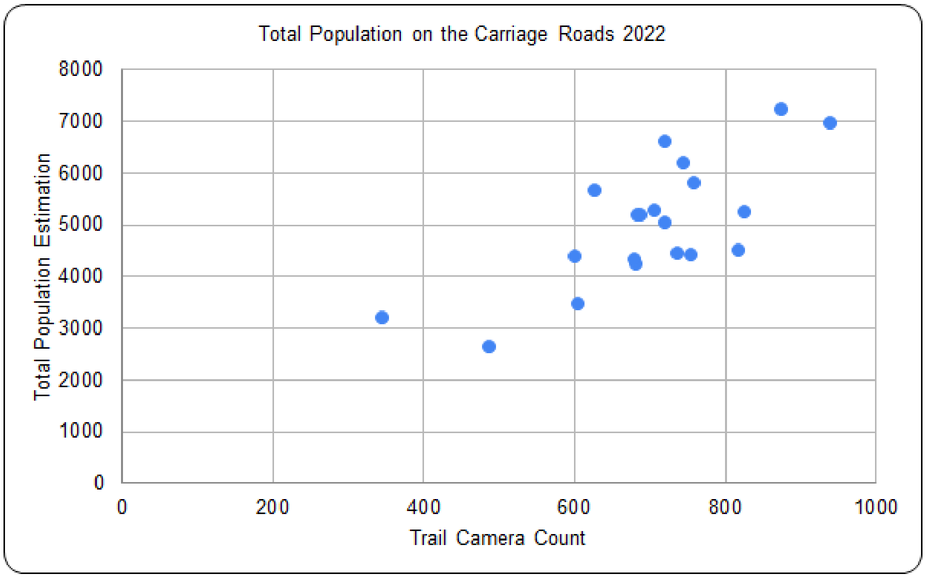
Electric Bikes			
Time Duration (Hours:Minutes:Seconds)	Mileage	Max Speed (mph)	Avg. Moving Speed (mph)
2:45:18	23.74	24.85	10.8
4:17:52	20.26	19.88	6.5
4:18:33	27.43	28.58	9.7
1:20:55	14.63	24.23	13
3:32:16	16.19	18.64	7.6
3:27:52	19.32	22.99	10.3
4:44:18	18.12	19.26	9.4
4:21:31	20.14	24.23	9.8
0:48:57	6.77	16.16	8.3
6:32:56	36.66	32.21	8
6:30:11	25.7	32.31	6.0
3:01:11	15.69	19.26	8.0
5:15:45	18.76	16.16	7.8
2:17:07	13.32	23.61	8.5
3:00:08	20.79	18.02	9.7
6:18:13	46.18	24.85	10
4:46:48	29.88	24.85	10.2
3:20:20	23.01	37.9	10.6
0:57:57	5.66	17.4	8.9
1:57:36	5.66	18.02	9.8
0:22:55	2.84	22.37	8.9
0:38:02	4.08	16.78	8.1

3:55:10	23.5	25.48	8.5
4:31:27	29.73	21.13	9.2
2:22:26	13.99	12.43	9.9
5:05:34	20.11	25.48	7.6
2:11:13	13.26	16.16	8.6
4:01:16	22.31	21.75	7.5
3:30:10	22.19	26.1	7.4
5:16:08	26.91	21.75	9.2
0:54:54	6.04	20.51	8.4
4:02:52	17.07	18.02	8.4
6:18:32	33.99	19.88	8.7
3:23:09	21.59	21.75	9.2
3:52:29	35.29	28.58	8.2
4:43:52	24.26	17.4	10.8
2:26:31	15.45	22.37	9.1
4:36:22	25.72	24.23	8.1
1:22:09	6.09	12.43	7.5
2:41:50	18.72	17.4	9.7
1:58:02	15.81	18.02	10.1
5:06:14	19.31	22.37	9.1
1:49:49	16.68	23.61	10.1
4:26:55	23.51	23.61	9.3
4:39:57	27.01	21.13	9.5
2:46:35	16.65	16.78	8.2
1:43:17	14.64	21.13	11.4
3:43:04	23.45	22.99	9.9

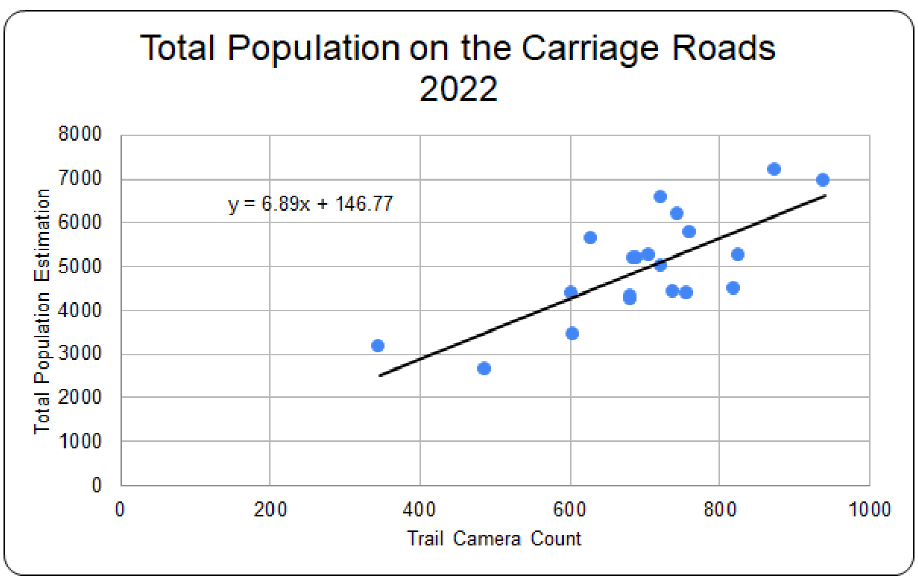
2:19:08	12.09	21.13	7.8
3:01:32	15.73	24.23	8.6
1:56:12	18.92	21.13	11.1
6:19:25	34.29	22.37	9.7
2:45:37	22	18.64	7.4
1:38:38	11.52	16.78	9.7
2:12:32	14.89	17.4	9.2
4:27:28	25.69	24.85	9.7
1:49:05	14.92	18.02	10.3

Appendix D: Alternate Description of our Regression Equation

The population data, which was collected with a trail camera in tandem with Streetlight Data, gave us a better understanding of the populations on the Carriage Roads. This data collection allowed us to create a scatter plot of our data.



Using this scatter plot we performed multiple types of regression to determine the best fitting equation. The types of regression had no significant differences, so we chose a linear fit because it balanced ease of use with effectiveness.



Through this graph, we were able to generate the equation which can be used to estimate the total population on the Carriage Roads.

$$y = 6.89x + 146.77$$

This equation states that there is an intercept at 147, meaning that when the trail camera counts zero people there are still an estimated 147 people on the Carriage Roads. In addition, for every person that is counted, there are an estimated 6.89 people on the Carriage Roads. In addition, while the correlation coefficient may be rather small at 0.56, based on our F-value of 0.0117, we can say with confidence that our regression model still shows a strong correlation between our count and the estimated number of people on the Carriage Roads that day.

Based on the equation we generated, we were able to draw a few conclusions. First, the equation that we generated is an improvement over the one generated by the previous research. We know this by a couple of methods, the first of which is the number of data points available. By using twenty data points as opposed to the ten gathered before, we can utilize more complex types of regression. This has allowed us to compare our fit line to several other fit lines to find the best function for our purposes. In this case, we chose to continue to use a linear fit line as well as linear regression, as opposed to polynomial, exponential or logarithmic regression. By comparing the fit line to other possible options, we have guaranteed that the park will have the most useful equation that we can provide them with based on our data set.

The second way that we can be confident that our equation is an improvement is by comparing the residuals squared value of the two equations based on the most recent estimation of the population on the Carriage Roads. Residuals squared is a numerical representation of how inaccurate a regression estimation is. To do this we ran a one-tailed t-test to compare the values of the residuals squared. We were able to determine with a 99% confidence interval that our residuals squared value is significantly lesser than that of the previous work, with the p-value being less than 0.0001. This is to say that there is less than a 0.1% chance that our equation is not better than the one generated in the previous study. This in tandem with the fact that our estimates are based on a more recent look at who is on the Carriage Roads has allowed us to say with confidence that the park should use our equation instead of the equations developed in the past.

Based on these estimations for the total population we were also able to draw an additional conclusion. This is because the carrying capacity on the Carriage Roads for the full 150-day summer season has been exceeded in the twenty days that we did our counts to build this model. With our average daily estimated population on the Carriage Roads being 4,979 and only one day falling below the 3,000 value set, we can say with confidence that the carrying capacity should be re-examined. We believe that this carrying capacity is being exceeded on account of the increasing population within Acadia, but also because of the growing popularity of eBikes.