WORCESTER POLYTECHNIC INSTITUTE

Visitor Mobility at The Hulls Cove Visitor Center in Acadia National Park

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An Interactive Qualifying Project Report submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Methods	Cameron Boucher, Sam Honor, Dillon McDermott, Sophia Lindsay	Cameron Boucher, Sam Honor, Dillon McDermott, Sophia Lindsay
Results	Sam Honor, Dillon McDermott, Cameron Boucher	Sam Honor, Sophia Lindsay
Recommendations	Cameron Boucher, Sam Honor, Dillon McDermott	Cameron Boucher, Sam Honor, Dillon McDermott, Sophia Lindsay
Appendix A: Timestamp Card Spreadsheet	Dillon McDermott	Sam Honor
Appendix B: Hardware Installation	Dillon McDermott	Sam Honor
Appendix C: Network Logistics	Sam Honor	Sam Honor
Appendix D: Microcontrollers	Sam Honor	Sam Honor
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Abstract

Acadia National Park's Hulls Cove Visitor Center (HCVC) has struggled with issues of crowding and congestion, yet there has never been an indoor visitor use study at the HCVC. This research aimed to understand visitor movement at the Visitor Center. We used a four-pronged approach that included traditional surveys, timestamp cards, Bluetooth Listening, and Ultrawideband Tracking. Through these methods, it was determined that the primary areas of congestion in the Visitor Center were the park information desk and the park store. All four methods reinforced the finding that interaction with park rangers is a significant reason for visitors to come to the Hulls Cove Visitor Center.

Acknowledgements

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Executive Summary

Project Overview

Crowd levels in National Parks have been on the rise since 2020 (U.S. Department of the Interior, 2021). Acadia National Park in particular has been one of the most visited National Parks in recent years. This increased visitation has put significant strain on park infrastructure, and NPS has noted that the current Hulls Cove Visitor Center (HCVC) is inadequate for evolving crowd patterns of Acadia National Park.

The National Park Service found several shortcomings of the HCVC. As Acadia's primary shuttle and information hub, the Visitor Center has had consistent issues with overcrowding and congestion, as well as a general lack of accessibility. Between having too few parking spots, only being accessible by stairs, and even fewer handicapped spots the building falls short in terms of visitor mobility. However, there has never been a previous indoor visitor use study conducted at the HCVC. Our team was tasked with studying the way in which visitors move around and utilize the Hulls Cove Visitor Center in order for the National Park Service to improve it and its future replacement.

Methods

Our group utilized both traditional and more technical methods to study movement in the visitor center. We used traditional surveys for visitors exiting the building, calculated total dwell times of visitors, recorded how many people were in the building throughout the day, and analyzed specific visitor movement paths. Each method is described in more detail below:

Exit Surveys: A survey was administered to visitors leaving the Hulls Cove Visitor Center, asking them how they heard about the HCVC, how they rated their experience and ease of movement through the building, and an optional section for open feedback.

Timestamp Cards: Visitors were asked to take a lanyard with a barcode on it; this barcode was scanned when they entered and exited to record their entrance and exit time. When they exited the building, they were given a verbal survey asking how they got to the Visitor Center, where they went inside, and their ease of movement inside. These times were used to calculate dwell times and the questions were used to correlate with these dwell times.

Bluetooth Listening: Bluetooth Listening technology was mounted on the ceiling of the Visitor Center to count the total number of Bluetooth devices in the building at a time, as well as in specific locations. They recorded the number of devices in the building every 15 seconds.

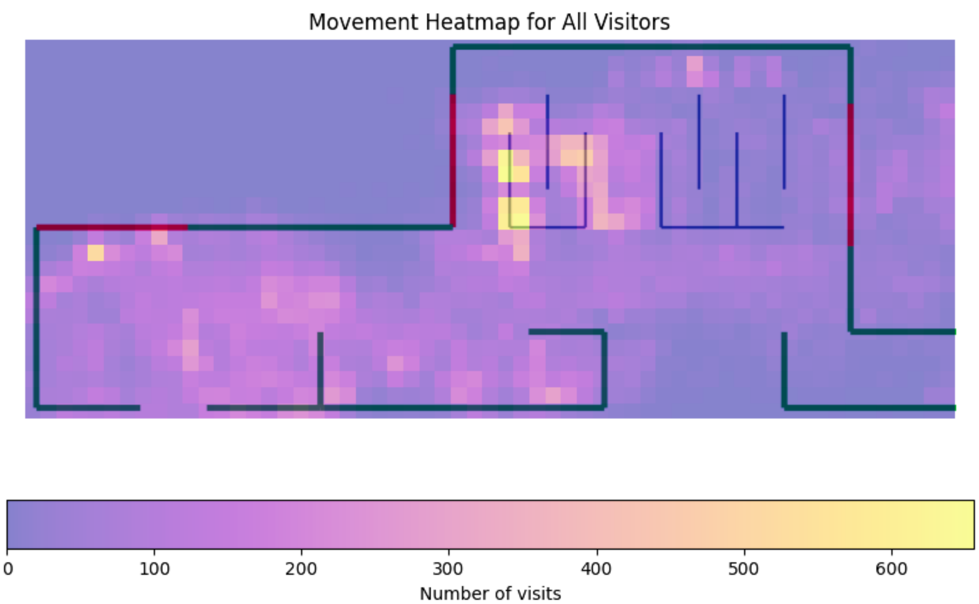
Ultrawideband Tracking: Lanyards with devices to track individual paths through the Visitor Center were given to visitors before they entered the building. They took a verbal survey asking their gender, whether or not they were with children, their group size, and if they had been to the Visitor Center before. Ultrawideband anchors were mounted on the ceilings to triangulate the position of the visitor and obtain their exact path.

Findings

Visitors want to interact with rangers at the HCVC. The surveys showed that 63% of visitors waited in line for the Information Desk. A heatmap of UWB data showed this line is one of the most congested areas, and the Bluetooth data showed that of all locations, the anchor near the Information lLine recorded the most people in the area. Many visitors made glowing comments about their interactions with rangers, though some complained of the queue to meet them.

Visitors spent the most time in the Park Store. Both the Timestamp Card data and the UWB data support the claim that visiting the Park Store will result in a longer time spent inside of the Visitor Center, as well as it being a more congested area.

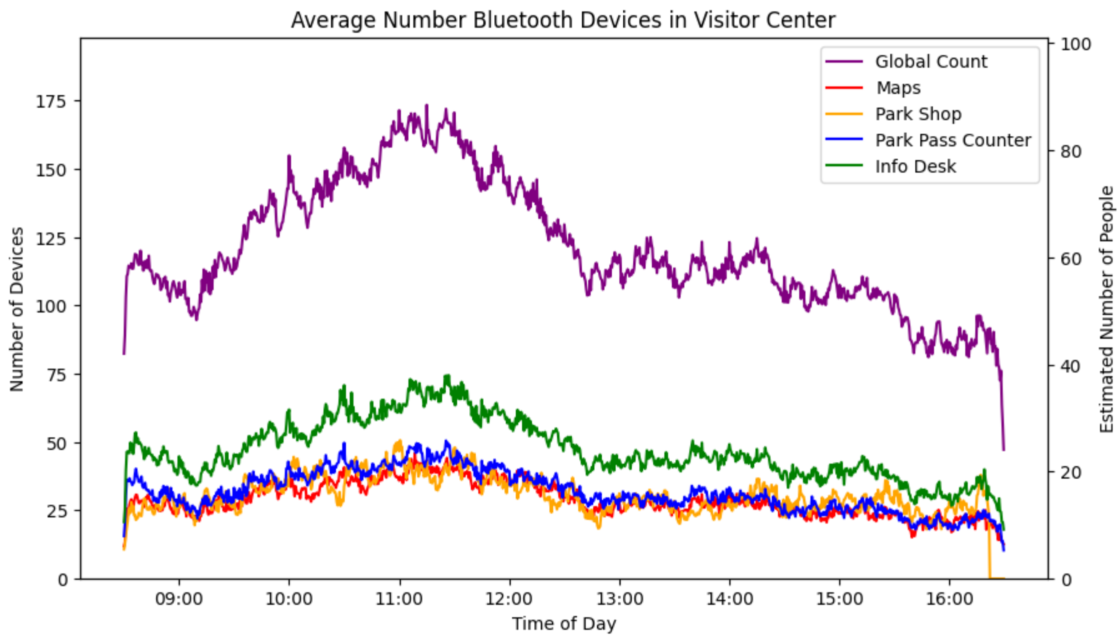
Figure A: Heatmap of Visitations from UWB.



The Timestamp Card data resulted in an average dwell time of 14:33 and the Ultrawideband data averaged about 12 minutes. These results were expected as there were almost 600 participants in the Timestamp Card study, and almost 500 in the UWB study. The closeness of these dwell times suggests that both sampled similar populations.

The Bluetooth data found the busiest hours to be between 10:30 AM and 12:00 PM. Over the course of the 120 hours that the Bluetooth anchors collected data, the most visitors were detected between these hours. Knowing the peak visitation period of the HCVC is crucial for the rangers on duty in the building to be aware of so that they can maximize the number of employees on duty and help to satisfy all visitor needs.

Figure B: Local Bluetooth Sensor Data Compared to Global Data



Visitors reported challenges regarding bathrooms and educational materials. Respondents of surveys noted the often inaccessible restrooms and the lack of educational material inside of the HCVC. Both of these findings should be taken into consideration when planning the layout of the next Visitor Center so that all visitors can be satisfied with their experience.

Recommendations

Provide more interpretive exhibits and opportunities to interact with rangers. Expanded opportunities for visitors to learn about the park may increase visitor satisfaction by… For example, separating the Junior Ranger Station from other lines would be helpful in reducing congestion at the Information Desk.

Let visitors access the restrooms inside of the building before and after the normal operating hours. This is a short term solution to the issues with the restrooms, as the layout of the doors to the main lobby are designed in a way that this could be considered. A long term solution would be to build outdoor restrooms for people to use both during the regular hours of the Visitor Center and after hours. This could improve the flow of visitors during the Visitor Center's hours of operation with less people going in the building.

Continue monitoring crowds. There is potential to introduce a more commercialized and professional system for autonomous Bluetooth listening and Ultrawideband Tracking to collect even more data about how visitors move through the building. With additional data about visitors, the park could gather a larger sample size of data to find more accurate data about visitors. This autonomous system could also help to introduce a live feed of how busy the Visitor Center is, which would be useful for the park and the general public to be aware of.

Table of Contents

Authorship ....
Abstract .... **i**
Acknowledgements .... **ii**
Executive Summary .... **iii**
Table of Contents .... **viii**
Introduction **1**
Background **2**
Acadia National Park Overview 2
Parking and Transportation Issues at Acadia National Park 2
Figure 1: Annual National Park Ranking Report for Recreation Visits in 2021 3
Figure 2: Hulls Cove Visitor Center Parking Lot. Note: Screenshot from Google Maps 4
Figure 3: Satellite Overview of Route 3. Note: Image from Google Maps. Purple line is the typical visitor path along Route 3 5
Hulls Cove Visitor Center 6
Figure 4: Renovated Hulls Cove Visitor Center Floor Plan (2019) 7
Previous Visitor Use Studies 7
Visitor Movement Studies 7
Figure 5: Spatial Structure of The Louvre Represented as Nodes 8
Methods **8**
Footpath Tracking Using Ultrawideband 9
Working Principle 9
Figure 6: Ultrawideband Tracking Tag Attached to a Lanyard 10
Figure 7: Ultrawideband Anchor 11
Crowd Level Metrics Using Bluetooth Listening 11
Figure 8: Bluetooth Listening Sensor 12
Privacy Concerns 12
Dwell Time Measurement with Timestamp Cards 13
Figure 9: Handing out Timestamp Cards 14
Measuring Satisfaction Using Surveys 14
Set-Up of Sensors and Data Logistics 14
Figure 10: HCVC Hardware Setup Diagram 16
Figure 11: Photo From Installation. 16
Figure 12: Flowchart of Data from the Various Collection Methods to the Database. 17
Results **18**
Crowd Levels 18

Figure 13: The Manual Count of People in the Visitor Center Overlaid with the Number of Bluetooth Devices Counted. 19
Figure 14: The Average Number of Bluetooth Devices in the Visitor Center Over All Days of Data Collection, with Rough Device:People Correlation on the Right. 20
Figure 15: Local Bluetooth Sensor Data Compared to Global Data 21
Wait and Dwell Times 21
Figure 16: Timestamp Card Dwell Time Graph 22
Hot Spots........23
Figure 17: Heatmap of Visitations from UWB. 23
Figure 18: Heatmap for First-Time Visitors 25
Figure 19: Heatmap for Returning Visitors 25
Path and Dwell Modeling 26
Figure 20: Park Store Entry and Exit Vectors 28
Figure 21: Park Store Dwell Time Data 28
Figure 22: Info Desk Entry and Exit Vectors 30
Figure 23: Info Desk Dwell Time Data 30
Figure 24: Map Entry and Exit Vectors........33
Figure 25: Map Dwell Time Data........33
Figure 26: Park Pass Entry and Exit Vectors........35
Figure 27: Park Pass Dwell Time Data........35
Figure 28: Average Dwell Times for All Locations 36
Visitor Experience 37
Error, Bias, and Potential Improvement 38
Recommendations........40
Appendix A: Timestamp Card Spreadsheet........43
Figure 29: Example of Timestamp Card Spreadsheet 43
Figure 30: Automatic Time Function Formula........43
Figure 31: Timestamp Card Participants Reasons for Entering the Visitor Center.....44
Appendix B: Hardware Installation........46
Figure 32: Neatly coiled ethernet cables........46
Figure 33: Wiring directly above the ethernet switch........48
Figure 34: HCVC Cartesian Coordinate System 49
Figure 35: Bluetooth Calibration in HCVC 50
Appendix C: Network Logistics........51
The Server........51
UWB Server-side Application 52
Ranging Tags 52
Bluetooth Server-Side Application........53
Appendix D: Microcontrollers........**54**

UWB Anchor 54
Figure 36: The ESP32 + POE Used UART to Trigger the ESP32 + DW300 to Range a Tag..55
UWB Tag 55
Figure 37: Ranging Exchange Between Anchor and Tag..56
Bluetooth Listener..56
Appendix E: UWB Analysis Software 58
Appendix F: Images...59
Figure 38: Disassembled UWB Tag 59
Figure 39: Disassembled UWB Anchor 60
Figure 40: Disassembled Bluetooth Listener...61
Figure 41: ESP32 + POE Module...62
Figure 42: ESP32 + DW3000 Module...63
Figure 43: Server...64
Figure 44: Switch 65
Figure 45: Server and Switch Set Up in HCVC 66
Appendix G: External Links...67
Appendix H: Parking Lot and Island Explorer Study 68
Project Goals 68
Methods..70
Figure 46: Route 1 map - Bar Harbor Road Island Explorer Bus (service every 30 min after 10 am until 8:40 pm): 72
Figure 47: Route 4 map - Loop Road Island Explorer Bus (service every 30 min from 9 am to 5 pm) 72
Figure 48: Route 5 map - Jordan Pond Island Explorer Bus (service every 30 min from 9 am to 4:30 pm) 73
Data Analysis 76
Bus Route Capacity Counters 76
Figure 49: Graph of the data recorded for Loop Road route on 7/6/23 79
Figure 50: Graph of the data recorded for Loop Road route on 7/2/23 80
Figure 51: Graph of the data recorded for the Jordan Pond route in the afternoon on 7/3/23 80
Recommendations..81
Conclusions:..82
Works Cited in this Appendix: 82
References..83

Introduction

Crowd levels in National Parks have been on the rise since 2020 (U.S. Department of the Interior, 2021). Acadia National Park in particular has been one of the most visited National Parks in recent years. This increased visitation has put significant strain on park infrastructure, and NPS has noted that the current Hulls Cove Visitor Center (HCVC) is inadequate for evolving crowd patterns of Acadia National Park.

The National Park Service noted several shortcomings of the HCVC. As Acadia's primary shuttle and information hub, the Visitor Center has had consistent issues with overcrowding and congestion, as well as a general lack of accessibility. Between having too few parking spots, only being accessible by stairs, and having even fewer handicapped spots, the building falls short in terms of visitor mobility. However, there has never been a previous indoor visitor use study conducted at the HCVC. Our team was tasked with studying the ways in which visitors move around and utilize the Hulls Cove Visitor Center in order for the National Park Service to improve it and its future replacement.

Based on key issues and unaddressed data needs raised in the Foundation Document, we decided to investigate the specific paths visitors take through the Visitor Center and timed how long visitors are spending at each indoor attraction. Alongside the technical aspect of our research, we surveyed park goers to work towards a holistic explanation of how congestion impacted experience. Our findings from these questionnaires helped pinpoint the most pressing issues park users saw with the Visitor Center. We used the data we collected from both tracking and surveying to answer our research question, **"How much time are visitors spending in different areas of the Hulls Cove Visitor Center, and what can be done to reduce wait times**

and congestion?" Using our findings, NPS could take action to work towards better crowd management in the HCVC.

Background

In order to determine the best methods with which to study visitor mobility, we researched the specific issues which NPS faces and what previous research has been conducted. Since we found no research at National Park visitor centers in the past, and since this research is the first of its kind by WPI standards, the methods had to be built from the ground-up. As such, we also looked to previous indoor visitor use studies at museums, which have conducted significant research in this field.

Acadia National Park Overview

Located in coastal Maine on Mount Desert Island and the Schoodic Peninsula, Acadia National Park boasts the tallest mountain on the Eastern Seaboard, near perfect darkness for stargazing, and over 150 miles of trails for hiking (*Things To Do*, n.d.). Annually, over 4 million visitors flock to the park (*Visiting Acadia National Park | Visitor Resources*, n.d.).

Parking and Transportation Issues at Acadia National Park

America's National Parks are some of its proudest and most popular attractions. However, they are not without their issues. All National Parks, according to the National Park Service (NPS), have faced problems with overcrowding and congestion in recent decades. During the start of 2020, visitation at National Parks decreased by 27.6% due to the COVID-19 pandemic. However, a third of the 423 parks in the NPS experienced a record number of visitors during peak months in the following year (U.S. Department of the Interior, 2021). In July 2021, NPS reported an increase in visitation concentrated in their 12-15 most popular parks. Acadia

National Park (ANP) falls into this category, being the 6th most visited National Park during the year of 2021 at just over 4 million visitors (**Figure 1**).

While ANP is one of the most visited parks, it protects under 50,000 acres of land (Harbor & Us, n.d.). In comparison, Yellowstone National Park protects over 2 million acres of land and was also in the range of 4 million visitors during 2021 (National Park Foundation, n.d.) (**Figure 1)**. Acadia's small geographic size and high visitation have led to overcrowding in many areas of the park. NPS has identified the Hulls Cove Visitor Center (HCVC) as a consistently congested area. In the HCVC, visitors can find general information about Acadia, buy passes, and also park their car in order to take the Island Explorer Shuttle. Due to the increased use of the Island Explorer Shuttle, the HCVC parking lot is often filled to capacity (**Figure 2)**.

Figure 1: Annual National Park Ranking Report for Recreation Visits in 2021

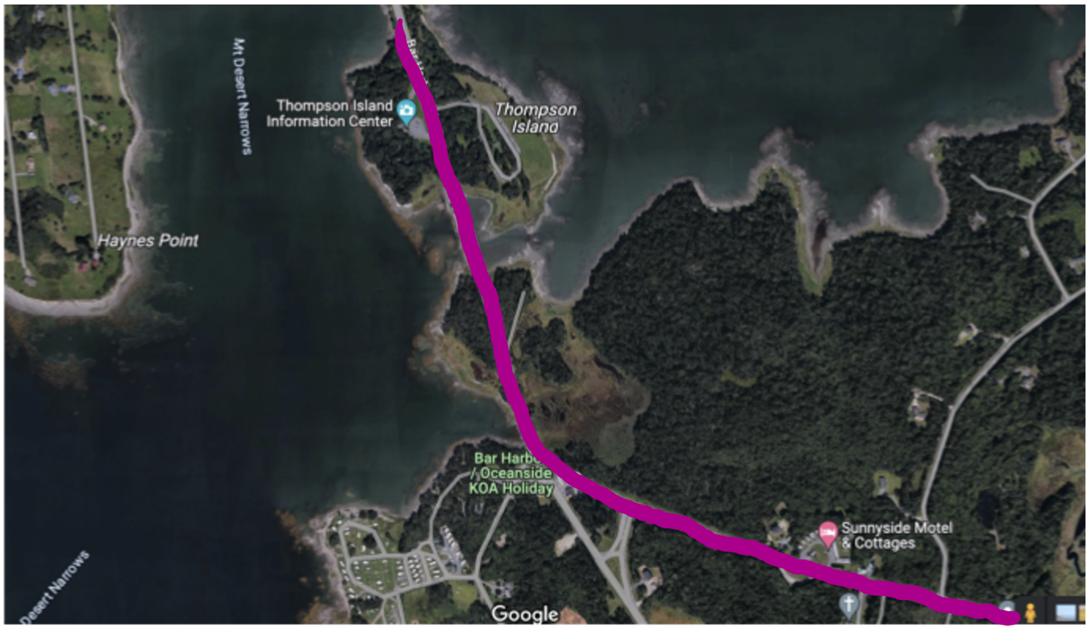
Park	Rank	Recreation Visits	% of Total
Great Smoky Mountains NP	1	14,161,548	15.35%
Zion NP	2	5,039,835	5.46%
Yellowstone NP	3	4,860,242	5.27%
Grand Canyon NP	4	4,532,677	4.91%
Rocky Mountain NP	5	4,434,848	4.81%
Acadia NP	6	4,069,098	4.41%

Figure 2: Hulls Cove Visitor Center Parking Lot. Note: Screenshot from Google Maps

While visitors utilize the HCVC parking lot to access the shuttle, there are also those who have the intention of going inside the Visitor Center. To access the building, visitors have to ascend 52 stairs from the main parking lot. There is an accessible parking lot if needed, which is closer in proximity to the center. However, handicapped parking is limited to a handful of spaces. All of these issues are part of the reason NPS intends on rebuilding the visitor center in the coming years (Broom, 2018).

There are a range of reasons people might be at the HCVC; buying passes, getting information, using the restrooms etc. Some of these amenities are also available at the Thompson Island Information Center (TIIC). The TIIC is on Thompson Island, and those who drive onto Mount Desert Island will drive past this center (**Figure 3**). Here, visitors can find maps, brochures, park rangers on site to answer questions, and purchase a variety of park passes (Hartford, n.d.). According to all "alternatives" in the Transportation Plan, the TIIC will be torn down in order to bring Thompson Island back to its original standing with nature. The removal of this location will likely cause an additional increase in visitation at the HCVC.

Figure 3: Satellite Overview of Route 3. Note: Image from Google Maps. Purple line is the typical visitor path along Route 3.



To relieve the issues discussed in the above section, NPS has developed several plans of action regarding different aspects of the development of ANP. These can be found in the Foundation Document, which serves as the master plan for the park. Published in 2016, this report lays out the Park's Fundamental Resources and Values (FRVs) and discusses current and future threats to conservation of park resources. FRVs guide all planning and development activities for Acadia National Park. According to the Foundation Document, "[FRVs] are those features, systems, processes, experiences, stories, scenes, sounds, smells, or other attributes determined to warrant primary consideration during planning and management processes because they are essential to achieving the purpose of the park and maintaining its significance"

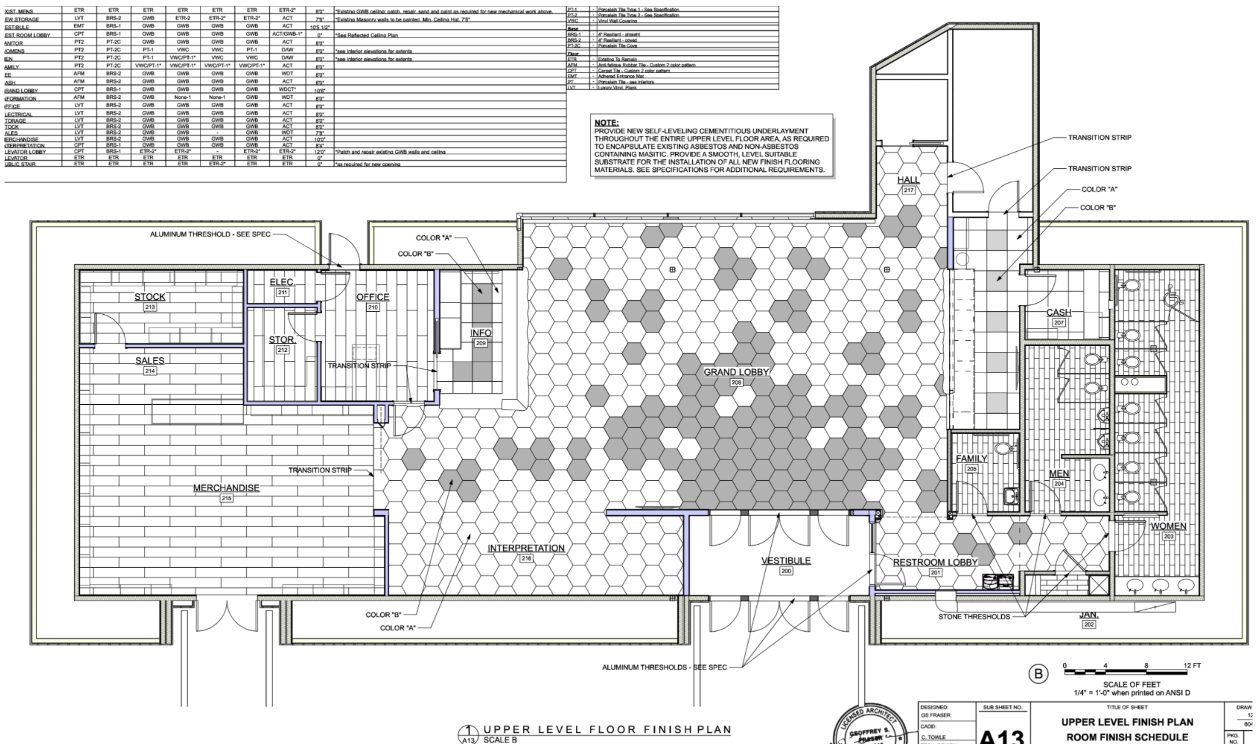
(National Park Service, 2016, p. 7). Park resources are allocated to preserve FRVs to the maximum extent (National Park Service, 2006, pp. 22–23).

Our research primarily concerns the “Range of Visitor Experiences” FRV. This FRV underscores that Acadia National Park values the visitor’s unfettered enjoyment of the park in its most natural state (National Park Service, 2016, p. 7). As discussed earlier in this section, many National Parks (including Acadia) are reporting adverse visitor experiences due to overcrowding (Snow, 2019). The Foundation Document highlights “traffic congestion, parking lot overflows, and visitor conflicts” as a key issue that impacts visitor experience and other FRVs. By mapping visitor movement through the Hulls Cove Visitor Center, we worked to address the “simulation model for traffic flows” data-need specifically related to this key issue of congestion (National Park Service, 2016, p. 13). Our findings will help NPS with future planning for the HCVC and other buildings by clarifying how guests move in an indoor space.

Hulls Cove Visitor Center

The Hulls Cove Visitor Center was designed and built in 1967. Construction was completed in 1986, with the building situated atop a hill providing a view of the Atlantic Ocean and certain nearby islands (National Park Service, 2022). The HCVC had its most recent renovation in 2019, which was meant to improve traffic flow through the building. The floor plan from the renovation can be seen below in **Figure 4**. The Visitor Center can be accessed via 52 stone stairs which lead from the parking lot to either of two doors: the main entrance and the park store entrance. There is an additional accessible parking lot at the back of the building, allowing for individuals with mobility issues to circumvent the stairs. However, this lot has very limited parking.

Figure 4: Renovated Hulls Cove Visitor Center Floor Plan (2019)



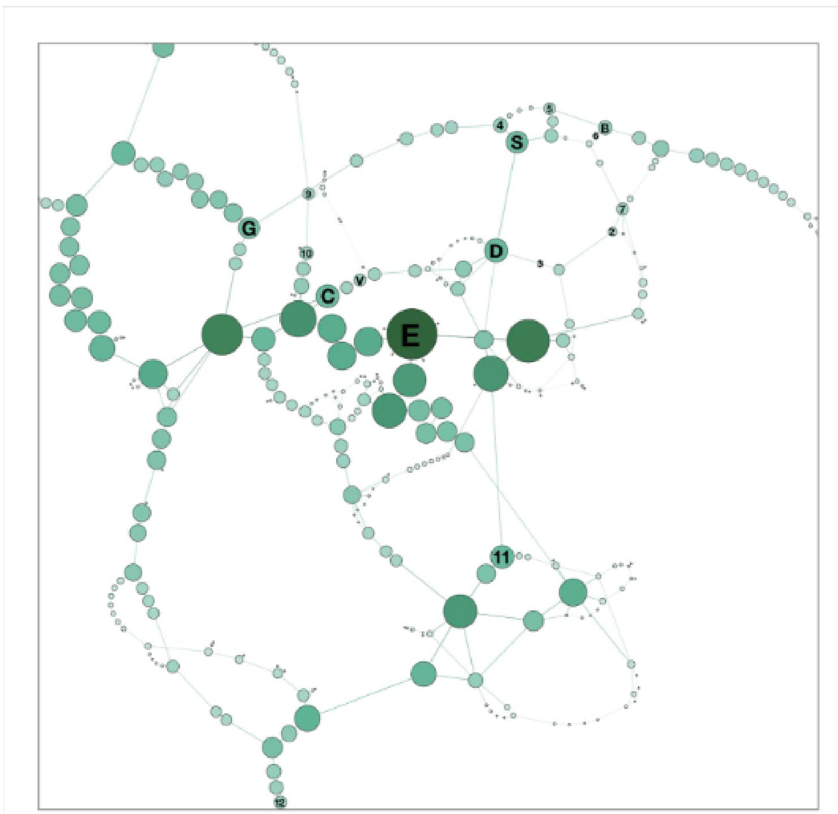
Previous Visitor Use Studies

Visitor Movement Studies

While previous WPI research projects at National Parks have investigated how visitors move over a wide geographic area (Jozitis et al., 2021) (Jemison et al., 2019), none have looked at movement within small indoor spaces where it is effectively untrackable by GPS. This methodological gap is not just present in WPI research, however. While little research has been conducted on visitor movement through National Park visitor centers, there have been a great deal of studies on crowd movement through museums. As researchers Yoshimura et al. note in their study of movement through The Louvre, most previous studies concerning museum visitor behavior relied on fairly limited “paper and pencil” methodologies (Yoshimura et al., 2019, p. 2).

Instead, Yoshimura et al. used Bluetooth MAC loggers to track cellular devices as they moved about the museum. These “Listening posts” logged when a device entered and exited their range (Yoshimura et al., 2019, p. 5). This provides data about what region a visitor is in, but cannot detect the location of the visitor within that region.

Figure 5: Spatial Structure of The Louvre Represented as Nodes



Methods

Our main objective was to understand congestion and crowding at the Hulls Cove Visitor Center. To study different aspects of congestion, we utilized a combination of Bluetooth Listening (BLE), Ultrawideband (UWB) tracking, and Timestamp cards. These methods allowed us to track the movement of visitors through the HCVC and monitor the amount of time that they spent in certain zones, such as waiting in line for park passes. In conjunction with these primarily numerical methods, we used exit surveys to gauge ease of movement and visitor satisfaction. These surveys provided visitors a place to tell us what areas of the Visitor Center impacted their overall experience the most. Each method used in this study offered unique insight into different aspects of mobility throughout the building.

Footpath Tracking Using Ultrawideband

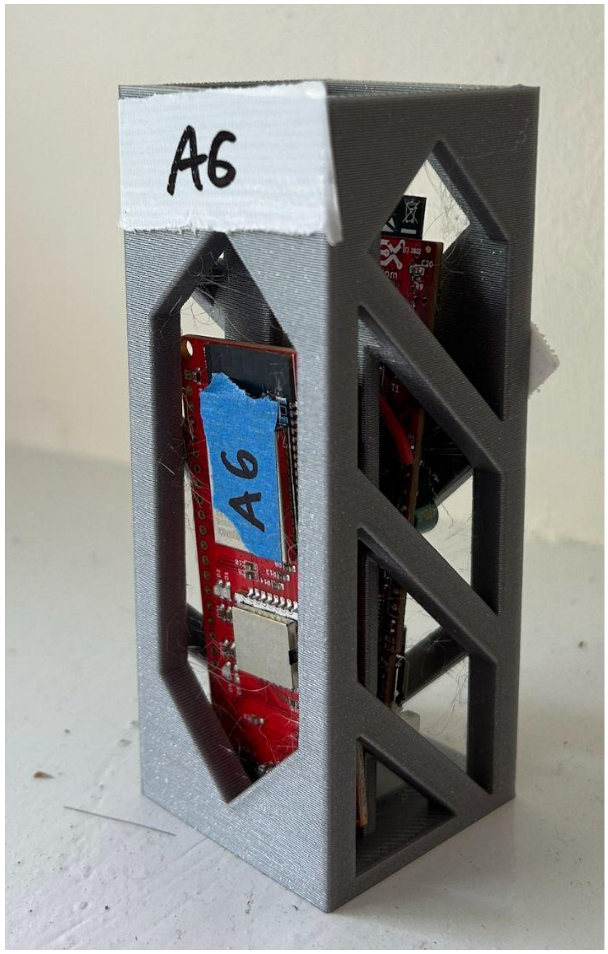
UWB radio has become standard for precise indoor tracking across a variety of industries (Wang et al., 2022). This method of localization uses a network of stationary anchors to detect the position of tags in a limited area. We utilized a UWB tag-tracking system to gather data on the exact path visitors took through the Visitor Center. This precise footpath data can illuminate how long visitors spend in certain attractions at the HCVC and the order in which visitors visit each attraction. Visitors participating in the UWB study took a survey before entering the building. Using data from this survey, we studied how specific populations such as first time visitors, women, and groups with children move about the Visitor Center in different manners.

Working Principle

The UWB tracking system consisted of two components: tags and anchors shown in **Figure 6** and **Figure 7**, respectively. The system worked by taking ranges from the ceiling-mounted anchors to the visitor-carried tags. An algorithm converted the set of distances gathered from all anchors to a tag into a cartesian coordinate for the tag. Because this system worked best when the anchors had line-of-sight to the tags, we mounted multiple anchors around busy areas of the Visitor Center for maximum effectiveness **(Figure 9)**. For an in-depth discussion of the hardware and software that comprised the UWB tracking system, please see **Appendices B and C.**

Figure 6: Ultrawideband Tracking Tag Attached to a Lanyard

Figure 7: Ultrawideband Anchor

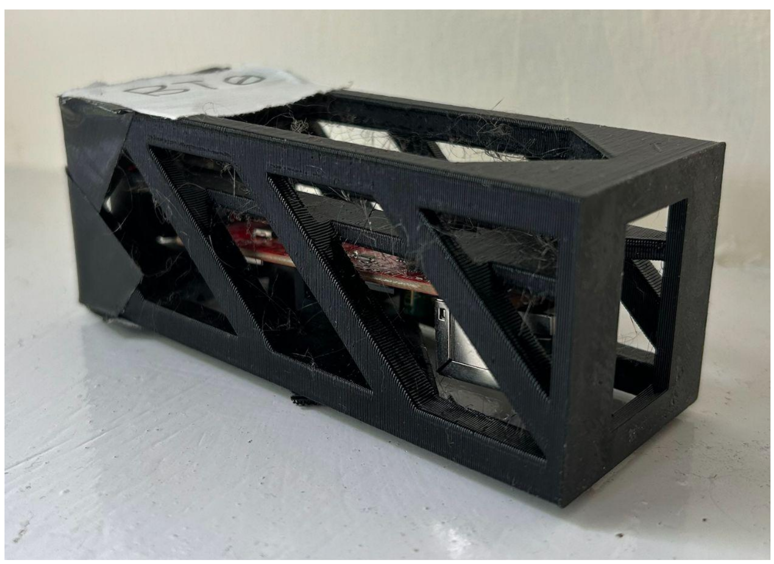


Crowd Level Metrics Using Bluetooth Listening

To passively monitor the number of people at certain locations in the Visitor Center, we used a network of ceiling-mounted microcontrollers to count the number of nearby Bluetooth devices. In a process called advertising, most Bluetooth devices (such as cellphones, headphones, and laptops) broadcast their MAC address to signal their availability to other devices in the area (*Intro to Bluetooth Advertisements*, 2017). Our sensors counted the number of unique MAC addresses detected in a ten second interval to gauge the crowdedness of an area. For an in-depth discussion of the technical details of this system, see **Appendix C**.

While the Bluetooth Listening system did not provide a direct measure of the number of people in an area, trends in the number of detected devices can act as a proxy metric for the ebb and flow of crowds throughout the day. Spikes in Bluetooth advertising traffic indicated times at which a large number of people entered the Visitor Center in a short period of time. Furthermore, manual observation was used to calculate a rough correlation between the number of devices and number of visitors. With this technique, we were able to determine what the busiest times of day were.

Figure 8: Bluetooth Listening Sensor



Privacy Concerns

In order to maintain visitor privacy, the Bluetooth Listening method never logged MAC addresses to the server. Addresses were stored locally on the listener microcontroller for ten seconds (to prevent repeat counts), and were then purged. The only metric that was permanently logged to the database was the number of nearby Bluetooth MAC addresses detected. No data from the received advertising packets aside from the MAC address were ever accessed or recorded. Notices were posted on all entrances informing visitors on how to opt out of the study.

Dwell Time Measurement with Timestamp Cards

The timestamp card station was set up outside of the entrance and operated by one of our team members alongside the UWB tags being handed out. Visitors entering the building were asked to carry a card with a unique barcode on it, which was scanned using a USB barcode scanner to log entry time. When the visitor returned, the barcode was scanned again to obtain an exit time. A spreadsheet shown in **Appendix A** calculated the total time spent inside of the HCVC. We then asked them several questions about what they did while they were inside, and their responses could correlate with their total dwell time. We were able to record accurate timestamps to determine average dwell time, and compare specific dwell times with locations within the HCVC that the visitor went to.

Figure 9: Handing out Timestamp Cards

Measuring Satisfaction Using Surveys

In order to gain insight on the visitor experience, we asked visitors to fill out a paper-and-pen exit survey. This survey had several questions, including a rating of the HCVC's utility and ease of movement, as well as an open feedback section. Data from this methodology was used to qualify the degree to which crowding impacts the visitor experience. Notes from the open response section in particular illuminated specific issues with certain aspects of the Visitor Center which numerical methods would miss (see **Appendix G**).

Set-Up of Sensors and Data Logistics

As shown in **Figure 10,** sensors were placed above waiting lines and in main areas of the Visitor Center. The installation took approximately 12 hours over the course of 3 days, being done after-hours. See **Appendix B** for more details about the specifics of the system set-up. Each day of data collection, we set up a table and a canopy outside the visitor center. Visitors would stop here on their way out of the building to complete the exit survey, or stop on their way into the building to participate in the UWB and Timestamp Card studies. On every day of data collection, the BLE system was run, with the system being connected/disconnected just after opening and before closing. At the end of the research period, the system was removed in a single 2 hour session.

In order to make sense of the data collected from all these sensors, we had to first store it. Since our methodology relied on nearly 25 microcontroller-based devices, it would have been impractical to store data using on-sensor portable media and uploaded nightly. Using a web server was also out of the question, as the internet connection at Acadia National Park is for government use only (*pers. comms*). To work around these issues, we used a Local Area Network (LAN) server to facilitate our experimental apparatus. This server hosted a Message Queuing and Telemetry Transport (MQTT) broker and database software. After we finished collecting data for the day, we saved copies of the databases to a USB flash drive and uploaded it to a WPI-hosted database using the internet connection at College of the Atlantic. A flowchart of our system can be seen below (**Figure 12**). In-depth discussion of how data and power flow through our system is available in **Appendix C**.

Figure 10: HCVC Hardware Setup Diagram

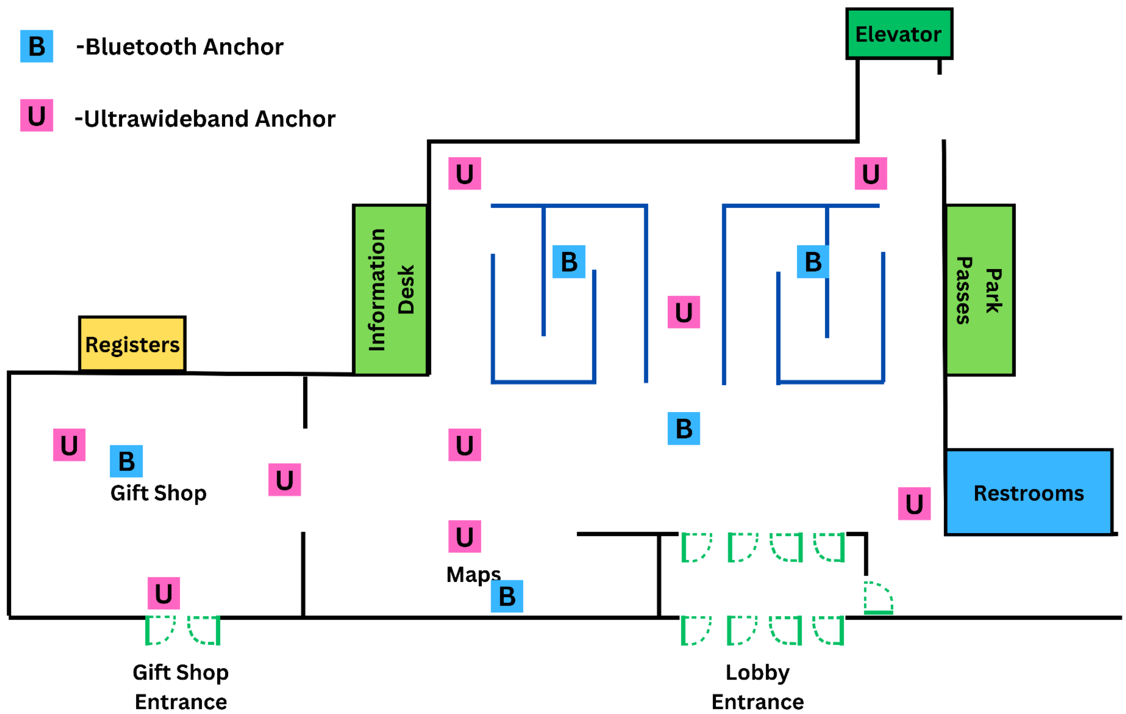
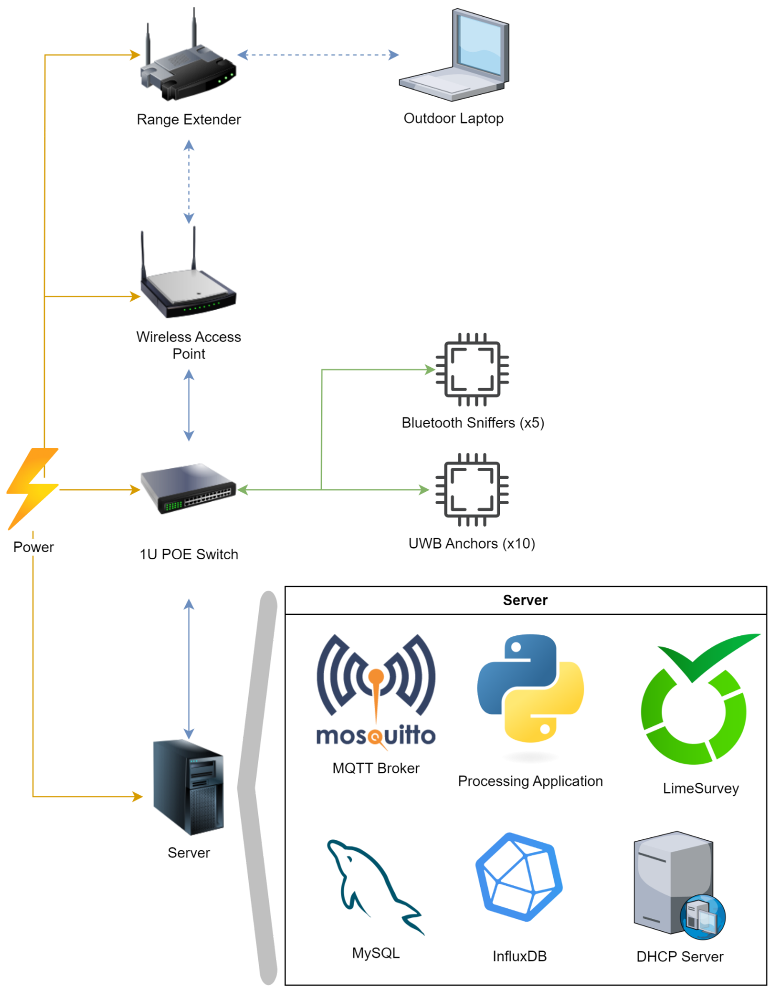


Figure 11: Photo From Installation.

Figure 12: Flowchart of Data from the Various Collection Methods to the Database.



Note: Blue line indicates data connection, orange means power, green means both. Dotted lines indicate wireless data connections.

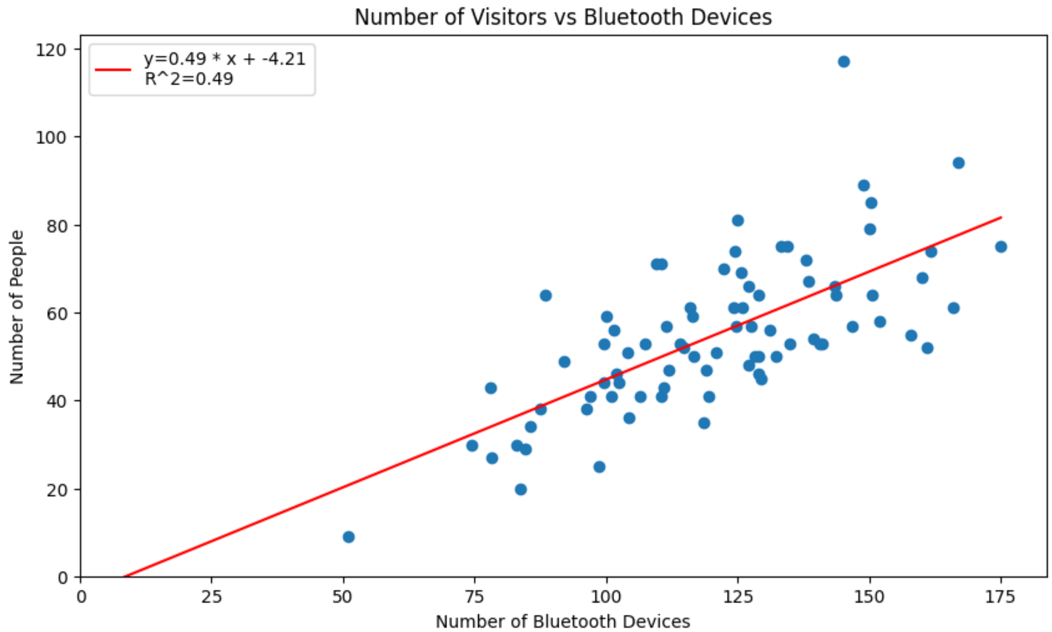
Results

The following results include assertions made by analyzing our data and feedback from visitors. The results come from all forms of the methods mentioned previously.

Crowd Levels

Our main measurement for crowd levels was Bluetooth MAC counting. Because the number of Bluetooth enabled devices a visitor carries is unknown, we calibrated this data by comparing it with manual observations. As seen in **Figure 13**, the number of detected devices shared a positive linear relationship with the number of visitors in an area. Aggregating our data from 8 hours of manual observation, we found that, on average, one visitor translated to 2-3 detected Bluetooth devices. We determined that this ratio was reasonable due to the fact that iPhones have two MAC addresses, and in today's society, people tend to have more than one Bluetooth device on their person. Some examples of devices with Bluetooth capabilities are smartphones, watches, headphones and even some hearing aids.

Figure 13: The Manual Count of People in the Visitor Center Overlaid with the Number of Bluetooth Devices Counted.



Peak crowding of the HCVC was observed between 10:30 AM and 12:00 PM each day. As seen in **Figure 14** below, the highest influx of visitors to the Visitor Center was between the hours of 10:30 and 12:30. This indicates that these should be the hours when peak congestion occurs. This finding can be corroborated anecdotally, as we observed the largest crowds of people entering the building between these hours on our data collection days. Additionally, the local BLE sensors demonstrate that the Information Desk has the highest visitation rates (**Figure 15**).

Figure 14: The Average Number of Bluetooth Devices in the Visitor Center Over All Days of Data Collection, with Rough Device:People Correlation on the Right.

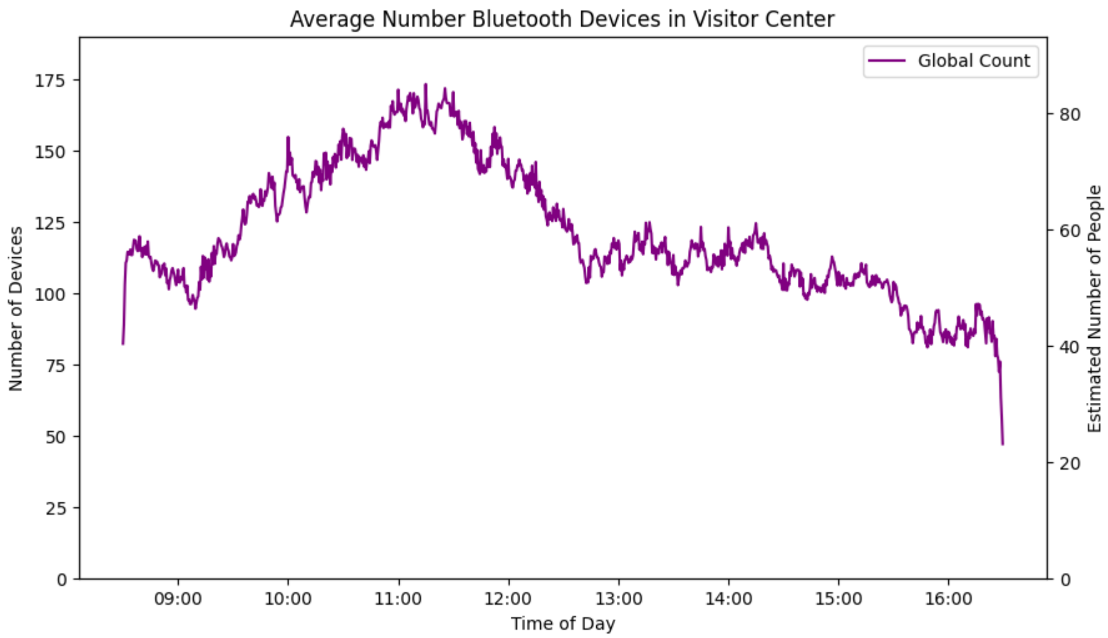
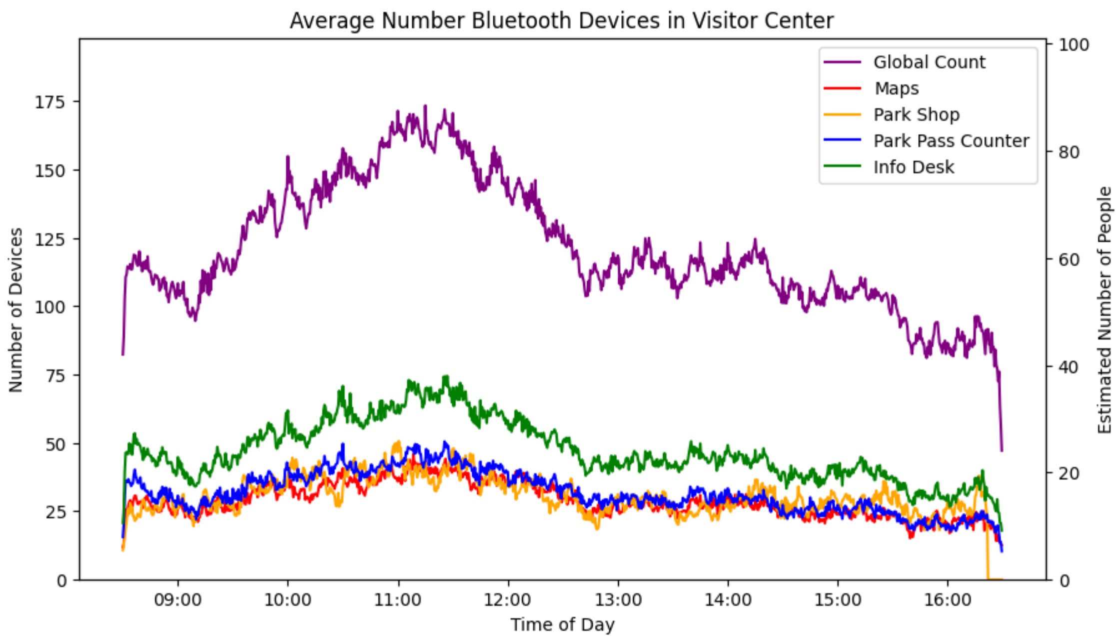


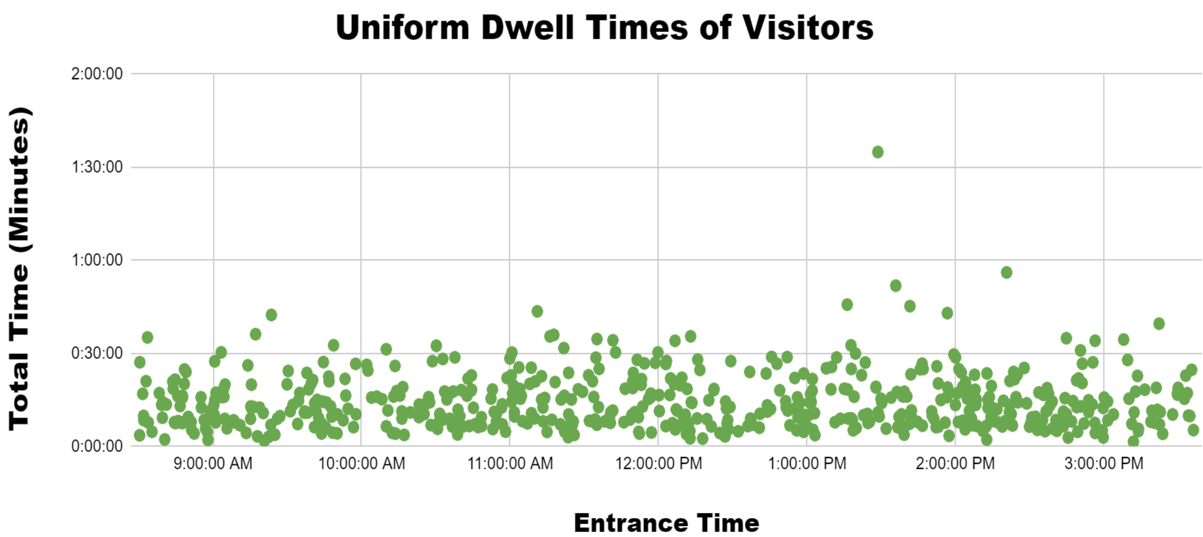
Figure 15: Local Bluetooth Sensor Data Compared to Global Data



Wait and Dwell Times

According to the timestamp card data collected, the average visitor spent 14:33 minutes in the Visitor Center, and most visitors spent the same amount of time inside throughout the day. Regardless of entrance time, visitors tended to spend between 5 and 30 minutes in the HCVC. All of the dwell times can be seen in **Figure 16**. The uniformity of this plot goes to show the consistent time spent inside of the visitor center.

Figure 16: Timestamp Card Dwell Time Graph

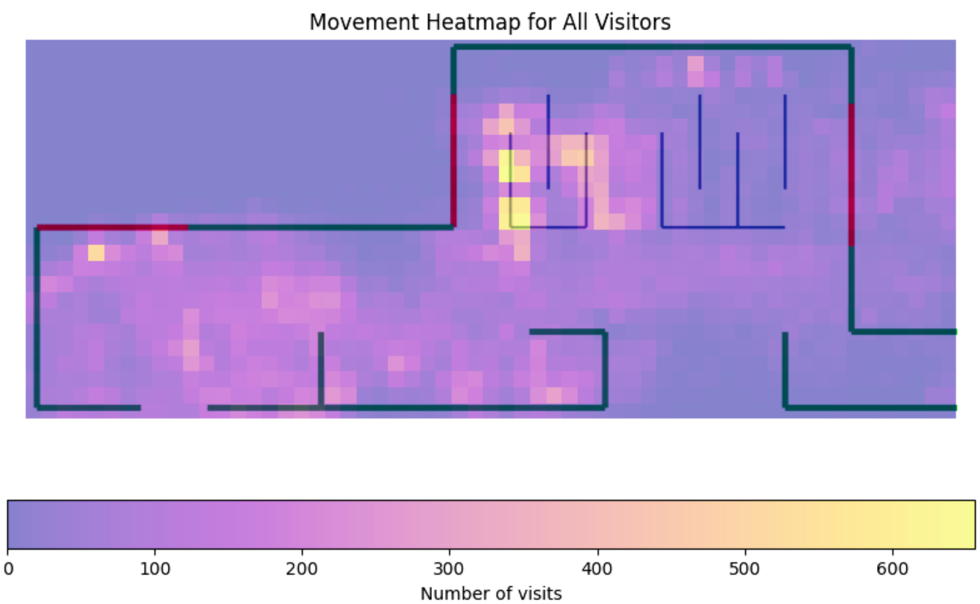


Use of the park store and restrooms led to longer HCVC visitation. There were a total of 575 visitors who participated in this Timestamp Card method, and the reasons they visited correlated with their dwell time. Visitors spent more time inside of the Visitor Center when they went into the park store compared to those who reported that they did not. The visitors who reported going inside of the store had an average dwell time of 15:18, and those who didn't only had an average dwell time of 10:23. Another finding is that visitors who used the restrooms in this study spent more time in the Visitor Center compared to those who did not. An average of 15:33 was spent in the HCVC for visitors that used the restrooms, and those that did not spent an average of 12:38. It is important to note that the restroom data may be due to sampling bias, as visitors who were in urgent need of the restroom and then quickly left were likely not going to stop to participate in our study.

Hot Spots

Combining all of the UWB data collected, a heatmap was generated (**Figure 17**). Brighter areas are the sections of the UWB grid that had more "visitations", with visitations being a combination of both the number of participations going to, and length of stay in, that area. This is able to shed light on what areas of the Visitor Center have the most people spending the most time.

Figure 17: Heatmap of Visitations from UWB.



The Park Information Desk and the Park Store are the points of highest congestion. As seen in the heatmap, the area with the highest visitation is the Information Desk and its line. This is likely due to entire parties going to the rangers and spending several minutes discussing trails, carriage roads, Junior Ranger program, etc. As such, both the desk and the line get congested.

Almost as bright in the heatmap is the Park Store. Similar to the Park Information Desk, the Park Store indicates high volumes of people spending significant time.

The Park Pass line is not typically congested. The Park Pass Desk and its line are relatively dark on the heatmap, indicating that they get low and/or short visitation. We observed a sign at the start of the queuing area asking parties to only send one visitor to purchase a park pass. This is likely a reason for the low volume of people in the line. Moreover, as the desk is just for purchasing a pass, visitors probably don't spend much time talking to the rangers at this station.

Figure 18: Heatmap for First-Time Visitors

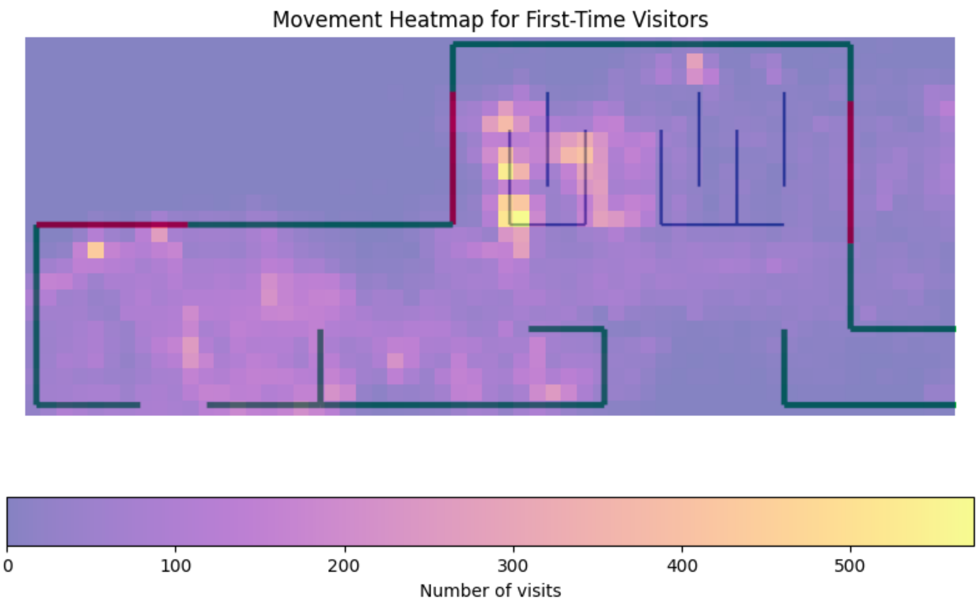
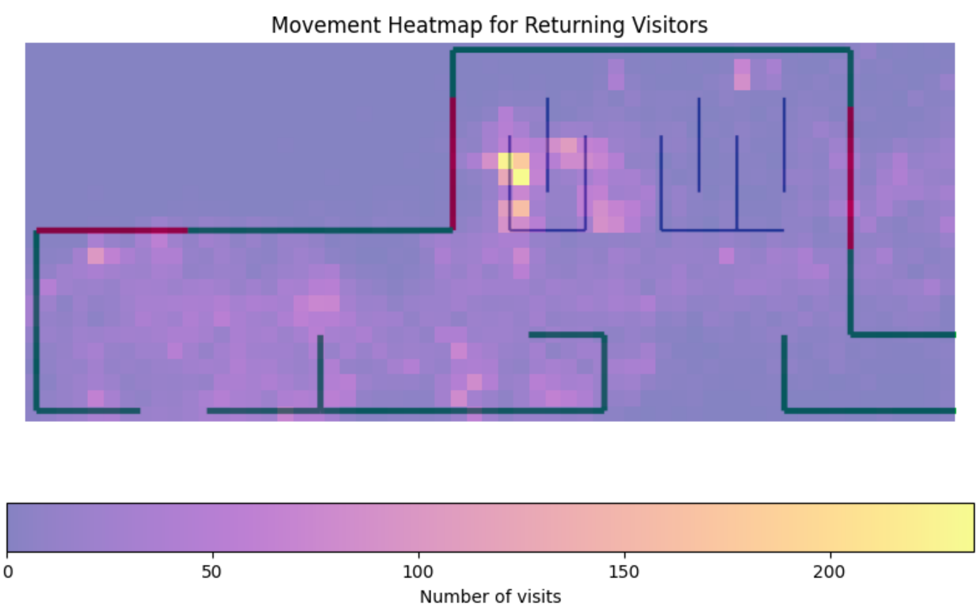


Figure 19: Heatmap for Returning Visitors



First-time visitors spent more time in the gift shop and park information desk line than returning visitors. Figures 18 and **19** display heatmaps filtered by whether or not the visitor had come to the Visitor Center before. There are notable bright spots around the park store and info desk in the former plot that are not as bright in the latter. This finding tells a reasonable visitor story. Those who already bought their souvenirs and knew about the park likely didn't need to repeat the process.

While this is not a groundbreaking discovery, it demonstrates how UWB can be used to study how different demographics of visitors move around the building in different manners. We collected data on gender, party size, first time visitation status, and whether or not the visitor was traveling with children. Due to time constraints, we did not collect an adequate sample size to find many meaningful patterns in the demographic filtered data. We do believe that this is an extremely powerful tool that future studies should leverage to better understand visitor mobility in different populations.

Path and Dwell Modeling

Through analyzing the order in which UWB participants moved between different attractions in the visitor center, we made a probabilistic model of visitor movement. This model informs us about the order visitors naturally visited different areas and where visitors were likely to enter or exit the building. The park can use our model to predict how visitors move through future visitor center designs.

For the purpose of this analysis, visitors were only considered to be "in" a space if they spent more than 30 seconds in the space. A soft-edge algorithm was used to prevent the logging of erroneous arrivals and departures of visitors standing on the edge of a space. Alongside modeling the order in which visitors moved between attractions, we also measured the time visitors spent in each space.

Figure 20: Park Store Entry and Exit Vectors

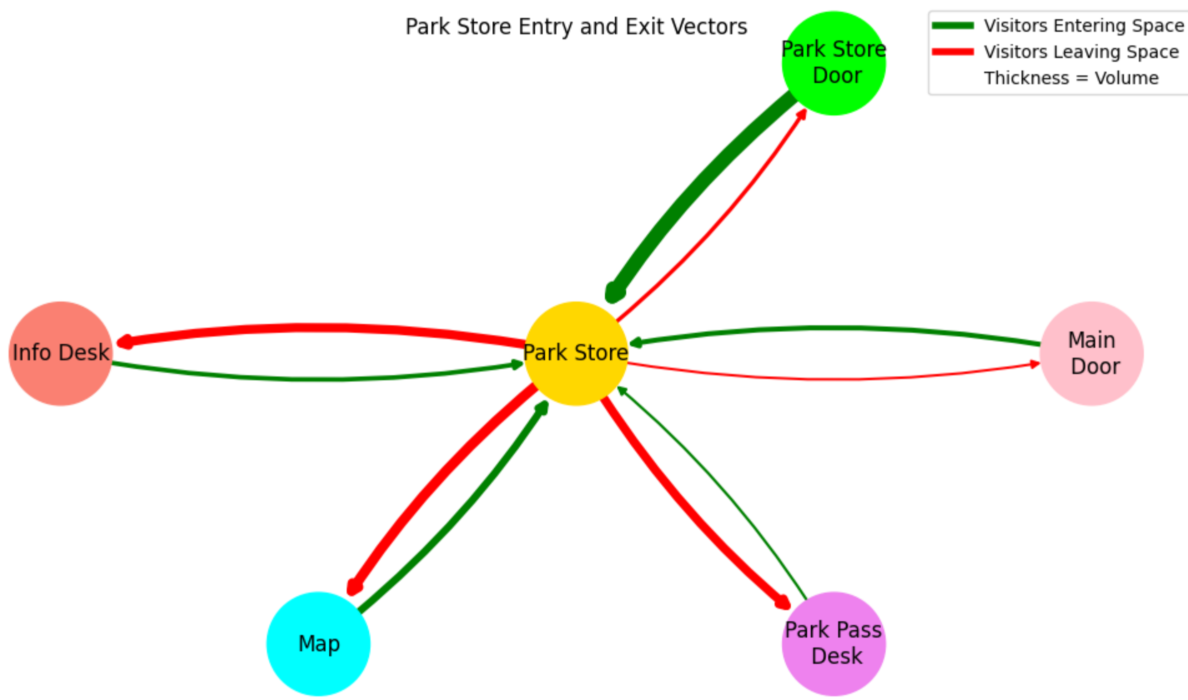
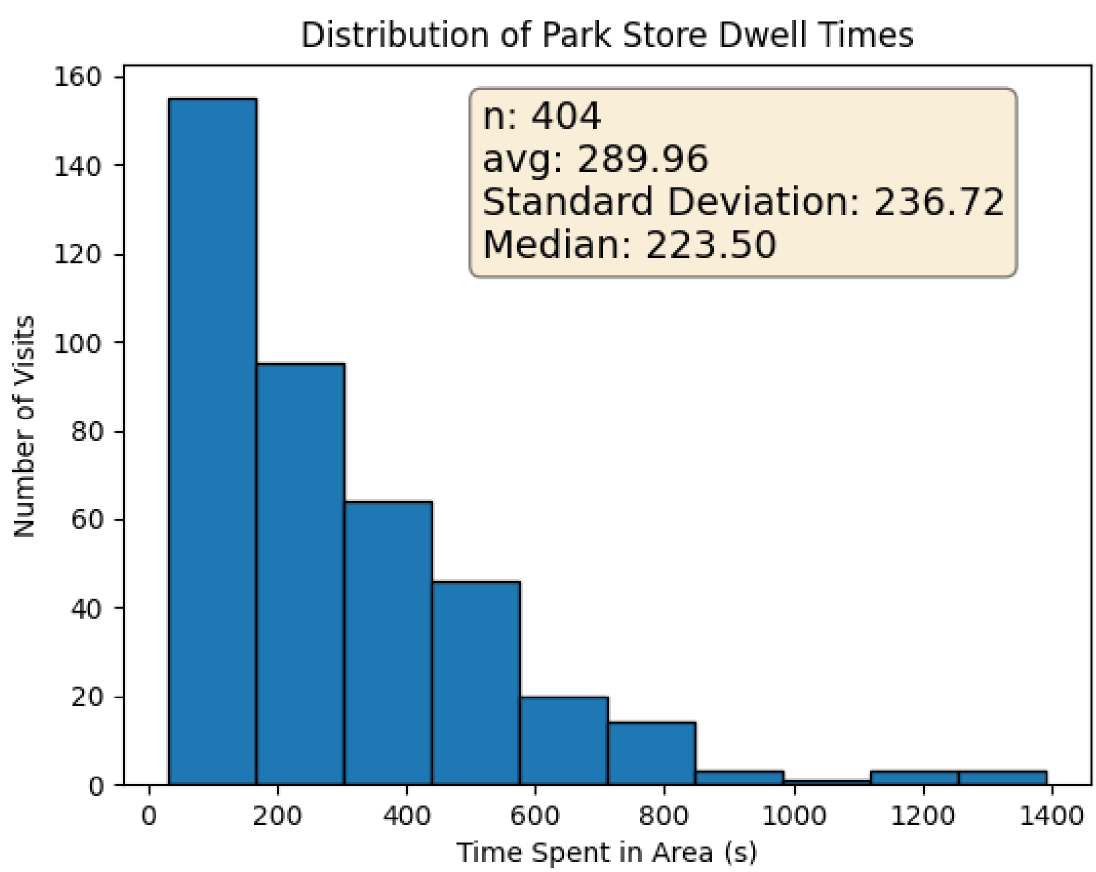


Figure 21: Park Store Dwell Time Data



The Park Store acts as a jumping off point for the Visitor Center. As shown in **Figure 20**, the park store sees similar entry volume from the park store door and the combined indoor areas of the Visitor Center. Visitors often roam around this area before continuing out to other areas of the building. After completing their time in the park store, visitors splay out all over the HCVC. The info desk, map, and park pass desk all get more visitors from the park store than they give to it.

Figure 21 demonstrates that the park store experiences a wide range of dwell times. While visitors in this area stayed for an average of 4:50, those within one standard deviation of the mean could stay for up to 8:47. A small, but significant, cohort meandered around for well over 10 minutes. This wide range of dwell times was expected in a gift shop, as some people tended to roam around browsing and others were dead-set on finding their item and heading to checkout.

This data, along with the heatmap discussed in the previous section, suggests that the park store is a critical spot for managing congestion. The high ingress from both the park store door and other areas of the Visitor Center can quickly oversaturate this relatively small area during peak hours. This is especially problematic seeing the low egress out the park store door--most visitors in this space exited through the door leading to the main lobby, which could create a chokepoint. Since this is such a popular first-stop, traffic in this area can impact whether visitors--notably those short on time due to bus scheduling--are able to reach other areas of the building in a timely manner.

Figure 22: Info Desk Entry and Exit Vectors

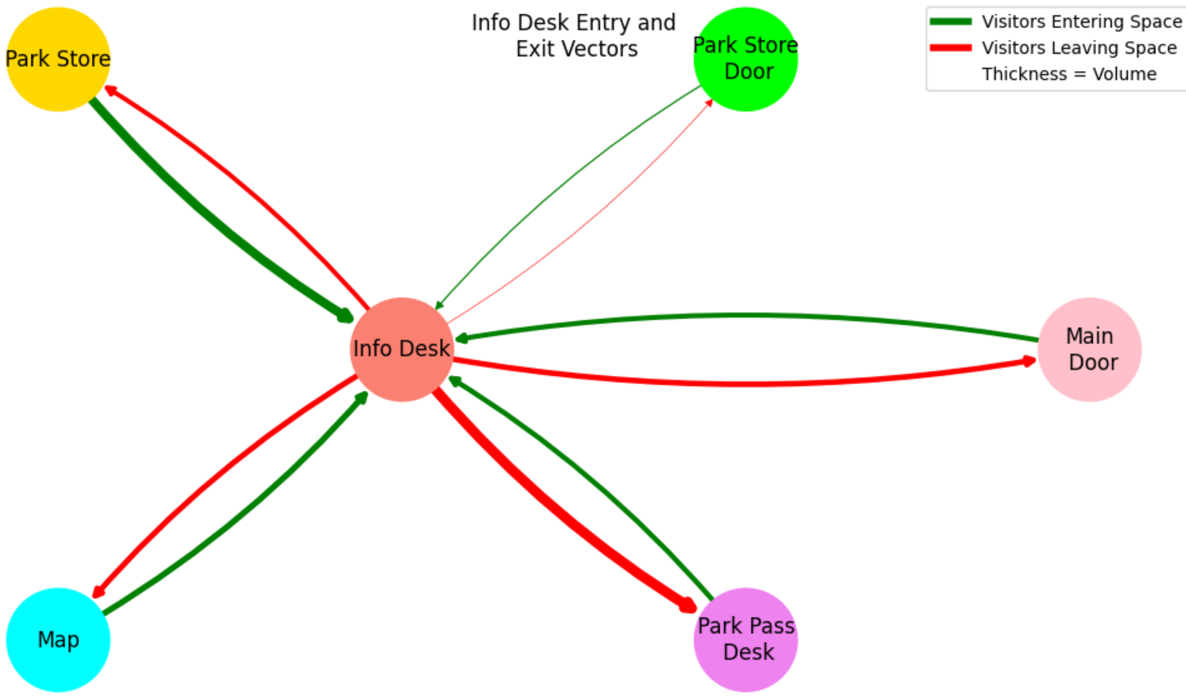
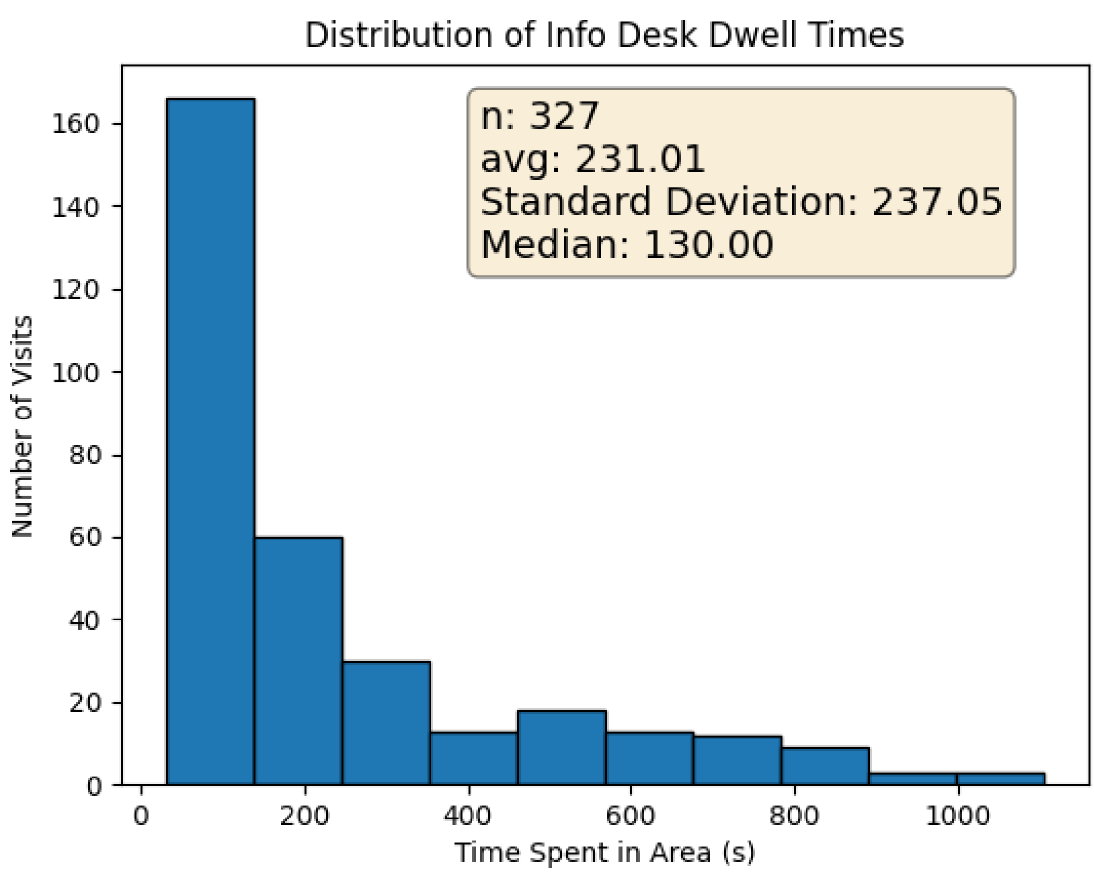


Figure 23: Info Desk Dwell Time Data



The Info Desk is a neutral destination. This area saw roughly similar ingress from and egress to all areas of the Visitor Center. While there was a small but notable tendency for visitors to exit to the park pass desk, it was still hard to predict where a visitor in this space came from or would go to. This undirected entrance and exit distribution makes sense in light of the area's offerings. The info desk provides visitors with an opportunity to speak with an expert to plan their day. Since different visitors arrive at the Visitor Center with different goals in mind, it is hard to generalize their behavior while planning their time in the park. Some may want to browse maps before talking to a ranger (another neutral destination; discussed below), others visit the gift shop before leaving for the day, yet others buy a pass and then figure out the details. There is not an outstanding intuitive order in which visitors need to visit the information desk to plan their day.

The diffuse transition vectors of the info desk come coupled with a similarly diffuse dwell time distribution. As seen in **Figure 23**, many visitors stayed in this space for under three minutes. These people could've been grabbing a free map, asking short questions at a time with no major lines, or--most likely--lingering in the measured area with no intention of visiting the desk. While these short-stay visitors made up the majority of logged visits to this space, there was a stable trail of long-stay visitors lasting from 5 to over 15 minutes. These long stays likely came from visitors waiting in line and speaking with rangers.

The exit survey, timestamp card survey, Bluetooth local data, and UWB heatmap all pointed to the info desk being the most popular destination in the Visitor Center. UWB path and dwell time data suggest that the best way to optimize this area of the HCVC is spreading the info out. As discussed in this subsection and below with the maps station, visitors in the planning stage of their trip wandered around. Unfortunately, there are only two productive places to wander to in the current Visitor Center: the maps and the info desk. If the park installed more interpretive opportunities, such as historical exhibits and topographical maps, visitors may be able to discover more about the park on their own and form more informed questions for rangers. As discussed later in **Recommendations**, our UWB path data shows that optimizing park education should be done through increasing opportunities for effective wandering--not serializing visitor experience.

Figure 24: Map Entry and Exit Vectors

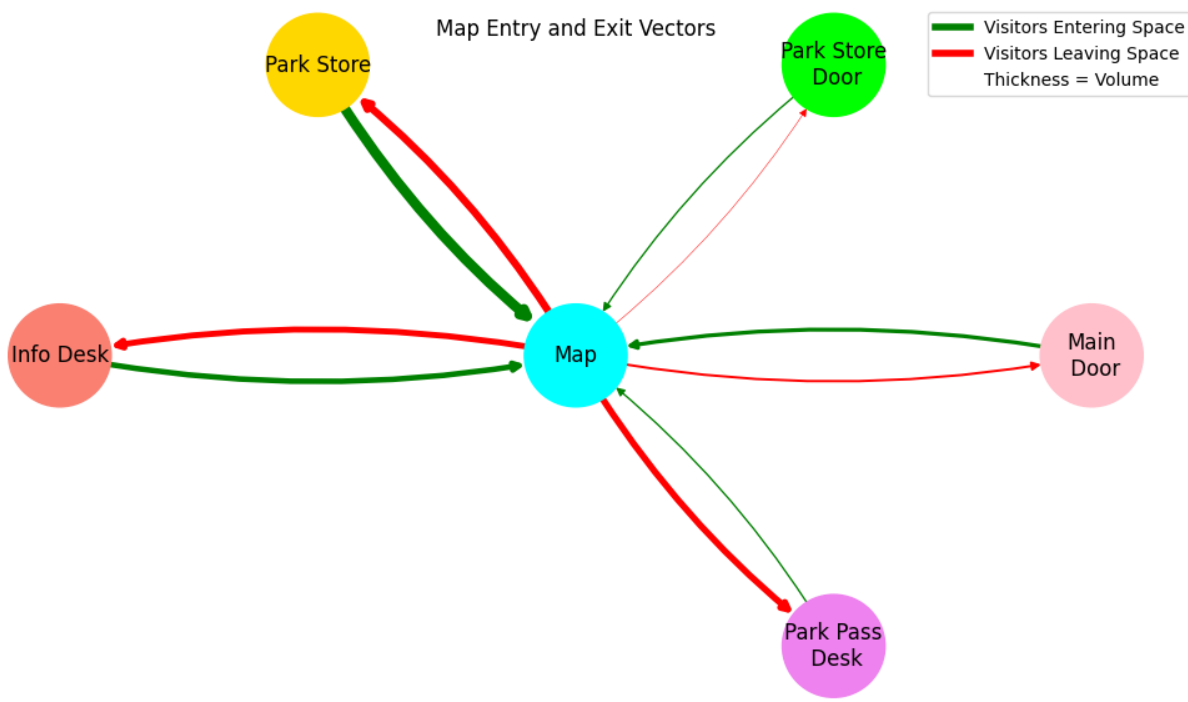
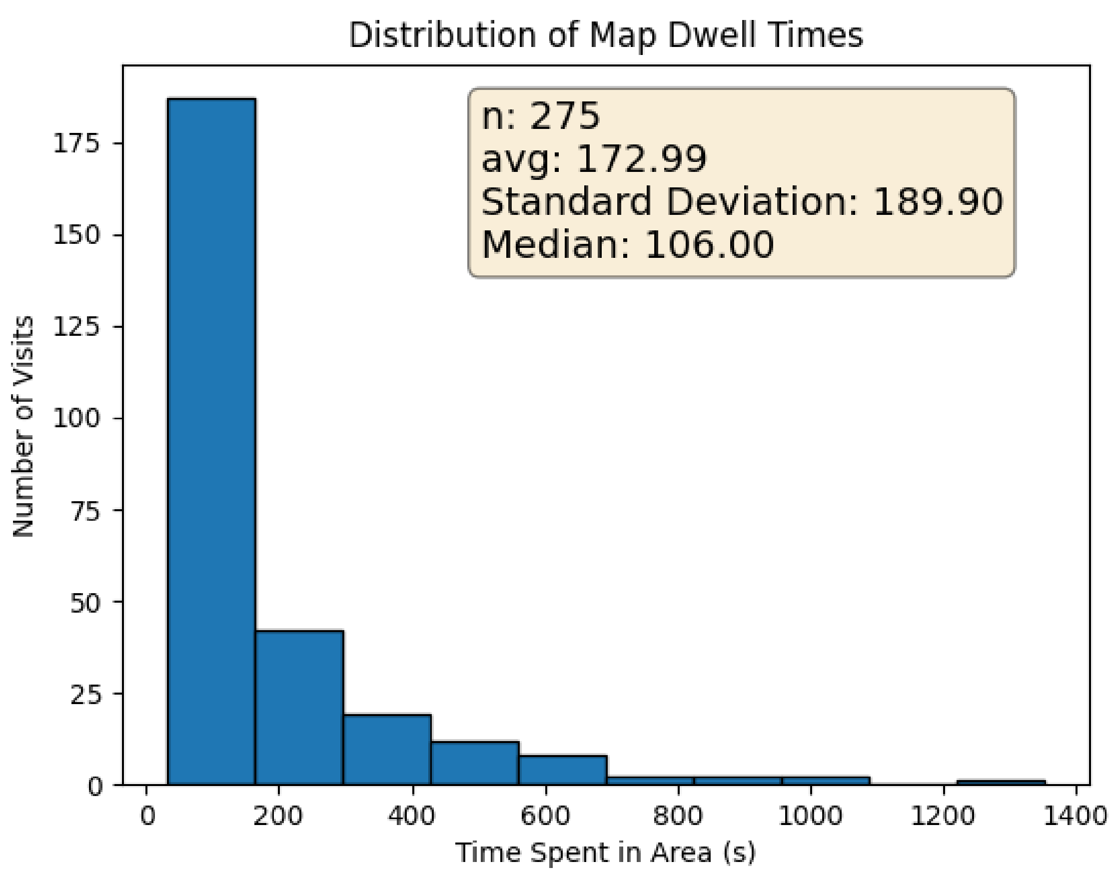


Figure 25: Map Dwell Time Data



Much like the Information Desk, the map alcove is a neutral destination. Visitors as a whole came into this area from all over and left in no particular direction. This is consistent with our findings on the info desk. Both of these areas provide a resource to visitors planning their day. While the info desk provides a space for visitors to ask an expert any questions they have about the park, the maps provide an opportunity for visitors to find information on their own.

The dwell times in the map area are by far the shortest in the entire HCVC. This checks out, as it is the only area we measured in which there is no line to wait in. Dwell times are tightly clustered within the 30 second to 5 minute range, with a few outliers. These outliers likely came from visitors who sat on one of the many benches in this area for a long period of time.

While the maps may not be the most visited area, the UWB pathing and dwell time data provided insight into how interpretive exhibits may be used in a future visitor center. Visitors went to the maps, stayed for as long or as short as they wanted to, and moved on. While the info desk is undeniably a more versatile resource, the maps provide a space for visitors to find information at their own pace. Interpretive exhibits play into the wandering, unpredictable movement of the planning visitor.

Figure 26: Park Pass Entry and Exit Vectors

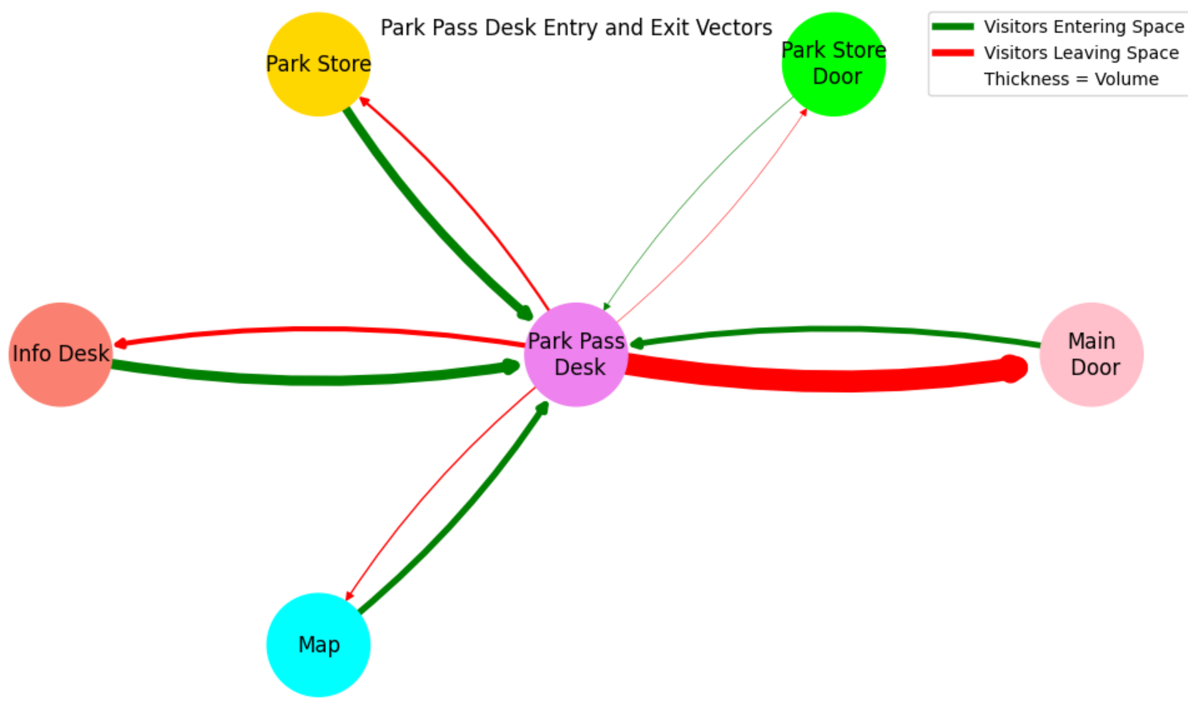
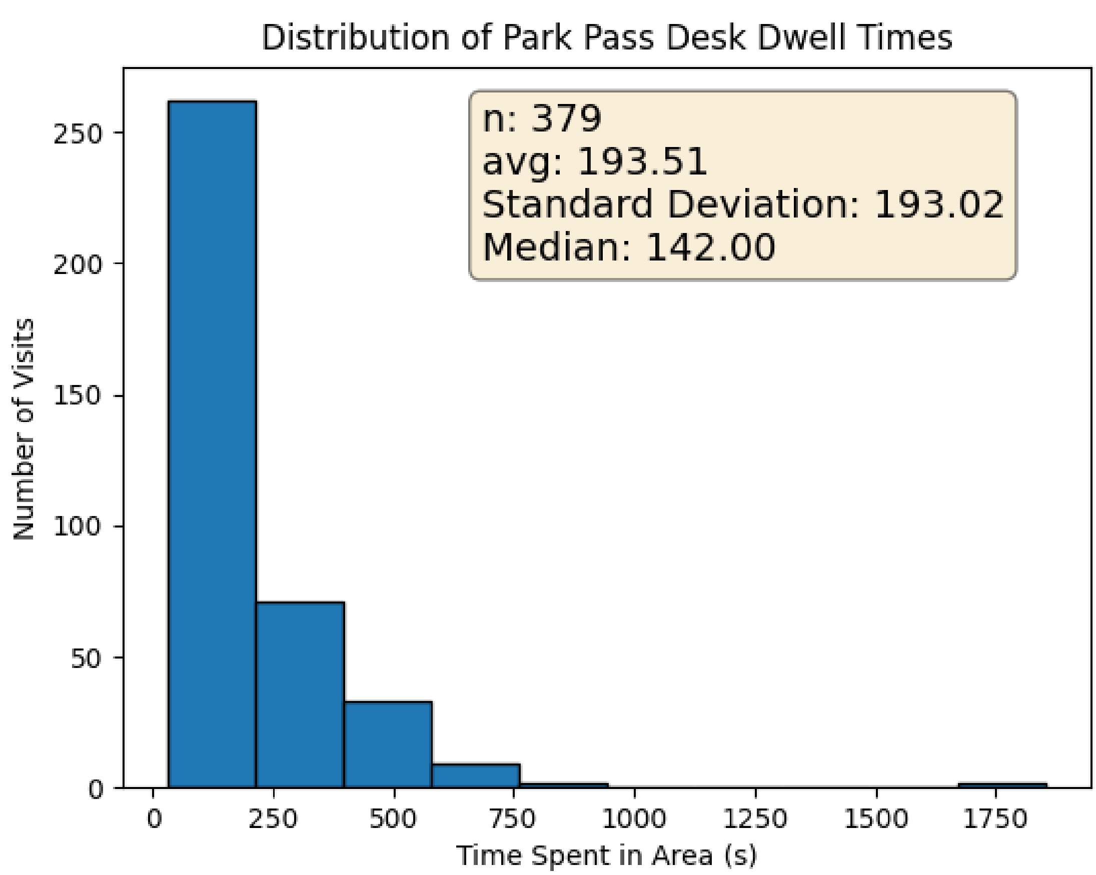


Figure 27: Park Pass Dwell Time Data



The Park Pass Desk acts as a concluding destination. While visitors came into this space from all over, the vast majority left this area by exiting out the main door. This massive egress bias suggests that many visitors use the Park Pass Desk as a last stop in the Visitor Center. Once a visitor has bought their souvenirs and gathered their park information, they headed out to their car and affixed their pass.

The distribution of dwell times in the park pass line corroborates its dimness on the UWB heatmap. **Figure 27** shows that the vast majority of visits to the park pass line lasted under 6 minutes. While there was a small subset of visitors spending up to 10 to 15 minutes in this area, this tail is nowhere near as notable as the one shown in the info desk data (**Figure 23**). Visitors just didn't spend enough time in this space to lighten up the heatmap like they did in the info desk line.

The park pass desk only attracts visitors who have the goal of buying a pass, as there is nothing else to do in this area. While people came from all over to fulfill this goal, most left through the main door. This pathing data suggests that--unlike the info desk and interpretive exhibits--the park pass desk is a candidate for serial optimization in the Visitor Center. Due to the overwhelming majority of people exiting after getting their pass, it may be beneficial to crowd flow to place this near a door as it is in the current visitor center.

Figure 28: Average Dwell Times for All Locations

Location	**Average Dwell Time**
Park Store	4:50
Info Desk	3:51
Map	2:53
Park Pass Desk	3:14

Visitor Experience

Surveys were implemented at the Visitor Center in order to gather data on how visitors felt about their experiences at the HCVC. These surveys had multiple choice questions for specific points of interest and an open feedback section. The exit surveys and the timestamp card verbal survey both asked what locations inside of the HCVC were visited, and how easy it was to move around. From the combination of these surveys, we gathered responses from over 500 visitors. **Most visitors don't perceive the building as being crowded or difficult to move around.** Most respondents rated the HCVC as a 2 out of 5 for crowding, where 1 is "Not Crowded" and 5 is "Extremely Crowded". Similarly, the typical visitor rated their ease of movement at a 5 out of 5, where 5 is completely unrestricted movement, and their overall visitor experience as a 5 out of 5. Open feedback on the surveys showed that many visitors would like to see increased clarity in lines and more parking.

Most visitors went to the Information Desk. Of the visitors who gave survey responses, 62.7% reported going to the Park Information Desk. This is corroborated by the aforementioned finding from the UWB method which showed that the Information Desk is a key point of congestion.

The bathrooms are a key issue for the visitor experience. A common complaint was that the bathrooms were too small or too few in number. It was also brought to our attention that the bathrooms often close for maintenance in order to be cleaned during the afternoon for about 20 minutes. During this time, visitors have to be directed downstairs to the handicap accessible entrance where there are 2 single use bathrooms. Considering that 52% of visitors from our surveys are there to use the restrooms, this is a serious cause of congestion. People are lined up on a narrow staircase to wait for the bathroom, and can potentially block the handicap accessible entrance.

The accessible lot/entrance is both poorly marked and too small. While there is an accessible lot, bypassing the 52 stone steps, many visitors with family members who have a disability made it clear to us that they were not aware of it. They said they never saw a sign for the parking lot itself and therefore would not have been able to utilize the accessibility entrance without going up the stairs to the Visitor Center to make the discovery. The signage that indicates the accessibility lot and entrance may not be sufficient. Additionally, 93.2% of participants in the Timestamp Card study came to the Visitor Center in a personal vehicle, yet the accessible lot has incredibly limited spaces.

Error, Bias, and Potential Improvement

Though our study collected a large amount of data regarding visitor mobility, there are a few places in which a future study could improve. In both the timestamp card and UWB methodologies, we likely undersampled visitors arriving at the visitor center on the Island Explorer shuttle. When asking people to participate in our study, many remarked that they did not have time because they needed to make their bus. Better understanding how those arriving on buses move around the visitor center will be critical for designing a visitor center that can handle the influx of people arriving from the Acadia Gateway Center.

UWB provided noisier data than we expected, which may have caused visitors to be logged as erroneously leaving or entering a space. This error is likely due to miscalibration of the anchors and using too few anchors in crowded areas. We believe that some of the short stays in the histograms may be caused by noise bouncing a visitor between spaces. Our fuzzy edge filter (discussed in **Appendix E**) could only be tuned so loose before it started missing actual data. As discussed in **Recommendations**, a commercial UWB system will have a higher sample rate and better localization accuracy. With large amounts of high quality UWB data, we could make a probabilistic model of foot traffic in the visitor center by mapping how likely a visitor is to travel from one heatmap tile to the next. This would allow for highly detailed random walk simulations.

While the global Bluetooth listener provided an accurate proxy measurement for visitor center crowd levels, we believe that local sensors often cross-sampled adjacent areas. If--in a future study--we obtain permission to temporarily log the discovered MAC addresses, we could average the RSSI of a device over time to better determine whether or not it is in a space.

Recommendations

The following recommendations mentioned are both short term and long term goals that the NPS can consider in order to improve the current HCVC, and to plan the layout of the next Visitor Center.

Provide more interpretive exhibits and opportunities to interact with rangers. All methods used in this study pointed to the information desk as the most popular destination in the Visitor Center. Visitors want to learn about the park and talk to rangers. The current building offers limited opportunities for this, with only an Information Desk and a small alcove filled with maps. At peak crowd levels, the Park Information Desk cannot effectively fulfill the needs of all visitors in a timely manner.

A future visitor center should be designed around educating visitors about the park. In conversations with visitors at our table, we heard that many were expecting a museum-like experience with topographic maps, historical exhibits, and a theater. These comments support our findings in the map and information desk areas of the UWB study, which showed that visitors tended to wander around when planning their day and learning about the park. Interpretive exhibits would provide visitors a resource to find their own answers and form more educated questions for rangers.

Alongside exhibits, it may be beneficial to expand and better delineate ranger coverage in the Visitor Center. Visitors had glowing reviews of the rangers, but often complained of the wait to talk to them. Aside from creating annoyance for those waiting in them, long lines can drive visitors away from speaking with rangers. While conducting our experiment, many visitors came to us to ask questions about the park. When we redirected them towards the rangers inside, many responded that they didn’t want to wait in such a long line. Staffing more rangers at the

Information Desk is the most straightforward way of reducing wait time; more rangers can handle more visitors. Providing a separate area for children's programs, such as Junior Ranger and GeoTour, may boost engagement with families who do not want to wait in a long line with children. While expanding staffing is monetarily and human-resource expensive, our data and conversations with visitors suggest that it might be the most effective way to improve visitor experience and better educate them about the park.

In future construction, restrooms should be expanded and include after-hours access. One key issue with the Hulls Cove Visitor Center is the current standing of the restrooms. They are cleaned throughout the day, being shut down during this time for about 20 minutes. This means the only available restrooms are the handicap accessible restrooms on the bottom floor of the HCVC, which many visitors were not aware of. For those who did know about it, they sometimes caused congestion in the stairwell that goes down to these restrooms. A short-term solution could be to only close one bathroom at a time upstairs so that not everyone has to funnel downstairs.

Also, many visitors said that they expected a restroom to be available to use when the Visitor Center was not open. As seen in the floor plan, there are 2 sets of doors at the main entrance, and before the 2nd set of doors that leads into the main lobby, there is a door to the restroom area on the right hand side once you go through the first set of doors. A short term solution for this issue is to have this first set of doors and the door to the restrooms stay unlocked for visitors to use before and after the regular operating hours of the Visitor Center, as the building is designed in a way that this would not cause a breach in the security. A long term solution for this issue with the restrooms is that an outdoor facility could be built by the entrance. This would help with both the issues of maintenance and visitors coming to use the restrooms outside of normal hours. Allowing visitors to use the bathroom during all hours of the day could improve visitor experience and reduce the impact of human waste on park biota.

Continue Crowd Monitoring. To further gather data on crowd trends, we recommend that the HCVC be fitted with a permanent Bluetooth MAC counting system (or comparable crowd meter). This will allow for the park to continue monitoring the crowd levels at the HCVC, and could even be utilized in other indoor areas of the park, such as the Jordan Pond House. Furthermore, ultrawideband tracking could potentially be continued via the National Park's mobile app, configuring the Apple U1 chip as the UWB tracking tag (*Ultra Wideband Security in IOS*, n.d.). Through our research, we only gathered a maximum of 15 days worth of data, and that alone led to very strong findings on visitor use and mobility. Further research would allow for an even greater understanding of visitor movement, and allow the park to study the areas where our research had gaps (such as the restroom lobby and the lower floor). This better understanding of crowd patterns could help the park make more informed decisions about staffing, reservations, and bus routes.

Appendix A: Timestamp Card Spreadsheet

Figure 29: Example of Timestamp Card Spreadsheet

Barcode	Time	Returned?	Total Time	Reasons	Transport	Group	Rating
100020	12:32:13 PM						
100020	12:37:05 PM	YES	0:04:51	ABD	A	BC	4
100021	12:43:56 PM						
100021	12:55:08 PM	YES	0:11:12	ABD	B	B	5
100022	12:45:16 PM						
100022	12:57:16 PM	YES	0:12:00	AB	A	B	5
100023	12:51:33 PM						
100023	1:04:08 PM	YES	0:12:35	BCD	A	C	5
100024	1:28:41 PM						
100024	1:39:36 PM	YES	0:10:55	BC	A	A	4
100025	1:50:23 PM						
100025	2:01:38 PM	YES	0:11:15	ABCD	A	B	5

Visitor entry and exit timestamps were recorded using a spreadsheet that utilized date and time functions. The barcode on the lanyard was scanned using a USB barcode scanner and automatically inserted into the actively selected column of the spreadsheet. The second column had a function with the "NOW" function inscribed within an IF statement. Our function displays the current time in the column if, and only if, the corresponding barcode cell has a value in it. The cell effectively utilizes the NOW function; which displays the current date and time in a serial number format. By formatting this column to be in time format, it displays the equivalent hour, minute and second from the serial number. The full function is shown below in **Figure 29**.

Figure 30: Automatic Time Function Formula

=IF(A2<>"",IF(B2="",NOW(),B2),"")

The third column will tell us if the barcode has been returned based on if the barcode has been scanned again, and the barcode number itself in the first column will also be highlighted green. This was achieved by using conditional formatting to highlight a barcode green if there is a duplicate. This could be problematic, as we might use the same barcode more than once during a day. For this reason, we made sure to hand out the timestamp cards in order of their number, and cycle through them. Once we handed out all 44 of these timestamp cards, we would begin a new sheet in excel and continue recording data. The final column will subtract the exit time from the entrance time, but only when the barcode has been scanned twice, otherwise the total time section will remain blank. The last few columns are questions from the verbal survey that was mentioned in the Methods section of the report. The reasons are for the question, "What did you do inside of the Hulls Cove Visitor Center today?". The possible reasons for our verbal survey are shown below in the table.

Figure 31: Timestamp Card Participants Reasons for Entering the Visitor Center

Letter	Reason(s) for Entering Visitor Center
A	Waited in line for a Park Pass
B	Acquired general information about Acadia
C	Used the restrooms and/or got water
D	Went into the gift shop
E	Used the NPS passport stamp

For each day that data was collected, there was a different sheet within the excel file to specify the date of the dataset. And at the end of each day, the data would be saved locally on the personal laptop it was on. Then, the data was consolidated into a separate file containing the data from every day the timestamp card data was collected.

Appendix B: Hardware Installation

The installation process was split up into 3 days of installation. The first day consisted of running ethernet cables through the HCVC to determine the length of the wires that run from respective anchor locations to the ethernet switch. We determined the length of each wire by having one person hold the wire up to the wooden lattice directly above the location of the ethernet switch **(Figure 43)**. Then, the wire was run along the lattice to where the device it is connected to would be mounted. Four feet of slack were added to this length of cable, and then it was cut. This was repeated for all anchors and Bluetooth listeners and each cable was coiled neatly and labeled with its respective anchor location.

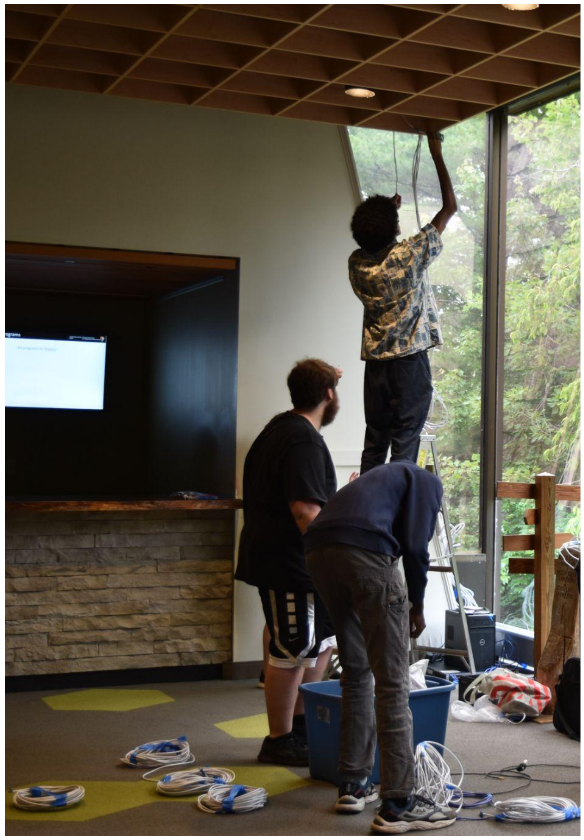
Figure 32: Neatly coiled ethernet cables

It is important to note that the four anchors in the park store needed two separate cable measurements; one cable from the ethernet switch to the wall above the park store gate, and a second cable from inside of the park store to the respective anchor location. This was necessary because when the HCVC is closed, the gate between the park store and the main lobby area must be closed.

Next, all of the ethernet cables had to have a Cat6 connector attached to each end of the wire. This process involved stripping each end of the wire carefully, and reorganizing the electrical wires that were twisted together. After the wires were placed in their respective order, they were inserted into the Cat6 connector, and then the connector and cable were crimped using a crimping tool designed for Cat6 connectors. This process was repeated for the ends of every wire, and each wire was recoiled and labeled with its respective anchor.

On the second day of installation, all of the ethernet cables were installed. This process involved us bringing back the ethernet cables, running them to their respective anchor location, and fastenting them in place. We started from the location of the ethernet switch, and ran each of the wires up above the wooden lattice.

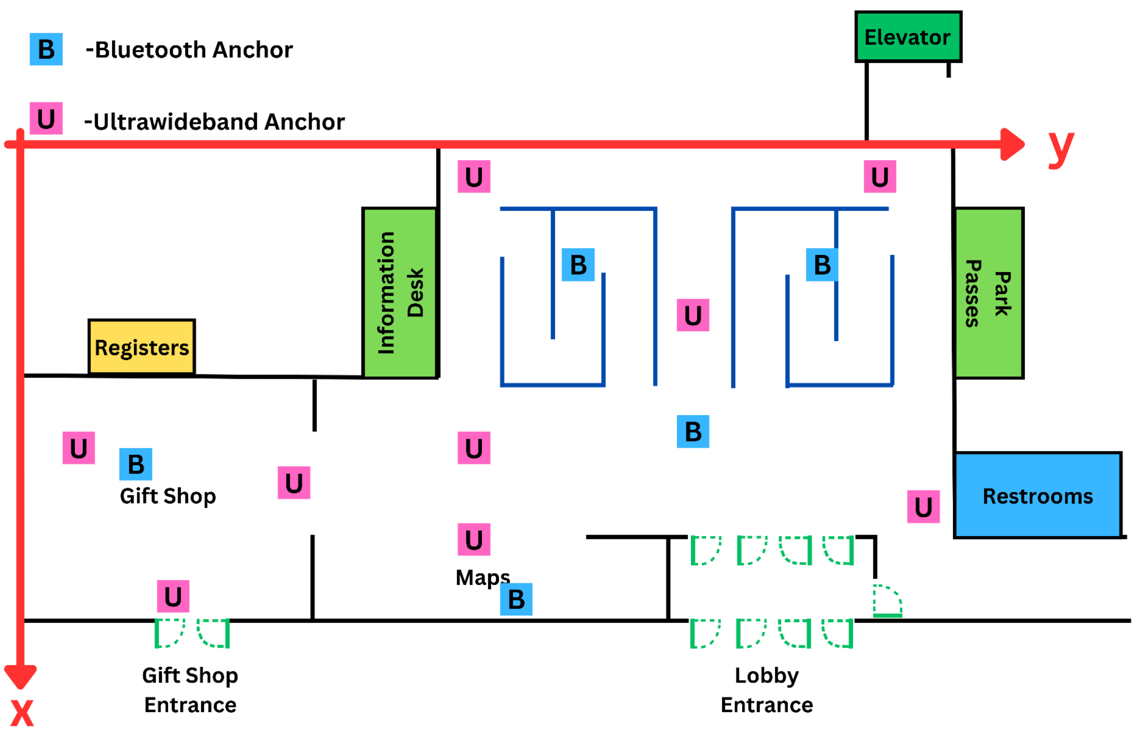
Figure 33: Wiring directly above the ethernet switch



Most of the wires were fastened to this corner of the wooden lattice using a 3M zip tie mount and a zip tie to secure the wires to the mount. Each wire was positioned to have the most direct path to the anchor while also attempting to keep the wires hidden from the line of sight of a visitor inside the building. Some fasteners were included in between the location above the ethernet switch and the location of each anchor to make the layout of wires as neat as possible. There were also wires fastened to walls to prevent sagging cables when transitioning from the wooden lattice. In total, we ran over 1400 feet of cable in this manner.

The final day of installation involved the installation, calibration and testing of UWB anchors and Bluetooth listeners. All of these microcontroller devices were fastened to either the wooden lattice, a wall, or a ceiling using hook and loop fastener command strips. For the calibration of the Ultrawideband anchors, we had to record the exact X, Y and Z position of each anchor in terms of a cartesian coordinate system of the HCVC, shown below in **Figure 33**.

Figure 34: HCVC Cartesian Coordinate System



All of these coordinates were measured using a laser measuring device. When an Ultrawideband anchor was attached to the ceiling, the laser was directed straight down and the height was recorded. The location directly below was also marked with painters tape and a sharpie. Using the point directly below the anchor, the exact distance from this point to our predetermined x and y axis of the HCVC were then measured using the laser. It is important to note that some reference measurements had to be made for some anchors as not every anchor had a direct line of sight to both the x and y axis. These coordinates were recorded for each of the

Ultrawideband anchors and used for the programming and calibration of the anchors to accurately locate a UWB tag.

To calibrate the Bluetooth listeners, an ESP32 loaded with testing software was held up on the ceiling using a long stick. The software on this device output over serial all nearby MAC addresses found in a ten-second scan along with their corresponding RSSI. An iPhone with a known Bluetooth MAC address was moved along the edge of the space we wanted the Bluetooth listener to measure. To calculate the threshold RSSI for the space, we took the average of all RSSI measured along the edge of the space. In future experiments, this methodology could be improved by varying the type of device sampled and adding a negative bias to the threshold to prevent cross-sampling with other areas.

Figure 35: Bluetooth Calibration in HCVC

Appendix C: Network Logistics

Since the Hulls Cove Visitor Center did not have an internet connection that we were permitted to use, we utilized a Local Area Network (LAN) to facilitate the operation of our Bluetooth Listening and UWB methodologies. The first major component of this network was the desktop workstation, which hosts the surveys, UWB driver, and databases. This computer was plugged into a 48-port (1U) network switch with power-over-Ethernet capability. This switch provided power and communication with the server to all microcontrollers used in this study. The final major components of the network were the wireless access points. These provided access to server resources at our setup outside the Visitor Center.

The Server

A desktop workstation running Ubuntu Server acts as the central controller in our system. It hosts several applications to enable communication with microcontroller devices as well as process and store data. Since this computer is operating on a local area network with a potentially fluctuating number of connected devices, it runs a DCHP server to assign IP addresses to all connected devices. This enables all other applications to communicate between multiple devices. MQTT is the primary inter-device communication protocol used in this network. Its lightweight nature allows for it to run efficiently on microcontrollers. The server acts as the hub for all MQTT communication by hosting the Eclipse Mosquitto Broker. As discussed in the following sections, both the UWB tracking and Bluetooth Listening methodology utilize MQTT to transport data from ceiling mounted microcontrollers to the server.

UWB Server-side Application

The UWB application is split in two parts: the survey and the anchor driver. We host the surveys locally using LimeSurvey, an open-source web application for making and conducting surveys. This application stores all survey responses in a MySQL database. By connecting to the WAP and accessing LimeSurvey through the browser, we are able to conduct surveys from a table outside the Visitor Center. A custom plugin for this software executes an HTTP request containing the unique survey ID when the UWB survey is completed. This request is processed by the anchor driver, which activates the next available tag.

The anchor driver Python script performs three main tasks: tag activation / deactivation, ranging tags, and multilateration. Tag activation is facilitated by a Flask thread Listening for GET requests from the LimeSurvey app. On a received request, the script puts the lowest indexed inactive tag into the pool of active tags and posts a line to InfluxDB denoting the received survey ID as “virtual ID” of the tag. The virtual ID correlates one use of a tag to one survey response. Tags are deactivated by manually publishing the tag ID to the ‘deactivate’ MQTT topic.

Ranging Tags

Getting the cartesian coordinates of a tag in the visitor center requires communication between the server, anchors, and tag. To initiate the ranging process, the server sends a set of MQTT messages telling each anchor to range a certain tag. Importantly, no two anchors range the same tag at the same time. If an anchor gets a range to a tag, it publishes it to the MQTT broker. After a short delay to allow all anchors to range and publish, the server repeats the process and tells all anchors to range a different tag. This pattern repeats until all anchors have ranged all tags. The entire process takes approximately 0.5 seconds.

If after all anchors range to all tags, a tag has at least three valid readings, the program can obtain the XY position of the tag. The position is acquired from the set of ranges using a geometrically-constrained least-square-error (LSE) algorithm. After calculating the coordinate, the program publishes a new row to InfluxDB, containing the tag ID, position, and a timestamp. A series of these cartesian coordinates comprise the path of a visitor in the Visitor Center.

Bluetooth Server-Side Application

To collect data from the array of Bluetooth listeners, the server runs a Telegraf MQTT-consumer agent. This program subscribes to the topics that the listeners publish to, and transform received messages into Line Protocol that InfluxDB can consume. Every publication from each sensor is logged as a new row in the database containing the ID of the listener, the number of devices detected, and a timestamp. For details on how the ESP32 Bluetooth listeners collect data, please see the Bluetooth section in **Appendix D**.

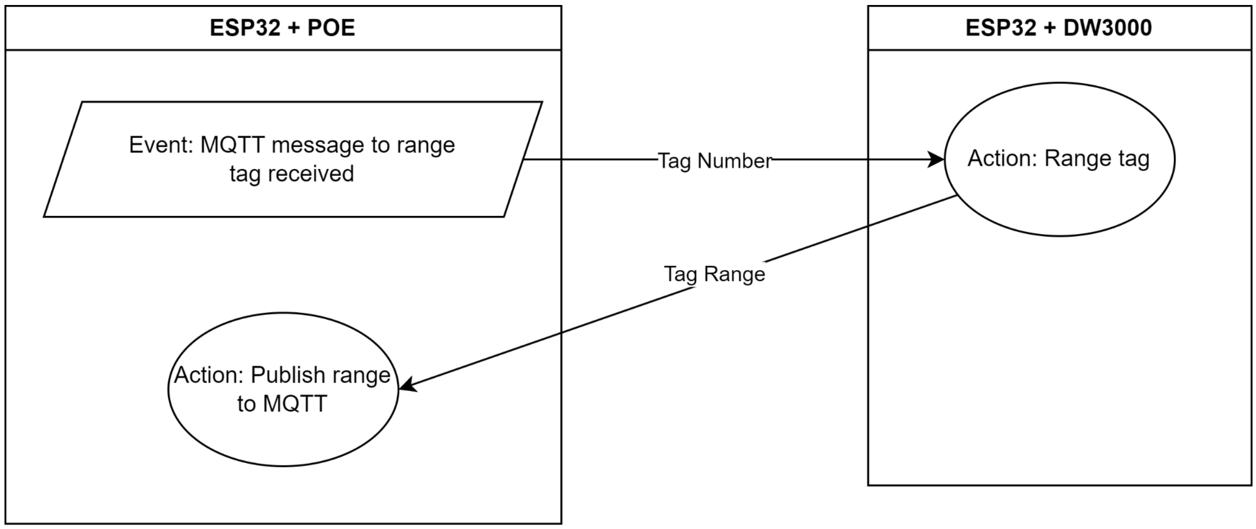
Appendix D: Microcontrollers

As discussed in the methodologies section of this paper, we used two microcontroller-based methodologies to monitor crowd levels in the Visitor Center. Both the UWB and Bluetooth Listening methods utilize ESP32s to collect data.

UWB Anchor

The most complex piece of hardware in our experiment was the UWB anchor. This device consisted of two ESP32s: one with POE capability and another with a DW3000 UWB antenna module. The two microcontrollers communicated with one another using a UART serial interface. The POE capable ESP32 was connected to the switch via Ethernet, which provides power and a data connection to the server. The DW3000 ESP32 was powered from the 5V pin of the POE board. The POE board conducted all MQTT reception and transmission operations. Upon receipt of a request from the server to range a certain tag, this board sent the tag ID over UART. This signaled the DW3000 equipped ESP32 to begin ranging to that tag.

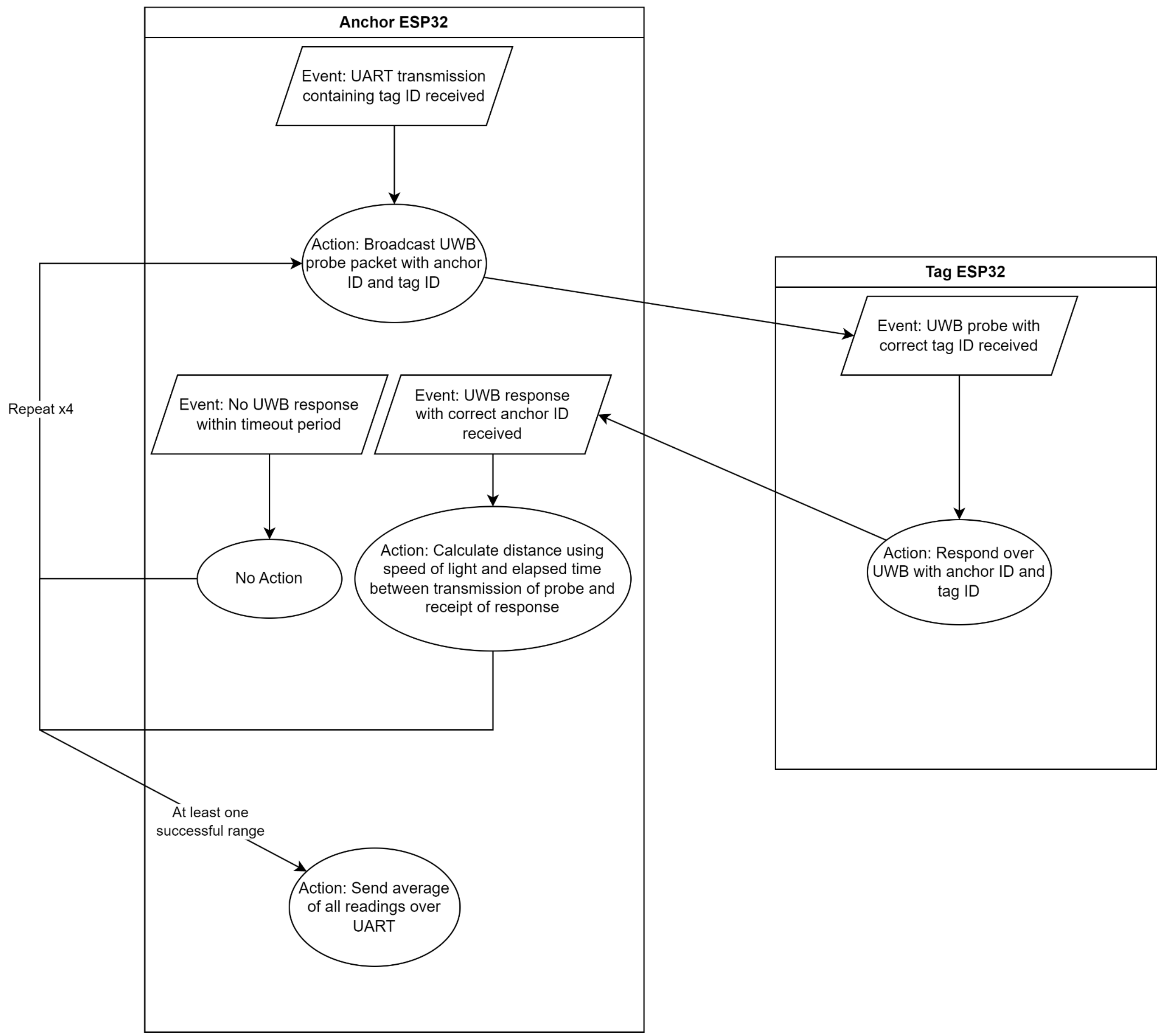
Figure 36: The ESP32 + POE Used UART to Trigger the ESP32 + DW300 to Range a Tag



UWB Tag

The UWB tag consists of an ESP32 with DW3000 module and a 3.7 V 850 mAh lithium-ion battery. With a full charge, the device lasts for approximately four and a half hours of continuous use before performance degradation occurs. The UWB tag constantly listens for probe packets and responds when it receives a valid one. The details of the ranging exchange between anchor and tag are detailed in **Figure 36.**

Figure 37: Ranging Exchange Between Anchor and Tag



Bluetooth Listener

The Bluetooth listener consisted of an ESP32 + POE module along with a fan due to the thermally strenuous nature of high-uptime Bluetooth radio. The ESP32 listens for Bluetooth and

BLE advertising packets and counts each unique MAC address received within a ten-second interval. MAC addresses are only counted should their RSSI exceed a threshold unique to each listener. This threshold exists to limit the range in which the listener counts Bluetooth devices. After the listener finishes counting MAC addresses, it publishes the count of devices to the appropriate MQTT topic. The server transmits any data to the Bluetooth listener.

Appendix E: UWB Analysis Software

We used a Python script to convert the set of points comprising a UWB participant's footpath to a directed graph of the locations they visited. This algorithm consumed in order the timestamped cartesian coordinates of the visitor's path. When it detected a point outside the visitor's currently established space (that is, the attraction where the visitor is known to be), it initialized accumulators for several criteria to determine whether or not the visitor had left the space. If the next point was also outside the established space, the accumulators ticked up. If it was back inside the established space, the accumulators were zeroed.

The algorithm to obtain this data looked at three criteria to determine whether or not a visitor has left a space: number of readings, time, and absement (first time-integral of position). The number of readings are used as a criteria to prevent erroneous location switches in areas with noisy coverage. One point randomly six meters outside the space is likely just noise. The time limit prevents logging departures for visitors who briefly step out of a space or stand near its edge. The final criteria, absement, provides a balance of retention and expulsion for visitors spending long times on the edge of a space. Visitors barely outside their established space will need to spend a long time in their position to be counted as out, while those far away from the space will quickly satisfy the absement requirement.

The hyperparameters for this algorithm were set as follows: minimum five consecutive readings, 30 seconds between first and last reading, and 10 meter-seconds of absement. While these parameters are rather conservative, we feel that any more aggressive than this could border on "dressing up" the data.

Appendix F: Images

Figure 38: Disassembled UWB Tag

Figure 39: Disassembled UWB Anchor

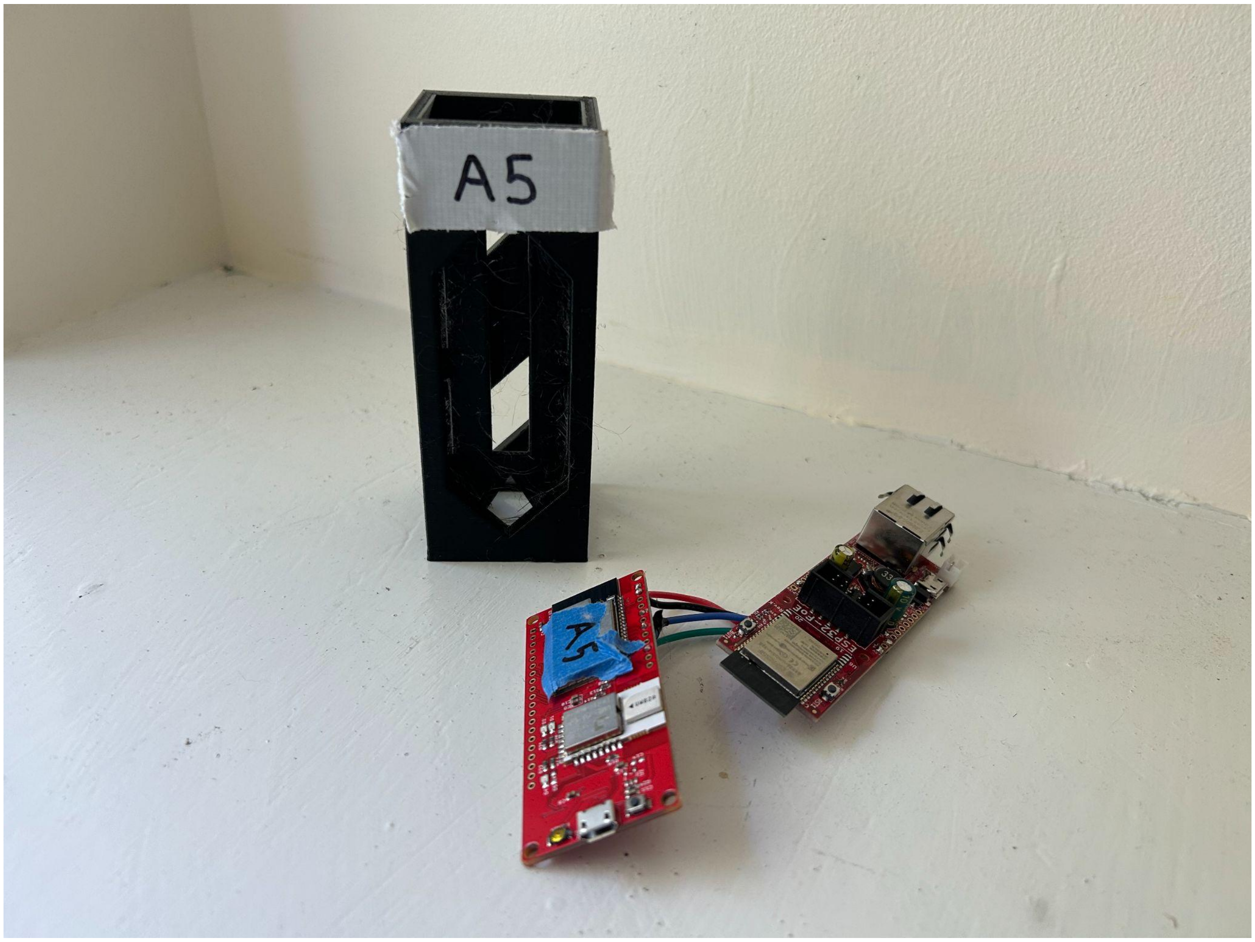


Figure 40: Disassembled Bluetooth Listener

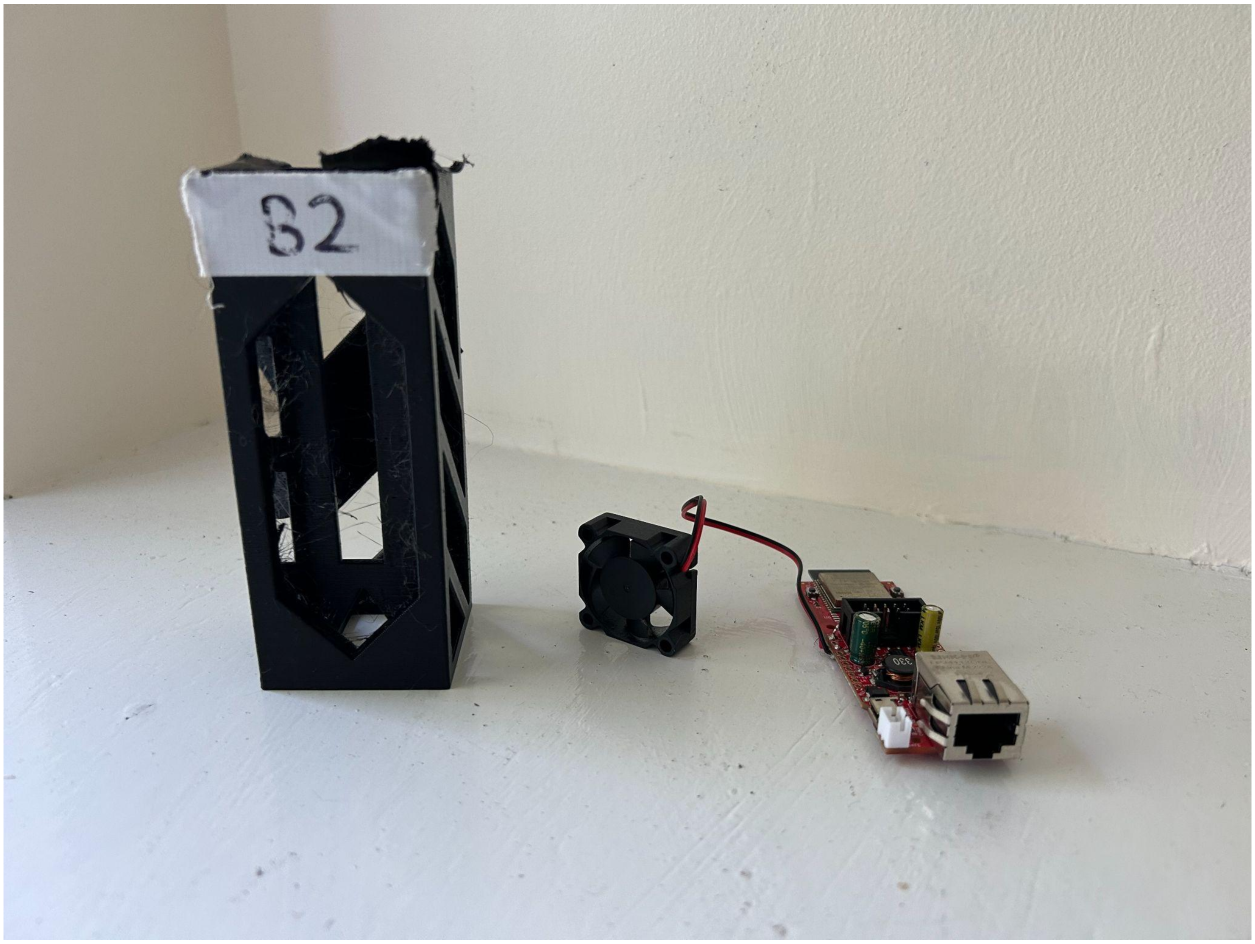


Figure 41: ESP32 + POE Module

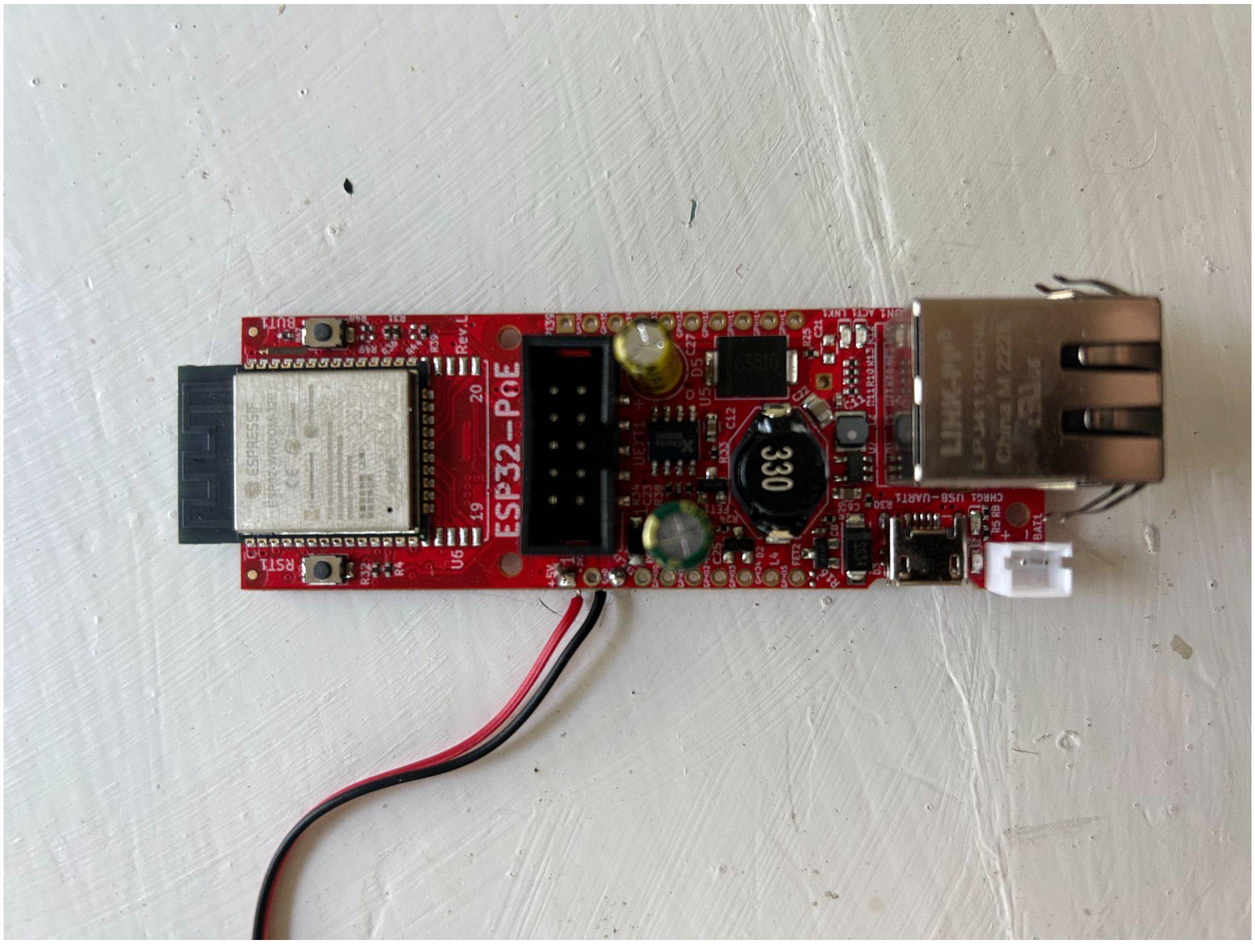


Figure 42: ESP32 + DW3000 Module

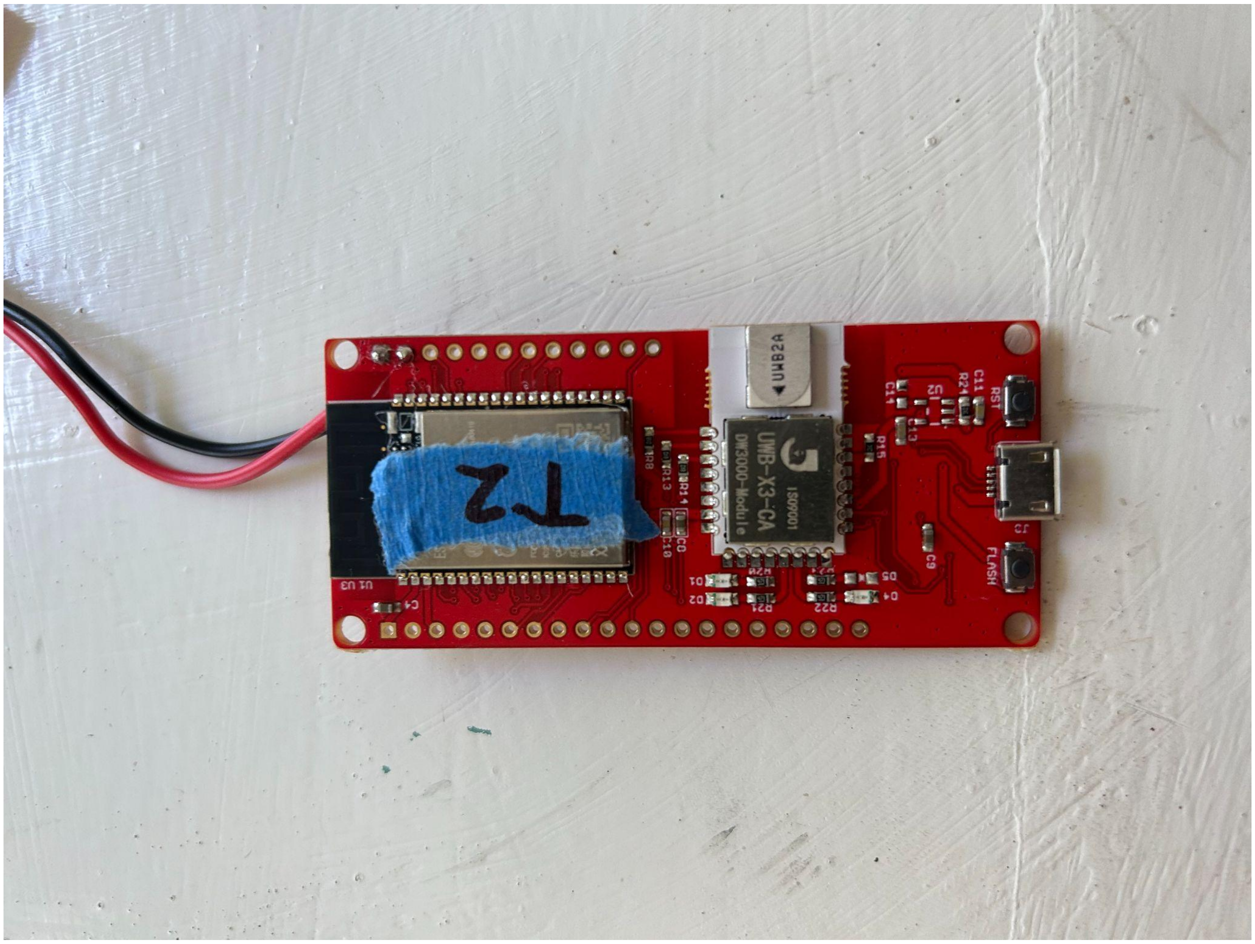
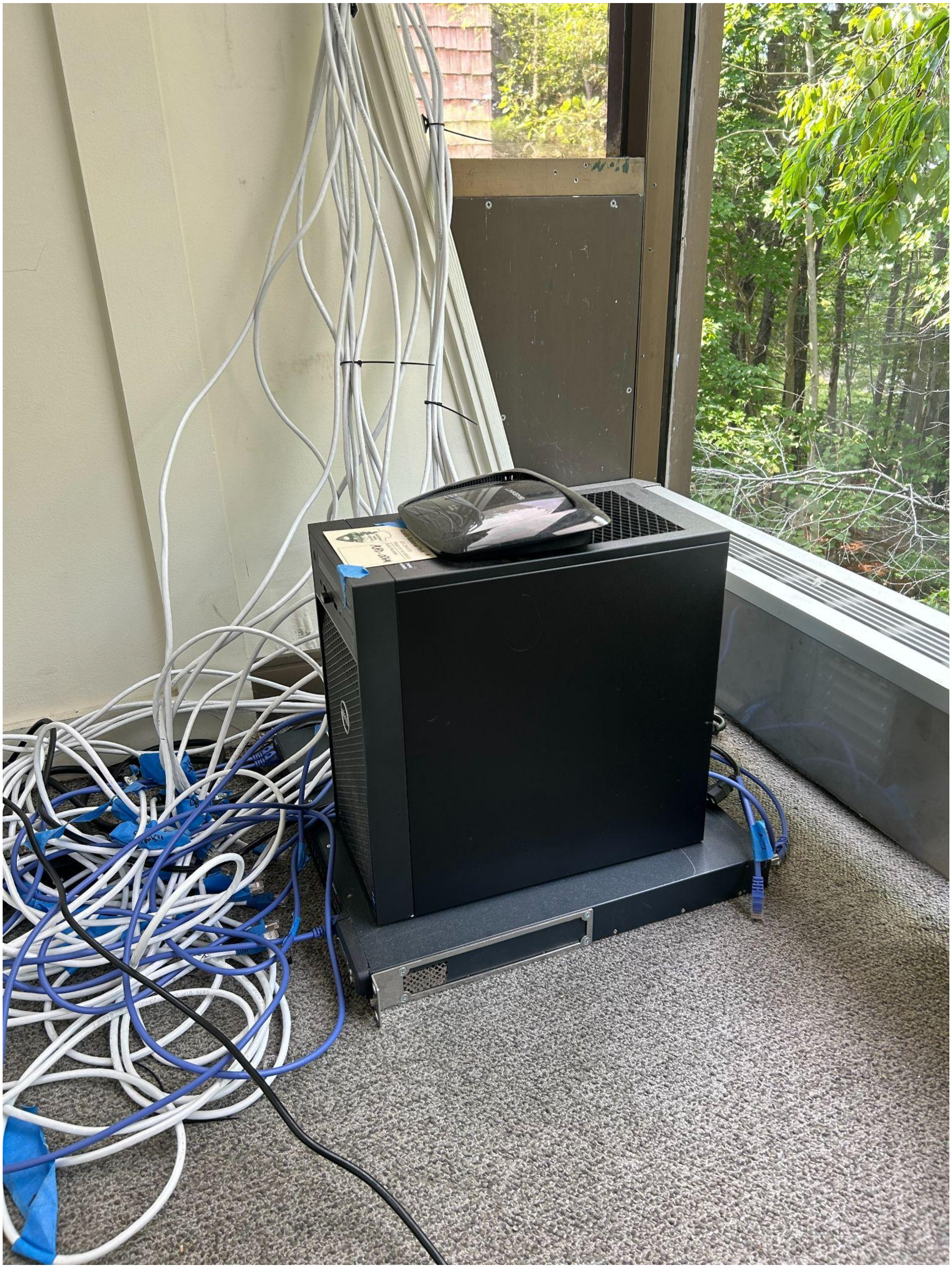


Figure 43: Server

Figure 44: Switch

Figure 45: Server and Switch Set Up in HCVC



Appendix G: External Links

Program for UWB Anchor ESP32-POE:

https://github.com/Acadia-Mobility-IQP-2023/Anchor-MQTT-Bridge

Program for UWB Anchor ESP32-DW3000:

https://github.com/Acadia-Mobility-IQP-2023/Anchor

ESP32-POE Bluetooth Sniffer Program:

https://github.com/Acadia-Mobility-IQP-2023/Bluetooth

Full dumps of InfluxDB (in line format) and MySQL (in MySQLdump format) servers:

https://github.com/Acadia-Mobility-IQP-2023/Data-Dumps

Survey responses:

https://docs.google.com/document/d/179XD9wmvdq8izil40UwTXe5IedFExWxyALyqaI2KsxE/edit

For inquiries about other programs used in the project, contact sjhonor@wpi.edu

Appendix H: Parking Lot and Island Explorer Study*

Project Goals

For this subproject of the Visitor Mobility at The Hulls Cove Visitor Center project, the research work was concentrated on the movement of vehicles in and out of the parking lot and usage of the bus transportation system. As the construction of a new Hulls Cove Visitor Center (HCVC) is planned for sometime in the next 5-10 years, this assessment will be useful in informing plans for the new center.

Automobile traffic has been a long-standing problem at Acadia, and has environmental, public safety, and congestion concerns due to the volume of cars and high prevalence of cars parking illegally throughout the park near trailheads and other attractions. Increased bus ridership, particularly with the cleaner propane-powered Island Explorer buses, would alleviate environmental pollution from gas-powered cars, lessen soil erosion and plant destruction from cars parking illegally on roadsides, and improve traffic safety from cars and pedestrians on narrow park roads. However, legal parking and bus usage must be convenient and easily available for visitors to have an enjoyable experience during their stay at Acadia. From our prior research, construction of a new Gateway Transportation Center in Trenton, Maine (across the bridge from entering Mount Desert Island and Acadia National Park) will be one part of the improvement plan to lessen or even eliminate private automobile traffic in Acadia National Park.

The Island Explorer Buses (a contracted third party to the Acadia National Park system) run 12 fare-free bus routes throughout Mount Desert Island. The buses are able to remain fare-free due to a generous sponsorship from the L.L. Bean company. Of these 12 routes, three routes (Bar Harbor Road, Jordan Pond, and Loop Road) stopped at the HCVC shuttle stop in the parking lot. All buses are propane-powered, and all buses had wheelchair lifts for increased accessibility for mobility-impaired passengers. Buses are also dog-friendly and can also carry up to 4-6 bicycles in an external bike carrier for visitors who wished to bring their dogs or use their bikes on the extensive Carriage Road and bike trails system.

According to Island Explorer Buses ridership survey of 2022, Island Explorer ridership survey indicated that riders felt that the bus was a positive experience, with statements like, “buses are clean” and “drivers are friendly and helpful” being rated as Excellent by over 80% of respondents, and “buses are on time” and “buses are easy to find” being rate Excellent by over 70% of respondents (Crikelair, 2022).

The bus system’s Excellent ratings for reliability and client satisfaction demonstrate that it is a positive transportation system for most Acadia visitors, and should be utilized more frequently for both less environmental impact and traffic congestion.

While the Island Explorer system continued to expand in popularity and usage, the HCVC has increased in popularity as a site for using the bus system. In 2015, 5% of riders got on at HCVC parking lot, while 18% of riders getting on at HCVC in 2022. This rate of this increase correlates with a sharp increase in visitors to Acadia NP. The Island Explorer company stationed staff members at every major bus stop - Hulls Cove Visitor’s Center and Jordan Pond were noted - to talk to visitors and encourage bus ridership instead of driving within the park. These staff members are made aware of smaller parking lots that are at full capacity and inform visitors that their parking options may be very limited within the park. They also reinforce that the buses are free, run regularly, and allow all guests to enjoy the ride.

The main goals of this subproject are:

1. Determine the peak capacity times and duration of parking at the HCVC parking lot to help with capacity planning for the new HCVC and Gateway Transportation Center planned for 2025.
2. Assess usage of the bus transportation system through counting bus riders and informational interviews with Acadia NP visitors and bus staff.
3. Develop suggestions for future improvements to the bus system to entice more ridership.

Methods

Bus Shuttle Counters: The plan used two counters to assess the total number of people who got on and off the Island Explorer shuttles each time they arrived. The researcher recorded the route name and the exact time visitors lined up next to the route sign. When the shuttle arrived, they recorded the time that the bus arrived and the number of people who got on and off each shuttle.

HCVC Parking Lot Capacity and Percent Usage: The researcher recorded the time the car entered the parking lot and then the type/brand of vehicle it was. When they exited, time was recorded to assess duration of stay.

Informational Interviews and Observations of Bussing: The researcher rode multiple routes in the transportation system to assess comfort and visibility from the bus, and spoke to visitors awaiting and using buses as well as the bus drivers and staff stationed at all major bus stops.

Observation days at Hulls Cove Visitors Center and riding bus routes:

- June 22 - initial review of HCVC space and layout, determination of placement for counting
- June 24, June 25, June 27, June 28 - parking lot car counts. Ultimately, this method was unsustainable for a single researcher as the volume increased and the sheer number of

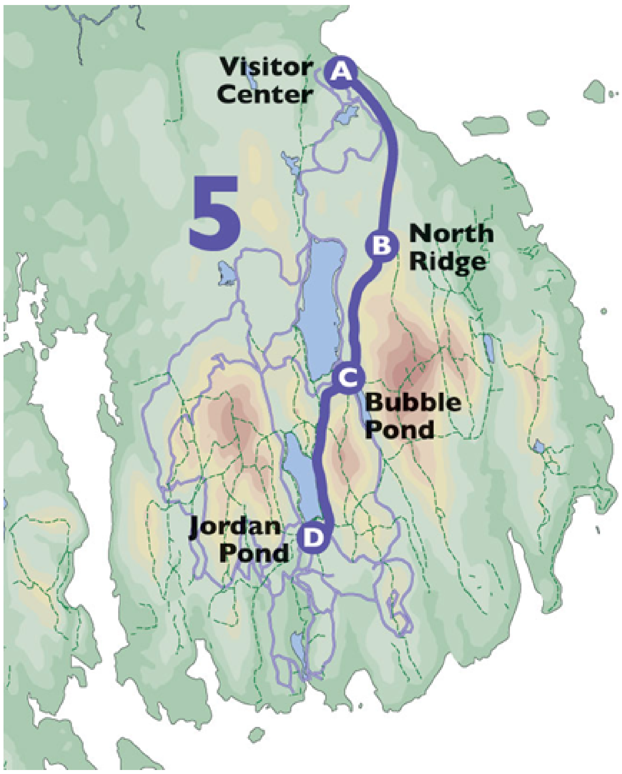
cars made it impossible to determine precisely the duration of stay. Therefore, the methodology was changed to shuttle capacity counting. However, it was noteworthy that the parking lot was generally at full or nearly full capacity by the time the researcher was able to arrive on the first bus to HCVC at 10:10 am.

- July 2, July 3, July 5, July 7, July 11 - bus capacity counting
- July 14, July 16, July 18, July 19, July 24, 2023 - bus rider and staff interviews

Figure 46: Route 1 map - Bar Harbor Road Island Explorer Bus (service every 30 min after 10 am until 8:40 pm):

Figure 47: Route 4 map - Loop Road Island Explorer Bus (service every 30 min from 9 am to 5 pm)

Figure 48: Route 5 map - Jordan Pond Island Explorer Bus (service every 30 min from 9 am to 4:30 pm)



Findings

HCVC Parking Lot Usage:

- Within the parking lot, there were 16 parking rows, with each row of parking spaces containing 14 spaces. There were additionally three rows of 15 spaces, and three rows of 13 spaces. Total capacity for regulated parking was 259 spots, not including oversized vehicles like RVs or illegally parked vehicles on the sides of the roads. There were an additional six wheelchair accessible spots outside of the main parking lot viewing area which were not able to be observed by the single researcher.

- In reviewing the information presented by the larger Visitor Mobility team, it appears that my parking lot and bus usage counts that indicated high usage times confirmed their data of high usage times. From my own observations on arriving on my first possible bus at 10:10 am, the parking lot was often at full capacity by that time. From interviewing bus drivers and personal observation, the researcher learned that the busiest times for bus ridership tended to be 10 am to 12:30 pm, with a steep decline in usage after 1 pm. According to the timetable, the last buses drop off at HCVC between 5 and 5:30 pm, which may keep visitors in the late afternoon from riding the bus for fear they will be stranded and unable to get back to their car in time.

- Many cars stay at the HCVC for less than ten minutes, which can lead to the conclusion that visitors are only stopping briefly to obtain maps, and parking passes. Therefore, most visitors are not utilizing the ranger-led nature programs at the HCVC and are continuing on to drive their private vehicles into the park.

- On busy high-season days, the HCVC parking lot can be at full capacity by 10 am. When visitors cannot find parking, they are more likely to drive on into Acadia NP with their own vehicle instead of leaving their car and using the bus system. This lack of available parking likely results in more vehicles and more illegal roadside parking within the park.

- Several commercial bike tours meet and leave from the HVHC parking lot which can cause traffic issues because bikes are placed in the middle of the road when unloading from the trailer.

Usage of Bus Transportation System

- The capacity for each bus is 45 people, with 30 seats and up to 15 standing per bus. Drivers had a requirement that any children under the age of 15 must be seated.

-Buses do not run at times that might be optimal for guests. The first bus from Village Green (where several lodging options are) to HCVC is after 10 am, which is difficult for visitors wishing to go on early morning hikes or nature observations. Several buses also end at 5 pm, which is a deterrent to leaving a car at HCVC and spending the day into the evening in Bar Harbor and Acadia NP.

- HCVC bus stop does not have benches for waiting bus patrons. This is an accessibility issue for mobility-impaired visitors often waiting 15-30 minutes for the next bus. In addition, mobility-impaired visitors often have to hunt for the accessible entrance as it is located in the additional parking lot and not the main one, and not well marked with signage.

- While riding the buses, multiple bus drivers and the researcher observed that many cars park on the side of the road, but do not completely pull off to the side which makes the Park Loop Road effectively a one lane road with greater traffic congestion and increased risk for car or pedestrian accidents.

- There is often a bottleneck in the parking lot at Sand Beach because there are only two spots for people to wash the sand off their feet, which slows traffic in and out of that parking lot.

- On busy days there can be a 15-20 minute wait at the fee station to get into the park. Buses also need to wait in these lines even though the fee station ranger does not check bus riders for park passes.

Data Analysis

Bus Route Capacity Counters

7/2/23 - Loop Road Bus

Time	Number of people who got on the bus	Waiting for next bus
10:30	44	2
10:53	43	0
11:11	28	0
11:24	15	0
11:42	41	0
12:01	23	0

Loop Road Bus

7/3/23

Time	Number of people who got on the bus	Waiting for next bus
10:21	19	0
10:51	41	0
11:19	23	0
11:19	23	0
11:51	34	0

Loop Road Bus

7/6/23

10:17	6	0
10:46	13	0
11:36	12	0
12:00	1	1
12:19	24	0

7/24/23

1:30	6	0
2:05	5	0
2:38	4	0
3:08	3	0
3:40	2	0
4:00	1	0

Jordan Pond

7/3/23

1:30	5	0
2:05	3	0
2:38	2	0
3:08	1	0
3:40	0	0

4:00	0	0

7/6/23

10:24	14	0
10:56	36	0
11:07	18	0
11:20	17	0
11:40	20	0
11:52	40	5
12:24	23	0

Village Green

7/6/23

10:29	29	0
11:02	12	0
11:14	24	0
11:39	19	0
12:16	17	0

Village Green

7/11/23

10:30	25	0

11:01	11	0
11:16	18	0
11:40	18	0
12:16	15	0

Figure 49: Graph of the data recorded for Loop Road route on 7/6/23

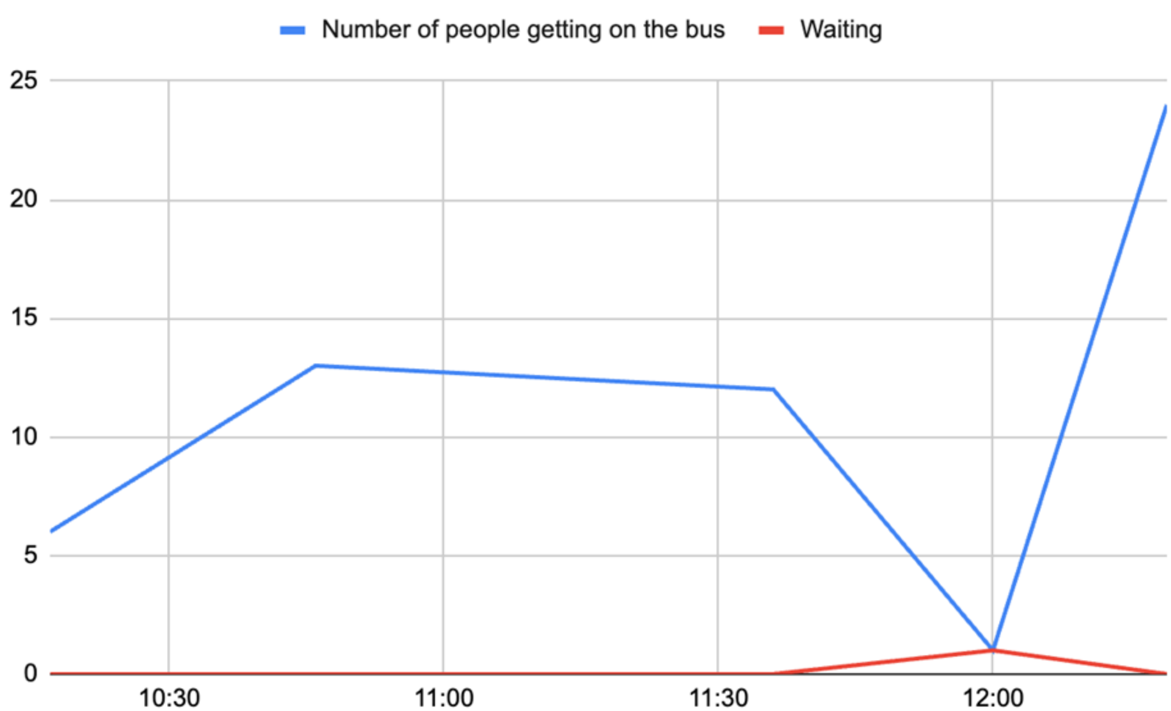


Figure 50: Graph of the data recorded for Loop Road route on 7/2/23

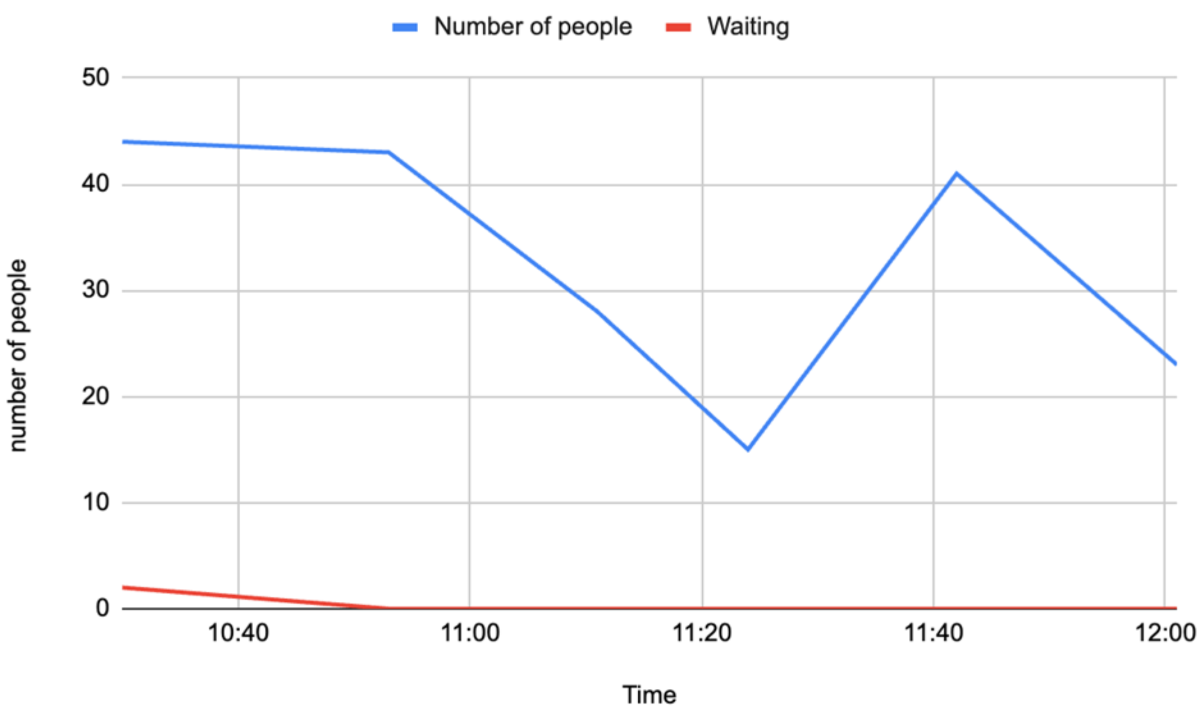


Figure 51: Graph of the data recorded for the Jordan Pond route in the afternoon on 7/3/23

Recommendations

- Increase amenities on the bus ride. An Acadia NP volunteer or ranger could provide information and history about the park during the ride as a tour guide, so that the bus has more of an opportunity to be informational and interactive. If staffing needs prevented a live guide or live information might be unwelcome by local riders who use the bus for daily transportation, an app could be developed by future teams to provide live sightseeing information while riding the bus. This could be linked to the Acadia NP educational ranger talks schedule, and be GPS-based so that bus riders are informed of nearby sites as they approach each stop. The history of Acadia, major sites, and animal and nature observation information could all be included within this application.

- Improve bus mobile app so that scheduling and real time location information are more accurate.
- Increase capacity in the parking lot to meet the needs of visitors.
- Earlier morning and later evening bus service, as well as more frequent buses, to match rider preferences.
- Provide more financial incentives for visitors to ride the bus, such as making it free to park and ride at the HCVC, but charging a fee to park within the Acadia NP boundaries.
- Greater enforcement and ticketing of cars that are illegally parked within the park or outside the designated parking lot area.
- Create an express lane at fee stations for buses to go through without waiting.
- Provide a separate parking area for tour groups to not clog the daily parking areas.

- For the new HCVC design, provide better ADA-compliant signage for wheelchair access both in the parking lot and on the pathways to the Visitor's Center.

Conclusions:

As future construction in 2025 on both the Hulls Cove Visitor's Center and the Gateway Transportation Center begins, it is hoped that the National Park planning team and future WPI IQP teams can take into consideration this research. Recommendations were made to create more efficient spaces that preserve Acadia NatioWorks Cited in this Appendix:nal Park natural resources as well enhance the visitor experience with less traffic frustration.

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*Appendix H was completed by a researcher separate from the team who created the previous sections of this paper. These two studies were conducted independently of each other.

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