Evaluating Pulse Scheduling in the Strætó Bus System

October 8, 2019

Authors:
Kyle France, Suverino Frith, Veronica Melican, and Sam Moran

Sponsors:
Ragnheiður Einarsdóttir and Sólrún Svava Skúladóttir

Advisors:
Professor Fred Looft and Professor Ingrid Shockey

Submitted to:
Worcester Polytechnic Institute
Strætó bs

Evaluating Pulse Scheduling in the Strætó Bus System

An Interactive Qualifying Project submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfilment of the requirements for the degree of Bachelor of Science

October 8, 2019

<u>Authors</u>**:**

Kyle France

Suverino Frith

Veronica Melican

Sam Moran

<u>Report Submitted to:</u>

Professor Fred Looft
Professor Ingrid Shockey
Worcester Polytechnic Institute

Ragnheiður Einarsdóttir
Sólrún Svava Skúladóttir
Stræto bs

Abstract

The public bus system in the Capital Region of Iceland, operated by Strætó bs, uses pulse scheduling, where buses from multiple routes meet at a common station at about the same time to facilitate convenient transfers. However, factors such as traffic congestion and rider boarding behavior have caused frustrating delays in the system. The goal of this project was to evaluate Strætó's pulse scheduling and develop recommendations to improve the service. We collected and analyzed data about the logistics of rider transfers made in the bus system and gathered stakeholder perspectives. Our research confirmed that pulse scheduling may no longer be the best strategy for Strætó. Our primary recommendation was that Strætó remove pulse scheduling and increase frequency to improve rider satisfaction.

Executive Summary

Introduction

A sustainable public transportation infrastructure is a key element in the development of cities worldwide. Public transportation systems can reduce automobile dependency and thus reduce traffic congestion in a city by providing a safer and less expensive alternative to cars. An effective public transit system allows people and resources to flow smoothly through a city, facilitates access to resources and trade markets, and improves the quality of life for individuals by enabling them to easily reach services such as education and healthcare (Bamwesigye & Hlavackova, 2019). The United Nations recognizes the value of public transportation in its sustainability goals for 2030. Part of the eleventh goal states that by 2030, cities should "provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport" (United Nations, n.d.).

Iceland's public transportation system consists of a bus network operated by the company Strætó bs. Strætó's network includes four major connecting stations operating on a "pulse" schedule, meaning buses from multiple lines arrive and depart at about the same time to minimize transfer times between buses (Strætó bs, 2019d). However, increased delays in Strætó's system since the implementation of the pulse scheduling have caused frustrations for riders. Strætó is considering modifying pulse scheduling to reduce costs and make transfers more convenient for passengers. The goal of this project was to evaluate the efficiency of pulse scheduling in the context of Strætó's overall public bus system and to develop recommendations for the system's improvement.

Public transit is a valuable part of urban communities, but providers have limited resources so they must prioritize carefully in order to provide the best service possible. This balance includes determining which services reach the most customers and which services are necessary to provide despite low ridership. Public transit providers must also balance the performance of their network with factors like coverage and service availability to preserve the highest priorities of the rider base. Effective planning of a transit system requires information about the behaviors and perceptions of passengers who use it. To give Strætó more information, this project investigated the performance of Strætó's pulse scheduling in terms of employee perspectives, passenger satisfaction, and bus timeliness.

Approach

Figure 1, below, summarizes the goal and objectives of this project.

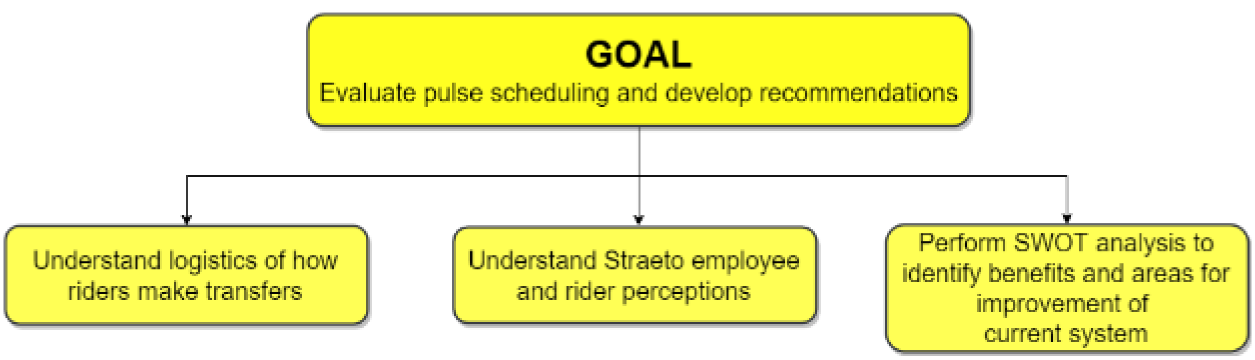


Figure 1. Project goals and objectives.

Our strategies included gathering data about bus transfers made within the system and analyzing bus timeliness data to understand the logistics of pulse scheduling. We also conducted interviews with Strætó employees and interviews and a survey of riders to gain stakeholder perspectives. Finally, we conducted a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to identify the pros and areas for improvement of pulse scheduling.

Results and Discussion

Analysis of our data revealed some general trends about the logistics and perceptions surrounding pulse scheduling in Strætó's system. Our data reinforced the idea that pulse scheduling is no longer the best strategy due to an increase in schedule delays in recent years. At each pulse station observed, we noticed that two to three bus transfers were utilized more than others. For example, at Hamraborg, roughly three times as many passengers transferred between buses #1 and #4 versus buses #2 and #4. While many riders remarked that the pulse scheduling is convenient when it works as planned, they also reported that the frequent delays are very frustrating.

Responses to our survey showed that the most common reason (38% of respondents) that passengers found transfers at pulse stations to be inconvenient was that buses arrived late, causing passengers to miss the bus they had planned on transferring to. **Figure 2** shows a bus stuck in traffic, which is one cause of delays. Our data about bus arrival times showed that at each station we examined, more than 12% of all buses arrived late across all times of day. At Ártún, the station we observed with the most delays, 42% of buses arrived late during the afternoon rush hour. This problem is not isolated to a single route or station, but rather affects routes across Strætó's network. The specific causes of the delays we observed was not a focus for our work but could be an area for future research teams to investigate.

Figure 2. A bus stuck in traffic (Iceland Monitor, 2016).

> *"There are many buses piling up in this connecting station. And one of them is late, and he calls the other bus to wait for him... at the connecting station. And so...all of the buses are getting later also."*
> *-Fleet Manager*

A fleet manager at Strætó commented in an interview that pulses sometimes cause delays in the system to propagate as buses on a pulse wait for a straggling bus to catch up. Removing the need for buses to wait for each other could help to reduce the scheduling issues caused by traffic and by other factors. In this way, the removal of pulses would not prevent buses from falling behind schedule but might isolate delays to improve the efficiency of the overall system.

The rider survey showed that waiting a few minutes for a bus to make a connection was the least commonly cited reason (only 6% of respondents) for transfer inconvenience at all three pulse stations in question. Based on this information and discussions in our informal rider interviews, a schedule without pulses in which popular routes arrive only a few minutes apart (but do not necessarily wait for each other) would keep transfers mostly convenient for riders while saving Strætó an estimated 230 million ISK annually. However, while short waits may be acceptable, increasing frequencies for popular or overcrowded routes may also be of interest to riders, whose third most common comment in the survey free response was a desire for increased frequency of buses.

In our informal interviews and survey, the general sentiment expressed by riders was that when pulse scheduling works as intended it facilitates convenient transfers, but that increasing delays in Strætó's system have resulted in buses often not being on time. Part of the frustration experienced by riders may be due to their expectations not being met rather than from the time they have to wait. People plan their schedules assuming they will be able to catch all of their transfers, and when buses become delayed it makes them late. One rider commented during an interview that he does not care what the bus schedule is as long as it is consistent.

Recommendations

1. Remove pulse scheduling across all times of day

Due to increases in schedule delays since the introduction of pulse scheduling to Strætó's network, as well as rider feedback regarding long wait times between buses, pulse scheduling may no longer be the best strategy for Strætó. Strætó employees stated that it is often not possible for buses to make their connections due to traffic, and riders indicated that they are frustrated by the delays in the system. For these reasons, we recommend that Strætó work to remove pulse scheduling from their system across all times of day. Removing pulses will prevent the propagation of delays caused by buses waiting for each other at pulses, making the system timelier overall. In addition, the savings from eliminating waiting periods and layover costs from pulse routes can be used to help offset the costs of increasing bus frequency for popular or overcrowded routes. Furthermore, based on the results of our survey and informal interviews, we believe riders will not mind waiting short times for their connection as long as they are expecting to do so, meaning transfers will still be convenient for riders.

Additional Recommendations:

2. Improve communication channels with riders

According to the results of our interviews and surveys, improved communications between Strætó and its users will increase rider satisfaction. For example, some riders mentioned that the schedules posted on the mobile app, website, and at stations were not always consistent. By ensuring that the information available to riders is clear and accurate, Straeto can enhance the rider experience.

3. Pursue additional priority bus lanes

While Strætó's existing designated bus-only lanes allow buses to bypass traffic, they are too disconnected to be fully effective. By adding additional bus-only priority lanes and connecting more of the existing lanes together, delays and inconsistencies caused by heavy traffic can be mitigated. We acknowledge the expensive nature of this improvement but recommend ongoing consideration for designated lanes as larger city projects such as the proposed bus rapid transit system develop in the future.

4. Implement AFC systems on all buses and fully utilize AVL data

Strætó is planning to add AFC systems to their buses in the future. The team encourages this decision for two main reasons: AFC will reduce passenger boarding delays by speeding up passenger payment and will generate additional data for analysis. Strætó has years' worth of archived AVL data for every bus in the network. We learned from our interviews with Strætó's data analyst that they do some evaluation, but typically focus on individual routes rather than the whole system. Analysis of AFC and AVL data will provide Strætó with a more complete picture of the end-to-end travel patterns of individual passenger which will be useful for future route planning.

Summary

The purpose of our research was to evaluate pulse scheduling in the overall context of Strætó's route network. Our research showed that increasing schedule delays in the Capital Region have made pulse scheduling less feasible. As Reykjavík grows, Strætó will continue to play a major role in how people navigate the city. By reorganizing their network and schedules Strætó could increase convenience for riders, save money, and ultimately increase their ridership. An increase in ridership will improve mobility in the Capital Region and thus promote economic growth, social equality, and environmental friendliness. By taking steps toward implementing a more sustainable public transit system, Strætó will align itself more closely to the United Nations' sustainability goals.

Figure 3. Our team. From left to right, Sam Moran, Kyle France, Veronica Melican, and Suverino Frith.

Acknowledgements

We would like to thank the following individuals for their support throughout this project:

Our advisors **Fred Looft** and **Ingrid Shockey** for their guidance and insights.

Our sponsors **Ragnheiður Einarsdóttir** and **Sólrún Svava Skúladóttir** for their mentorship and assistance in implementing our project.

The individuals who shared their experiences in our interviews, and Strætó's riders for their participation in our survey.

Strætó bs and **Worcester Polytechnic Institute** for the opportunity to take part in this research project.

Takk.

Thank you.

Authorship

This section lists the primary contributions of each team member. Sections of the paper not listed here were contributed to equally by all team members.

Kyle France:

2.2 Assessing Public Bus Systems
2.4 Public Transportation in the Capital Region of Iceland

Suverino Frith:

2.3 Technology for Bus Planning and Data Collection
4.1 Results: Bar Charts

Veronica Melican:

1.0 Introduction
2.1 The Value of Sustainable Public Transportation
2.4 Public Transportation in the Capital Region of Iceland

Sam Moran:

2.3 Technology for Bus Planning and Data Collection
4.1 Results: Web Charts
4.1 Results: Bus Timeliness Data Analysis

Table of Contents

List of Figures

Note: Pictures and figures without citations in the text were taken or created by a member of the team.

1.0 Introduction

> *"Transportation is the center of the world! It is the glue of our daily lives. When it goes well, we don't see it. When it goes wrong, it negatively colors our day, makes us feel angry and impotent, curtails our possibilities."*
>
> -Robin Chase, co-founder and former CEO of Zipcar

While an efficient public transportation system ensures that a city flows smoothly, a poorly designed one can lead to frustrating travel delays. By identifying how riders utilize and interact with their system, transportation providers can identify ways to improve their route networks, which in turn increases rider satisfaction.

Iceland's public transportation system consists of a bus network operated by the company Strætó bs. Strætó's network includes four major connecting stations operating on a "pulse" schedule. In a pulse, buses from multiple lines arrive and depart at about the same time to minimize transfer times between buses (Strætó bs, 2019d). However, passengers may have to wait up to half an hour between pulses if they miss their connecting bus because of traffic congestion or other factors. In addition, pulse schedules are expensive to operate because buses often have to wait at the ends of their routes in order to line up with the pulses. During this waiting time, idling buses waste fuel and drivers are being paid but are not driving passengers. Strætó estimates they would save about 230 million ISK annually by reducing this layover time. Strætó is considering modifying pulse scheduling to reduce costs and make transfers more convenient for passengers. To do this effectively, Strætó needs to understand the current travel patterns and perceptions of passengers so that any changes benefit a majority of stakeholders.

The goal of this project was to evaluate the efficiency of pulse scheduling in the context of Strætó's overall bus system and to develop recommendations for the system's improvement. To meet this goal, we collected data about the logistics of transfers at pulse stations and gathered the perspectives of Strætó employees and riders.

2.0 Literature Review

This chapter discusses the value of public transportation in urban communities, identifies measures that are used to assess the quality of a bus system and describes the bus system in Iceland.

2.1 The Value of Sustainable Public Transportation

A sustainable public transportation infrastructure is a key element in the development of cities worldwide. Public transportation systems can reduce automobile dependency and thus reduce traffic congestion in a city by providing a safer and less expensive alternative to cars (Bamwesigye & Hlavackova, 2019). **Figure 1**, below, compares the space compactness of thirty people on a bus, in cars, on bikes, and on foot.

Figure 1. A comparison of the space required to transport 30 people by bus, car, bicycle, and on foot (Luxembourg Times, 2016).

The increased mobility in a city fostered by public transportation promotes both social and economic growth. An effective public transit system allows people and resources to flow smoothly through a city. This flow facilitates “access to resources and trade markets” (Bamwesigye & Hlavackova, 2019, p. 1) and improves the quality of life for individuals by enabling them to easily reach services such as education and healthcare (ibid). A sustainable public transportation system also has environmental benefits. For example, public transportation is more fuel efficient than personal vehicles, consuming “3.4 times less energy per passenger kilometre than automobiles” (International Association of Public Transport, n.d., p.3).

As cities expand and their populations grow, it becomes increasingly important for their public transportation infrastructures to grow as well. If public transportation systems do not adapt to the growth of cities, increased traffic congestion could reduce mobility and thus limit social and economic progress. A 2019 report stated that “traffic congestion costs an average of 1–3% of a country’s GDP” (Bamwesigye & Hlavackova, 2019, p. 5). A public transit system that grows with and responds to its community ensures that a city can continue to develop.

To promote a sustainable future, the United Nations developed seventeen goals addressing global challenges to be completed by 2030. Goal 11, “Make cities inclusive, safe, resilient and sustainable,” involves providing access to sustainable public transportation systems. The second target of the goal states that by 2030, cities should “provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport” (United Nations, n.d.). By 2030, sixty percent of the world’s population is projected to live in cities (ibid). The United Nations hopes that by encouraging cities to engage in sustainable practices such as Goal 11 above, challenges associated with urban growth can be mitigated and cities can continue to develop.

Reykjavík’s municipal plan through 2030 aligns with the United Nations’ sustainability goals and aims to make “every city district... more sustainable and human friendly” (Department of Planning and Environment, 2014, p. 5). The Municipal Plan includes goals to increase the sustainability of Reyjkjavik’s public transit systems by increasing the ridership of the bus system in the city from 4% to 12% by 2030 (ibid). Improving mobility in Reykjavík will ultimately lead to increased economic opportunities, as well as social equality and environmental friendliness. By moving towards more sustainable practices, Reykjavík can play a positive role in its future outcomes.

2.2 Assessing Public Bus Systems

While public transportation is a valuable part of urban communities, providing affordable and accessible public transportation services to a community is a complicated task. Public transit providers often have limited resources, so they must prioritize carefully during development in order to achieve their sustainability and quality goals while staying within their budget. Public transit providers are sometimes criticized for low ridership or face political pressure to trim operational costs. However, because the government provides public transport as a service, profitability is not always a major strategic goal unlike most private businesses. Consider the following passage from the blog Human Transit by public transit consultant Jarett Walker:

> *"In democracies, whoever makes the decisions for a transit authority is accountable to voters. These officials listen to their constituents, and sometimes decide that to some degree, low-ridership services are necessary and important. This is usually because either (a) someone feels entitled to service ("We pay taxes too!") or (b) someone needs the service really badly ("If you cut this bus, we'll be trapped."). Those can both be valid government purposes, but they lead to the creation of services where ridership is not the objective." (Walker, n.d.)*

Routes with low ridership that are still deemed necessary are referred to as coverage services. Although socially valuable to communities, it is important to recognize that coverage services can be expensive to provide due to the low return from fares. Effective public transport networks need enough economical, ridership-based services to avoid financial burden balanced with enough coverage services to provide for a community's needs. To maintain this balance, strategic assessment of the system has to be a regular part of service upgrades.

The performance, or quality of service (QOS), of public transportation depends on a wide variety of factors and can therefore be measured in several dimensions. For example, the frequency of bus service, defined as the time between consecutive buses on a route (Walker, n.d.), is one of the most commonly cited and important QOS metrics. Other measures of public transportation infrastructure include transit coverage, transit supply, and route diversity. These three refer to the percentage of a district served, the "magnitude" of service (number of stops, number of vehicles in service, etc.), and the access between regions via the service, respectively (Hawas, Hassan, & Abulibdeh, 2016). Almost every aspect of the QOS of public transportation is connected in some way, making design decisions difficult to balance. For example, when coverage is widespread, the frequency with which buses arrive at stops may be low. Conversely, a smaller area of coverage may allow high frequency of bus arrivals but might not serve a diverse number of routes.

As with any product or service, responding to consumer demands is fundamental for transit companies to encourage ridership. However, since adjusting a public transit network can have both positive and negative impacts, providers must be careful to preserve the highest priorities of their rider base when modifying or designing a transportation network. The need for a balance of services and the interconnectedness of service qualities create the need for transit providers to gather information about the needs and wants of their riders.

2.3 Technological Strategies for Bus Planning and Data Collection

Transit planning is driven by data; as one Strætó employee put it, "in this business, the more information the better" (personal communication, September 10, 2019). To make the job of bus planners easier, technology can be used to gather information about bus systems. Technology enables transit providers to monitor public transit systems more reliably and in greater detail than via manual data collection techniques. Having more data enables planners to improve reliability and coverage (Wilson, Zhao, & Rahbee, 2009). Recent years have seen improved capacity to coordinate data collection with improvements to transportation networks.

2.3.1 Passenger Counting

Attaining the optimum distribution of buses in a fleet across various routes is fundamental in optimizing a public transport network and reducing costs (Bartolini, Cappelini, & Mecocci 1994). A key factor when deciding how many buses to assign to each route is knowing how many people are boarding and exiting each bus. Motion detectors, used to sense people and other moving objects, can be used to automatically and anonymously count passengers. The two types of motion detectors that are commonly used for counting passengers are passive infrared sensors and video camera software (Noone, Bergman, & Lynch, 2015). Strætó has infrared motion sensors installed on 40% of the buses in their fleet that collect data about the ridership of each of their buses. **Figure 2** shows three infrared motion detectors above the middle doors of a Strætó bus.

Figure 2. An image of three motion detectors (circled in yellow above the doors).

One limitation of motion sensors is that they do not identify and track individual passengers. While they provide information about the number of passengers entering and exiting each bus, they do not yield insights into where passengers came from when entering a bus or where they go after leaving a bus.

2.3.2 Origin and Destination Data

Automatic Fare Collection, or AFC, is a form of transit technology that automates fare payment and makes the payment process faster. Transit passes in AFC systems typically contain wireless technology that allows passengers to simply tap their passes on readers in order to pay for their trip. Some AFC systems also accept a wide variety of payment methods, such as PayPal or credit cards, which makes public transit more affordable and accessible (Rubiano & Darido, 2019). In addition to increasing convenience for passengers, AFC provides bus companies with insights about rider habits for use in planning networks. Unique identifiers associated with each AFC payment method enable planners to anonymously track individual commuter trips from start to end. According to the World Bank, "AFC systems generate a wealth of anonymized data... AFC data combined with Automatic Vehicle Location (AVL) data is an increasingly common resource for planners to understand mobility patterns better" (Rubiano & Darido, 2019). **Figure 3**, below, displays a typical card reader.

Figure 3. An AFC card reader (Viriyinci, 2009).

The data collected from AFC allow planners to more closely estimate ridership of existing routes and better anticipate total passenger load on future planned routes (Wilson et al., 2009).

2.3.3 Bus Tracking and Information Displays

The Global Positioning System, more commonly referred to as GPS, is a satellite navigation system that provides geolocation and time information. Bus companies can equip their buses with GPS-based computers that transmit geolocation data as part of an Automatic Vehicle Location (AVL) system in order to automatically collect and store vehicle location data. These data can then be processed and made available on traveler information systems (Wei-Hua & Jian, 1999). An example of a traveler information system is the use of digital displays showing the arrival time of buses at bus stops (ibid). Strætó does not use digital displays at bus stops, but displays AVL data on its website, shown in **Figure 4**, which enables passengers to track buses in real-time and see when a bus is running late, on-time, or early. Strætó also keeps records of AVL data, such as when buses arrive at bus stops, which they use for planning purposes.

Figure 4. An image of Strætó's website, with bus locations displayed in real-time.

2.3.4 Modeling Software

Shifts in city development such as increases in traffic, population density fluctuations, and new construction all impact the travel patterns of public transit users. Modeling software allows planners to predict what the needs of an urban area will be in the future and adapt public transportation in anticipation of changes (MacKechnie, 2018). An example of such modeling software is Remix, a transit planning software system that accounts for population density data, traffic information, and passenger counts on current routes. These tools aggregate large amounts of input data and allow planners to easily draw new routes and compare estimated ridership, cost, and service coverage to existing routes.

Data from passenger counting, automatic fare collection, and vehicle location systems are all important for assessing and improving transit systems. Not only do these data provide planners with insights into how effective their current network is, they also factor heavily into planning decisions. Aided by transit modeling software, planners can combine data from each of these sources in order to visualize the performance of planned routes.

2.4 Public Transportation in the Capital Region of Iceland

The Capital Region of Iceland, shown below in **Figure 5**, encompasses approximately 1,007 square kilometers across seven municipalities (Sveinbjörnsdóttir, 2002). The region has an extensive public transportation system operated by Strætó bs. While there are private taxi services, the public bus system is a less expensive option (“Taxi”, n.d.). There are no ridesharing services such as Uber or Lyft operating in Iceland.

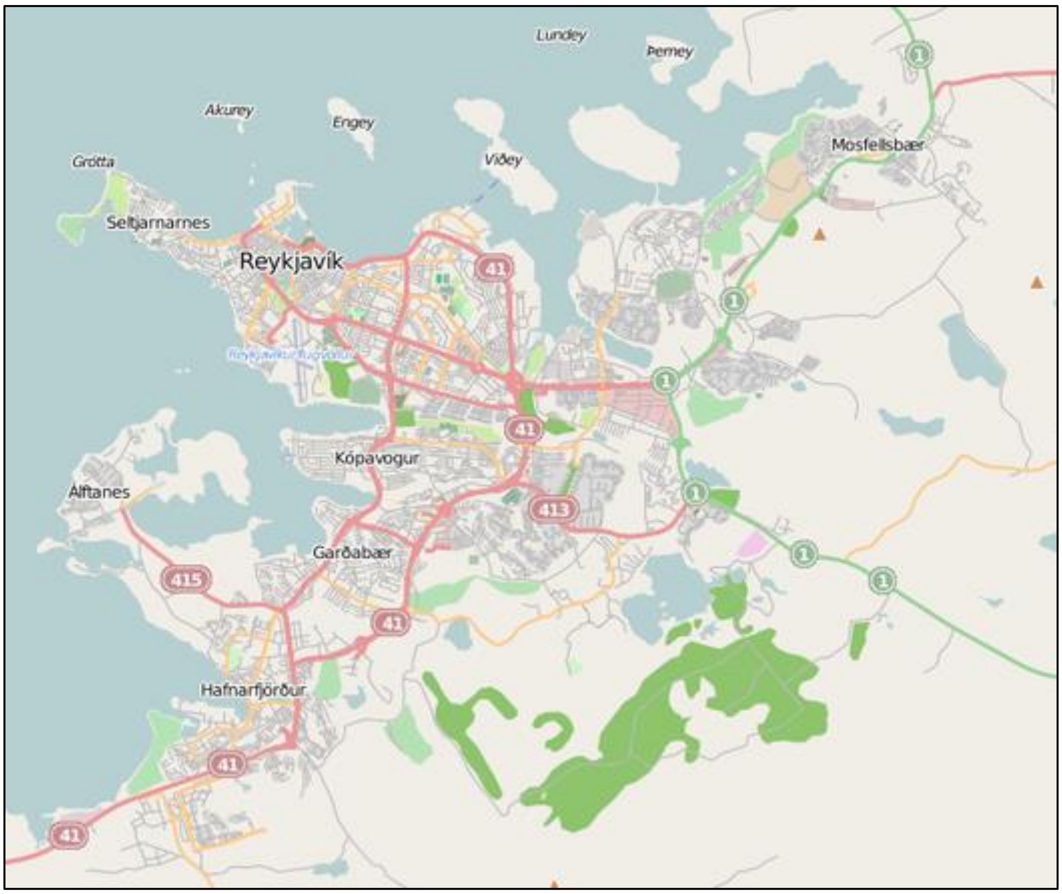


Figure 5. Capital Region of Iceland, including the seven municipalities (OpenStreetMap, n.d.).

Strætó bs is owned by six of the municipalities that make up the Capital Region: Reykjavík, Kópavogur, Garðabær, Hafnarfjörður, Mosfellsbær and Seltjarnarnes (Strætó bs, 2019a). The company employs approximately 300 people, 200 of whom are bus drivers. The remaining staff are employed in management, administration, washing stations, warehouses, and customer service offices. Strætó is focused on the needs of their customers and states that the three main values of the company are “reliability, a driving force, and togetherness” (Strætó bs, 2019b).

Strætó's network currently includes elements of pulse scheduling, where buses from multiple routes arrive and depart at a common station at about the same to facilitate convenient transfers. The major terminals in Strætó's network that utilize pulses are Ártún, Fjörður, Hamraborg and Mjódd (personal communication, September 16, 2019). These stations are labeled below in **Figure 6**.

Figure 6. Strætó's route network with major pulse stations labelled in red (Strætó bs, 2019d).

Pulse scheduling was implemented in 2005 to establish faster and more convenient connections between suburbs and different areas of the city. The introduction of pulse scheduling was met with confusion and frustration at first as riders tried to make sense of the new routes and schedules. Many riders reported that they were forced to walk long distances to bus stops after some stops were eliminated (Jónsdóttir, 2007). However, riders were eventually able to adjust to the new system. **Figure 7**, below, shows a pulse at Mjódd.

Figure 7. A pulse at the Mjódd station with additional buses waiting for passengers.

Strætó maintains a website and a mobile app that riders can use to plan their routes. With both interfaces, users can view a map to determine which buses to take, make ticket purchases, and see where buses are in real-time via GPS tracking (Strætó bs, 2019c; Strætó bs, 2018). However, the mobile app has mixed reviews (3.0 out of 5 on Google Play and 2.4 out of 5 on the App Store[1]), indicating that it may need usability improvements. For example, users have reported that the app has given them inaccurate information about bus stops ("Strætó bs", n.d.). **Figure 8** shows a screen capture of the mobile app in use.

Figure 8. Strætó's app (Strætó bs, 2018).

[1] App ratings are from October 2019.

In recent years, population growth in Reykjavík has led to urban sprawl and increased car ownership, which has caused traffic congestion and delays that impact Strætó's system. An article from 2017 states that "Population forecasts for Reykjavík estimate that the city's population will increase by 70,000 over the next 25 years, and if the current number of tourists remains unchanged, a 65 percent increase in travel times and 80 percent increase in travel delays around the city is expected" (Iceland Review, 2017). A 2014 study also revealed that 80% of people in Iceland use private cars rather than public transportation. With high private car usage among a growing population, traffic along three major sections of highway in the metropolitan area increased from 135,000 cars per day on average in 2014 to 167,000 cars per day on average in 2018, roughly a 24% increase in just four years (Vegagerðin, 2019). **Figure 9** below charts data from the Icelandic Road and Coastal Administration showing the total number of vehicles on the road during each month combined for the three sections of road observed (ibid). Each shaded bar represents traffic for the selected month year by year, with 2019 (up to present) shown as a trend line. Predictions for the final months of 2019 are also shown as a lighter trend line.

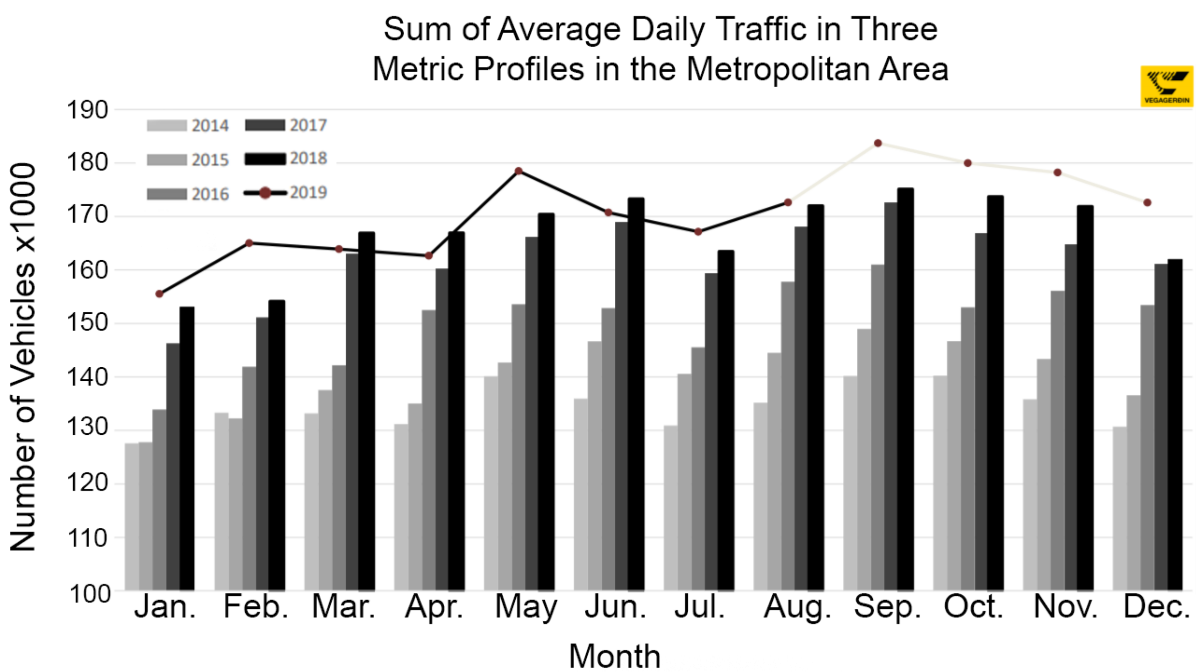


Figure 9. A graph depicting the monthly traffic totals in the Capital Region from 2014-2019 (Vegagerðin, 2019). Labels were translated and enlarged for readability by the team.

This graph illustrates how traffic has increased since 2014. Discussion with our sponsor confirmed that traffic congestion has been a growing source of frustration for both Strætó and their passengers as people commute in and out of the city center daily.

Beginning in 2011, the seven municipalities in the Capital Region and the state started devising plans for the development of a BRT system in Reykjavík (COWI, 2017). The goal of implementing a bus rapid transit (BRT) system is to increase the number of users of public transportation in Reykjavík and thus ease traffic congestion (ibid). BRT systems feature dedicated bus lanes, offboard payment stations to reduce delays caused by onboard payment, and platform-level boarding to increase accessibility. These characteristics of the BRT system make them faster and more reliable than traditional bus systems (Institute for Transportation & Development Policy, n.d.). In fact, the utilization of BRT systems nearly quadrupled worldwide between 2004 and 2014 as cities began to realize that their current form of public transit could not keep up with population growth (Institute for Transportation & Development Policy, 2014). The planned BRT system in the Capital Region will not replace the Strætó network but rather will operate in a limited corridor. **Figure 10**, below, is a rendering of a BRT stop and dedicated driving lane.

Figure 10. A rendering depicting a bus rapid transit system (Trumm, 2019).

2.5 Summary

This literature review introduced the value of sustainable public transportation to a developing city and familiarized us with metrics used to assess the effectiveness of a transit system, as well as some of the challenges associated with transit planning. A key challenge facing transit planners is the interconnectedness of key metrics, such as frequency, which make changes to a transportation network delicate to balance. Further information was presented regarding technologies utilized in planning and operating transportation networks, as well as future plans for responding to traffic congestion in the Capital Region of Iceland. The information gathered during the literature review prepared our team for detailed conversations with our sponsor and informed our evaluation of how Strætó's pulse scheduling operates in the context of the overall system.

3.0 Methodology

The goal of this project was to evaluate the efficiency of pulse scheduling in the context of Strætó's overall public bus system and to develop recommendations for the system's improvement. Our research followed three main objectives:

1. Understand the logistics of how riders make transfers at pulse stations
2. Understand Strætó employee and rider perceptions
3. Implement a SWOT rubric to identify benefits and areas for improvement of the current pulse model

Figure 11, below, depicts the goals and objectives of this project, as well as the methods used to carry about each objective.

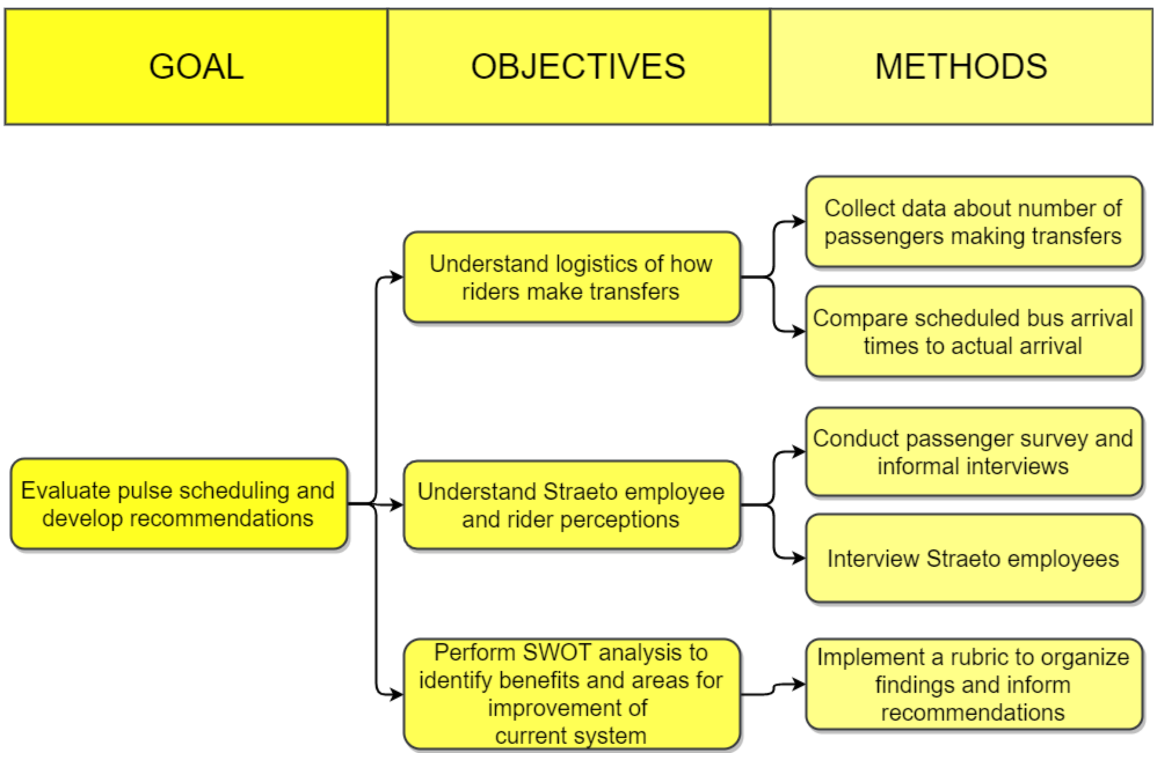


Figure 11. Project goal and objectives.

Objective 1: Understand the logistics of how riders make transfers at pulse stations

The purpose of our first objective was to inform our understanding of how Strætó's pulse scheduling currently operates. To achieve this objective, we collected data about which routes riders transfer between at pulse stations. We also used real-time GPS data gathered by Strætó about the arrival times of buses to determine how closely the buses were following the pulse schedule.

At the recommendation of our sponsor, we focused our data collection on the following stations and buses: buses #5 and #6 at Ártún, buses #3, #12, and #4 at Mjódd, and buses #1, #2, and #4 at Hamraborg. These three stations feature pulses with three or more buses, and these buses typically have the highest passenger load. Each data collection period was 1.5 hours, with sessions taking place from 7:30 - 9:00, 11:30 - 13:00, and 15:30 - 17:00. These time slots represented the morning rush hour, midday, and afternoon rush hour respectively. We collected data for each bus in both directions: during the morning rush hour sessions we observed buses headed into the city, and during the afternoon sessions we studied buses headed out of the city. The direction for the midday collection periods was arbitrarily chosen to be out of the city because there was no significant difference in traffic in either direction at times outside of rush hours.

All four team members collected data for each bus. Two were stationed at the front of the bus tracking passengers boarding the bus, and two were stationed at the back of the bus tracking passengers exiting the bus. Each pair carried a sign that read, "*Which route are you transferring from/to?*" in both English and Icelandic, illustrated in **Figure 12** below.

Figure 12. The team's sign for data collection at the Mjódd station.

The signs listed bus numbers that passengers could point to as they completed their connections. In addition, the sign listed an option marked “No transfer”. **Figure 13**, below, shows an example of the team using the signs at the Mjódd bus station. We made the decision not to ask passengers which direction they were travelling in because we believed it would take too long and lower the response rate.

Figure 13. The team collecting data at Mjodd.

In addition to the numerical data, we made notes and recorded observations about how passengers were interacting with the system, such as whether they missed their bus and had to wait a long time or appeared frustrated. We calculated the percentages of the total number of riders that transferred to and from each bus, then heat mapped the compiled data tables to indicate which buses had more transfers and created charts to visualize the data. We used these charts to look for trends in how riders were utilizing the transfers available at the pulse stations. We also compared the data collected during the rush hours and midday to see the difference, if any, in transfers based on the time of day.

To augment our data, we obtained archived data from Strætó about the arrival times of the buses we observed. These data were collected by Strætó’s automatic vehicle location system. We compared the actual arrival and departure times of each bus to its scheduled time in our analysis to determine how closely the buses were following the pulse schedule.

Objective 2: Understand Strætó employee and rider perceptions

The goal of the second objective was to gain an understanding of the perceptions and experiences of riders and Strætó employees. The team gathered qualitative data from passengers waiting at pulse stations, an online survey, and Strætó employees in order to ensure that we understood the perceived benefits and drawbacks of the current system from multiple points of view. The Strætó employee interviews helped us understand the operational perspective of the bus system, while the rider interviews and survey exposed us to the experiences of Strætó's riders.

The consent of the participant was obtained for all interviews. The interviews with Strætó employees were semi-structured, meaning that we had a set of questions designed to guide the conversation while also allowing the interviewee to bring up topics or ideas that we could not anticipate (Beebe, 2014). For interviews with Strætó employees, all project team members were present, with one member leading the discussion and another recording notes. With the permission of participants, the Strætó employee interviews were audio recorded and transcribed for accuracy. The recording files were deleted afterwards. Questions for the interviews with Strætó employees are in Appendix A. For interviews with passengers, only one or two team members were present, and field notes were recorded directly afterwards. Guiding questions for our informal interviews with riders are in Appendix B.

We conducted a survey of riders to reach a larger audience. The survey started by asking the respondent age and gender followed by questions regarding how often the respondent made transfers at the pulse stations and how convenient those transfers were. Participants were required to be 18 or older to respond. An open-ended response for general comments concluded the survey. The full survey is included in Appendix C in both English and Icelandic.

Strætó posted links to the survey on their social media, website, and their mobile app in both English and Icelandic. By hosting the survey digitally, passengers could easily complete the survey at their own convenience, and paper forms were not required. Although online surveys generally have a lower response rate than in-person surveys (Nulty, 2008), our digital format allowed us to reach a greater number of people overall: Strætó estimated that the last time they posted a survey on social media, they received around 2000 responses. We kept the survey intentionally short (less than 5 minutes to complete) to maximize completion rate. At the end of the data collection period, we compiled and sorted the data.

Our team developed a common coding procedure to analyze the interviews and the survey free responses. We labeled patterns and trends in transcribed interviews and sorted them into categories. We then created graphs to visualize the results of the survey multiple choice questions.

Objective 3: Implement a SWOT rubric to identify benefits and areas for improvement of the current pulse model

The purpose of our third objective was to use the insights gained from completing objectives one and two to assess the efficiency of Strætó's system.

We combined the analyses of objectives one and two into a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats). The SWOT analysis allowed us to map both positive and negative elements of Strætó's pulse scheduling (Section 14. SWOT Analysis, n.d.).

Figure 14, below, illustrates the rubric that the team used to help organize findings identified in the study. (Section 14. SWOT Analysis, n.d.)

	STRENGTHS 1. 2. 3. 4.	**WEAKNESSES** 1. 2. 3. 4.
OPPORTUNITIES 1. 2. 3. 4.	Opportunity-Strength (OS) Strategies Use the strengths to take advantage of opportunities 1. 2.	Opportunity-Weakness (OW) Strategies Overcome weaknesses by taking advantage of opportunities 1. 2.
THREATS 1. 2. 3. 4.	Threat-Strength (TS) Strategies Use strengths to avoid threats 1. 2.	Threat-Weakness (TW) Strategies Minimize weaknesses and avoid threats 1. 2.

Figure 14. Example SWOT rubric.

After developing each element of the SWOT, the team completed the inside of the matrix by considering how each category interacts. For example, how can Strætó leverage their strengths to take advantage of opportunities? We considered the key results of this analysis when developing recommendations to Strætó that could improve the efficiency of the system.

4.0 Results and Discussion

In this chapter we highlight key findings for each objective and then discuss the trends and patterns that emerged from the data. The analysis in this chapter informed our development of recommendations in Chapter 5.

4.1 Results

Objective 1: Understand the logistics of how riders make transfers at pulse stations

We counted transfers to and from various bus routes at the Ártún, Mjódd, and Hamraborg stations. Charts representing the entirety of this data with heat mapping can be found in Appendix D. For each bus route we collected data during three different time periods: 7:30 - 9:00 (Morning), 11:30 - 13:00 (Midday), and 15:30 - 17:00 (Afternoon). Web charts were used to summarize connections between bus routes across all times of day. Stacked bar charts were used to show more detailed information about transfers, divided by the time of day and whether passengers were exiting or entering the bus.

Figure 15, below, shows two sample web charts - on the left, transfers involving bus #6 at Ártún, and on the right, transfers involving bus #2 at Hamraborg. The bus under study is located at the center of each web chart, with buses that passengers came to or from represented as surrounding nodes. Connections between the bus we studied and other buses are represented by lines, with width depending on the total number of transfers made between the two buses. The node labeled "None" indicates the passengers that were beginning or ending their trip, and therefore not transferring to a different bus.

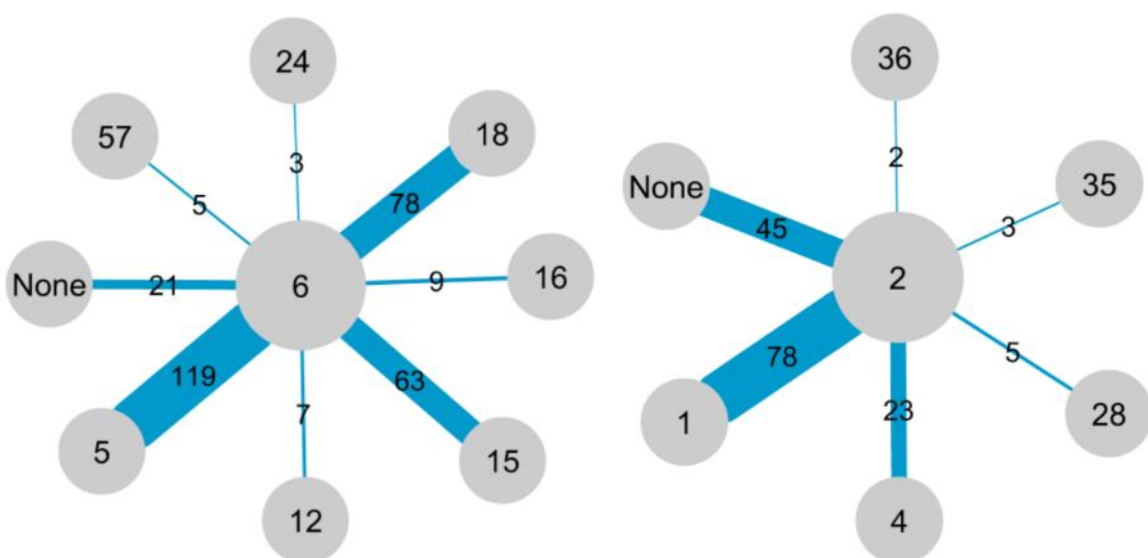


Figure 15. Web charts displaying transfers to and from Ártún bus #6 (left) and Hamraborg bus #2 (right).

As evident in the charts above, at Ártún (Figure 15, left) the vast majority of passengers transferred between bus #6 and just three other routes: buses #5, #15, and #18. A similar pattern is displayed in the chart for Hamraborg bus #2, where 93% of respondents fit into the top three bus routes: bus #1, bus #4, or no transfer. In fact, we found that for most buses at most stations, just two or three routes made up a large majority of transfers made by respondents. Web charts for each bus are displayed in Appendix E.

Figure 16 below illustrates the entry and exit data we collected from bus #6 at the Ártún stop. The time periods in the chart, the morning rush, midday, and the afternoon rush, refer to the times 7:30 - 9:00, 11:30 - 13:00, and 15:30 - 17:00 respectively. We received 144 responses from passengers entering the bus and 156 responses from passengers exiting the bus. The figure indicates that a popular transfer is from bus #5 to bus #6 in the morning and from bus #6 to bus #5 in the afternoon. It also indicates that a popular midday transfer is from bus #6 to bus #18. Complete sets of bar charts for each bus can be found in Appendix F.

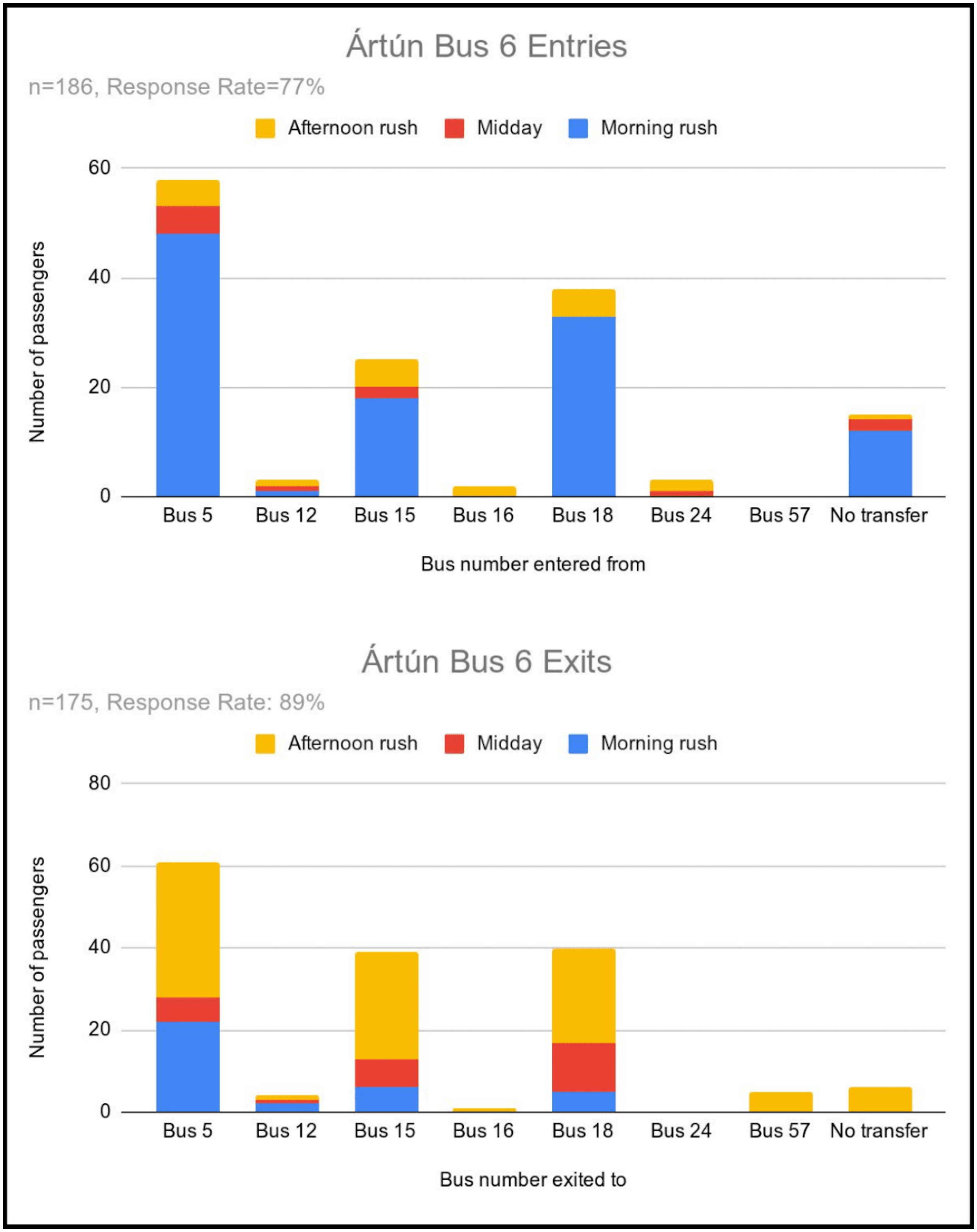


Figure 16. Ártún bus #6 entries and exits by time of day.

There were some challenges that the team encountered with the bus transfer data collection. When there was a large group boarding or exiting a bus during rush hours, it was difficult to get an exact count of passengers. **Figure 17**, below, shows a large number of passengers boarding a bus at Hamraborg that we found difficult to accurately count. In addition, some passengers misinterpreted our signs, which read "*Which route are you transferring from/to?"* in both English and Icelandic. Some passengers told us which bus they were going to when we wanted to know which bus they were coming from and vice versa. We attributed this to the ambiguous wording of the sign. Having separate signs for boardings and exits could mitigate this problem in the future. The team also faced a language barrier; some passengers did not speak English and were not able to respond to our questions.

Figure 17. A large crowd waits to board bus#1 at Hamraborg.

In addition to our transfer data, we obtained archived bus timing data from Strætó covering three weeks from late August to mid-September for both 2018 and 2019. This date range approximated the time frame in which our other data collections took place in 2019. The percentages of all buses arriving on time, early (more than two minutes ahead of schedule), and late (more than three minutes behind schedule) at Ártún in both 2018 and 2019 are displayed in **Table 18** below.

Ártún 2018	Early	On-time	Late
Morning	15%	73%	12%
Afternoon	19%	51%	30%
Midday	23%	68%	9%
All Times	24%	65%	11%

Ártún 2019	Early	On-time	Late
Morning	10%	72%	19%
Afternoon	13%	45%	42%
Midday	18%	65%	18%
All Times	18%	63%	18%

Table 18. Percentages of buses that arrived early, on time, and late at Ártún in 2018 and 2019.

In this table, 'Morning' refers to buses scheduled from 7:30-9:30, 'Afternoon' refers to buses scheduled from 15:30-17:00, 'Midday' refers to buses scheduled from 9:30-15:30 and 'All Times' includes ALL bus arrivals, including those outside of the other time periods.

These data indicate that more buses arrived late at Ártún in 2019 compared to 2018 during the same time period, while the number of early and on-time buses decreased. Data from Mjódd and Hamraborg indicated similar trends. The number of buses arriving late to Mjódd increased from 9.5% in 2018 to 13.6% in 2019; at Hamraborg, the number increased from 9.4% to 12.3%. Appendix G contains tables with more information about bus arrival data at each station.

Breaking the data down even further, we investigated not just whether or not buses were early or late, but by how much. We found no consistent overarching trend for how early or late buses were between stations, routes, or times of day. The only trend we found between bus routes and stations was that a larger number of buses overall were later in 2019 versus 2018.

Objective 2: Understand Strætó employee and rider perceptions

Gaining Strætó Employee Perceptions

Our team interviewed four Strætó employees: a fleet manager, a data specialist, a bus driver, and the project manager of the call center. These interviews clarified for our team that while Strætó believes the pulses make transfers convenient for riders, significant delays make executing pulse schedules challenging. The main reason cited for these delays was heavy traffic in the city, especially around rush hours. There are some designated bus lanes that allow buses to bypass traffic but they are too limited and disconnected to be truly effective. A second reason cited for delays was the behavior of riders entering the bus, such as asking the driver questions or taking a long time to pay. The team also learned that much of the data Strætó logs from the GPS bus trackers is primarily used for case-by-case

> *"It is my belief that we don't look at the complaints well enough [...] In some cases I know that the bus driver who was responsible is not aware of this complaint, his supervisors even are not aware of this complaint, because as soon as the suggestion or complaint is open in our system, they close it immediately."*
>
> *-Call Center Project Manager*

investigations of incidents or traffic scenarios rather than systematic performance tracking. Similarly, the logged data from passenger calls or feedback is often not analyzed regularly, with complaints often being closed in the system without communication to drivers or their supervisors.

> *"Maybe when we have more special lanes it will be better but…I suggest today it [is] not possible when traffic [is] heavy to go through with connections."*
>
> *-Fleet Manager*

When asked what they thought about the idea of removing pulse scheduling in favor of increased frequency on major bus routes, the Strætó employees we interviewed typically responded that they were in favor of the idea. Respondents cited simplified logistics and increased flexibility to deal with overcrowding as potential upsides to removing pulses, but they pointed out that preserving convenience of passengers for transfers remains one of the most important factors for Strætó to consider. Possible ideas for improvement of the system included expanding the use of designated bus lanes and addressing communication issues within Strætó. An observation the team made during these interviews was the interest or even surprise shown by the participants when discussing ideas for changing established features of the bus network. Participants had to think for a while before answering these questions and indicated that they had not considered such changes before.

Gaining Rider Perceptions

The team conducted both informal interviews and a survey to gain rider perspectives. We also received data from Strætó's call center about the most common reasons that passengers called in to make a complaint or compliment.

We conducted informal interviews with 35 individuals waiting at the stations Ártún, Mjódd, and Hamraborg. **Figure 19**, below, shows the common themes that riders mentioned during the interviews. Respondents displayed a variety of sentiments regarding pulse scheduling. Fourteen individuals stated that they thought the pulse scheduling worked while 13 individuals stated that either the pulses system did not work or that it sometimes did not work. Respondents also stated that they did not like the half hour frequencies that exist at some stations and would like these frequencies to be increased.

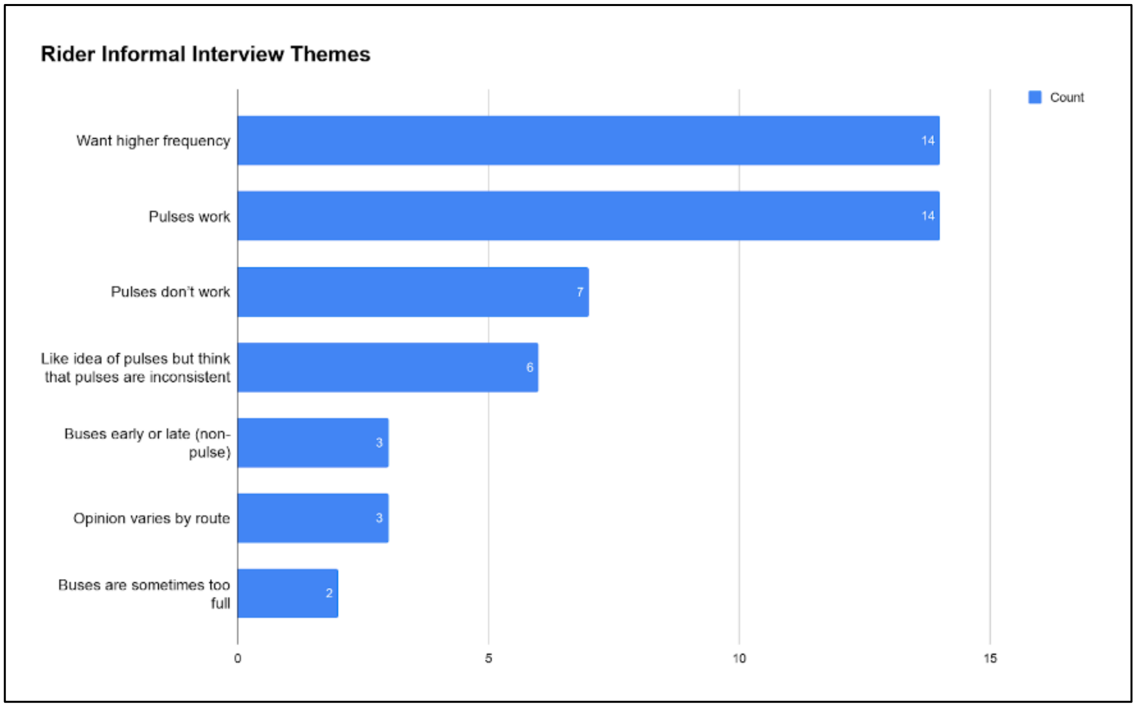


Figure 19. Common themes from rider informal interviews.

In addition to informal interviews, we conducted an online survey of riders and received 990 responses. Key findings of the survey are described below, and a full summary of the survey results can be found in Appendix H.

To begin, we were interested in how riders perceived the convenience of making transfers at three pulse stations: Ártún, Mjódd, and Hamraborg. **Figure 20**, below, illustrates the perceived convenience of transfers at each station we studied.

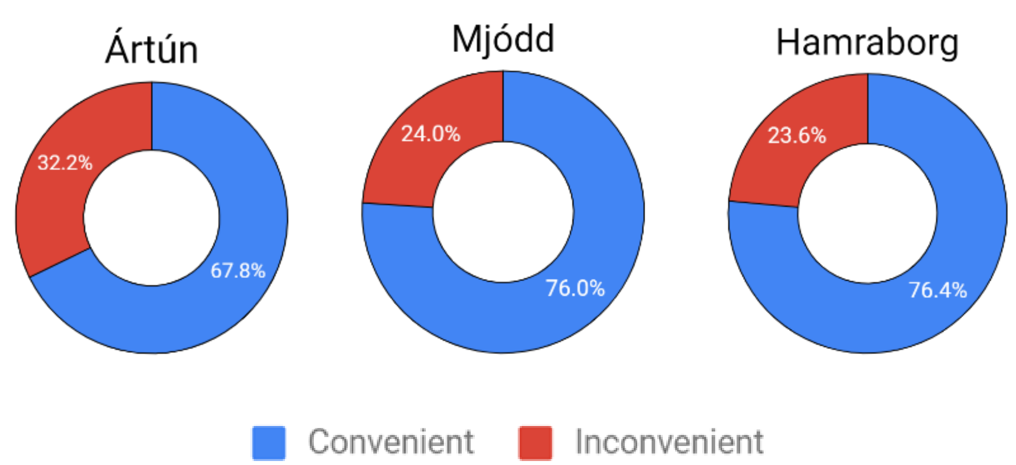


Figure 20. Convenience of transfers at Ártún, Mjódd, and Hamraborg.

Even though the majority of riders at each station stated that transfers were convenient, approximately a quarter to a third of riders at each station still found transfers inconvenient. The most commonly cited reason for inconvenience was that the rider's bus arrived late to the stop (209 responses, or 38%). **Figure 21**, below, shows why riders found transfers to be inconvenient.

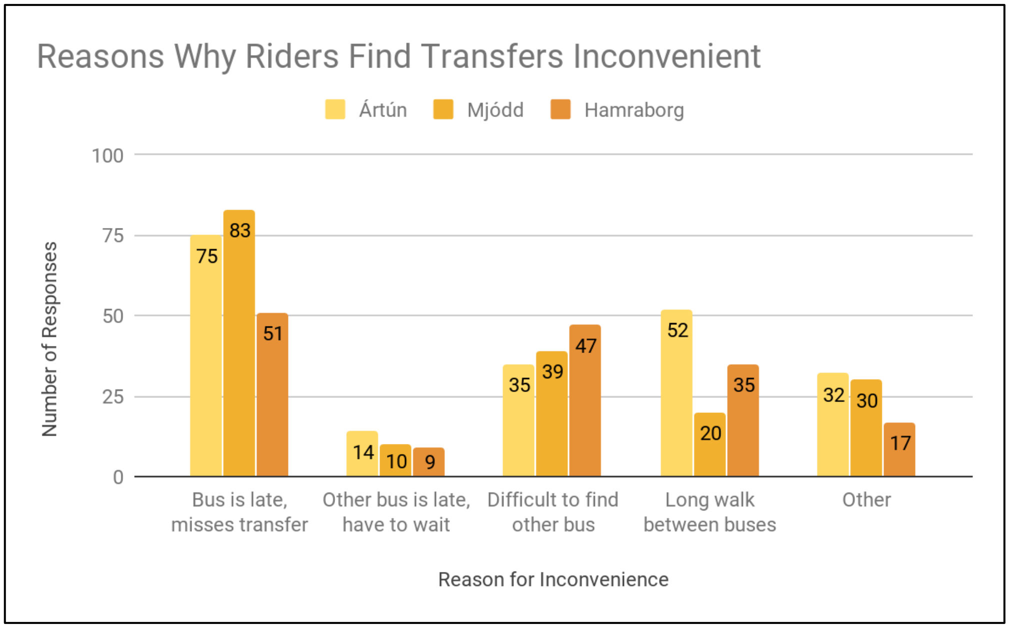


Figure 21. Reasons for inconvenient transfers at Ártún, Mjódd, and Hamraborg.

A breakdown of the "other" responses can be found in Appendix H.

At the end of the survey, respondents had the option to make additional comments. A total of 244 people made comments (142 English and 102 Icelandic). We used Google Translate to translate the Icelandic responses. The team coded the responses according to common themes. The top ten themes are displayed below in **Figure 22**. For a complete list of the themes and counts, refer to Appendix H.

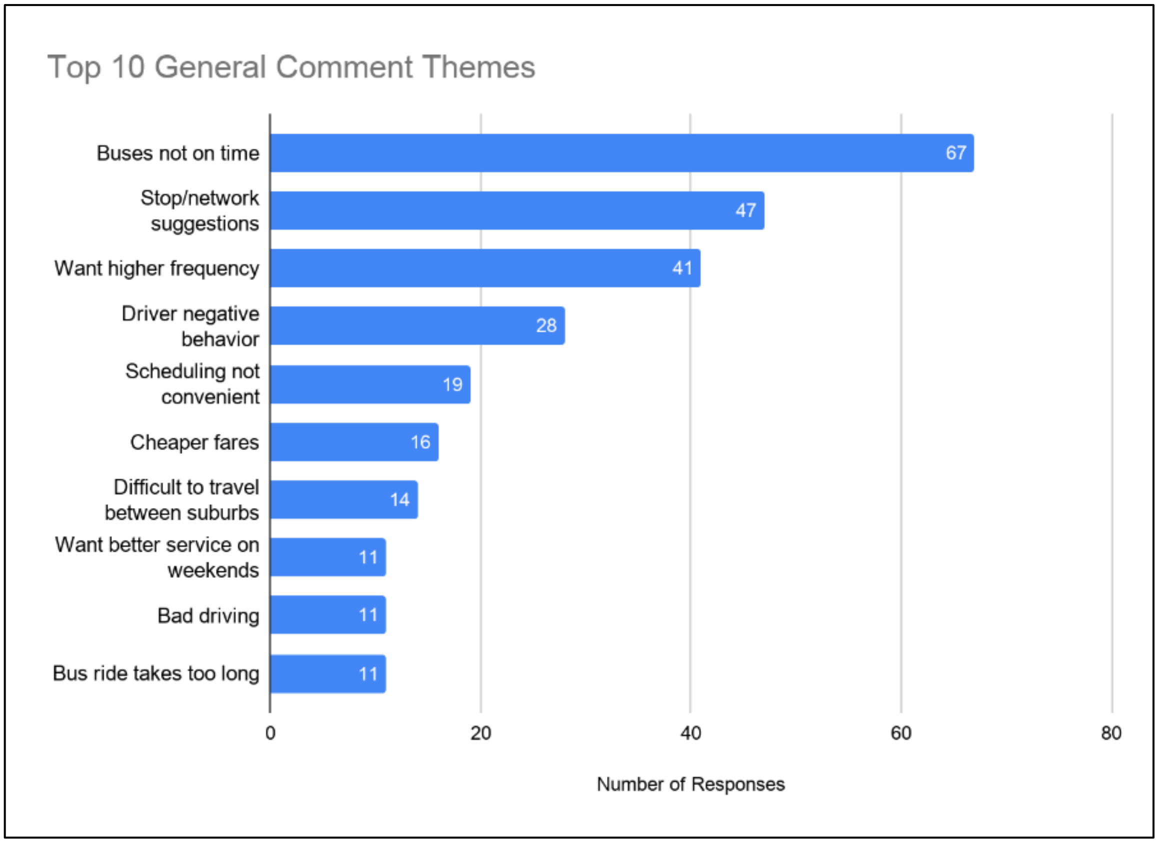


Figure 22. The ten most common themes from the additional comments section.

In addition to the survey results, we evaluated call center data. **Figure 23** below presents data regarding the top 10 most common categories of calls that the Strætó call center received between September 1, 2018 to August 31, 2019. Sixty-five individuals (28%) made complaints about buses not following the schedule (either arriving too early or too late). Forty individuals (17%) indicated that they would like higher frequencies. Other top comments mentioned negative behaviors from drivers, or that because of scheduling issues, it was difficult for riders to make transfers.

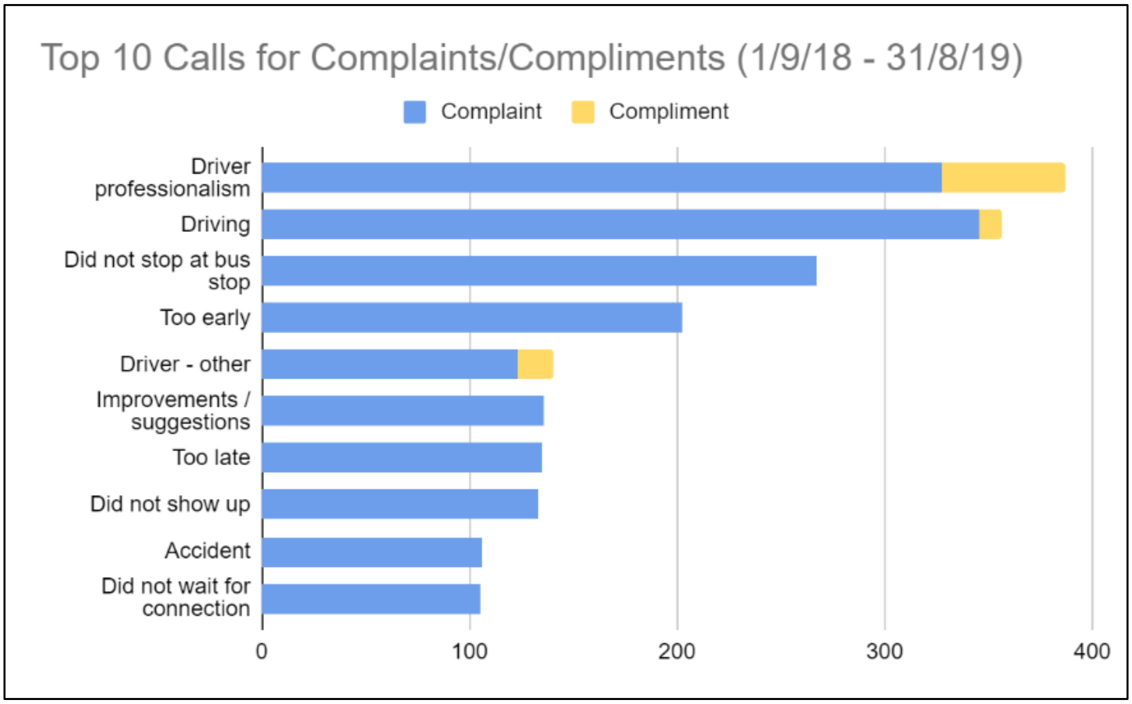


Figure 23. Most common categories for complaints or compliments made to the call center.

The categories are listed on the left side, while the bars represent how many complaints or compliments were made. Complaints are shown in blue and compliments are shown in yellow.

Objective 3: Implement a SWOT rubric to identify benefits and areas for improvement of the current pulse model

We conducted a SWOT analysis of our data in order to help inform our recommendations to the Strætó bus system. **Figure 24**, below, illustrates our metrics as well as our sorted findings.

	STRENGTHS • Convenient transfers at pulse stations • Widespread coverage of the Capital Area • Cost effectiveness of public transportation	WEAKNESSES • Low frequency between pulses • Cost of pulse scheduling • Limited budget • Limited data • Poor driving from time pressure • Inconsistency of pulse scheduling
OPPORTUNITIES • BRT • AFC • Monetary savings	Opportunity-Strength (OS) Strategies • Route network can be condensed to preserve coverage but redistribute resources • Inexpensive public transport can be marketed along with BRT (improve ridership)	Opportunity-Weakness (OW) Strategies • Money saved from removing pulses could allow higher frequency • AFC could allow for significant data analysis to improve route network
THREATS • Traffic congestion • Municipal approval • Passenger expectations	Threat-Strength (TS) Strategies • Cost of buses may persuade passengers to use them more which could lower rate at which traffic congestion is increasing	Threat-Weakness (TW) Strategies • Pulse delays are likely to increase as traffic gets worse • Unreliability of pulses frustrates passengers

Figure 24. SWOT Analysis of findings.

Conducting the SWOT analysis allowed the team to identify both strengths and weaknesses of pulse scheduling in Strætó's system. Key points for discussion moving forward are the Threat-Weakness strategies involving the ongoing problems with traffic for passengers, and the Opportunity-Weakness strategies regarding the possible benefits of removing pulses.

4.2 Discussion

Our analysis revealed some general trends about the logistics and perceptions surrounding pulse scheduling in Strætó's system. At each pulse station observed, we noticed that some bus transfers were utilized more than others, and that some transfers were only used by a few passengers per bus. In addition, our data reinforce the idea that pulse scheduling is no longer the best strategy due to an increase in schedule delays and inconsistency in recent years. While many riders remarked that the pulse scheduling is convenient when it works as planned, they also reported that the frequent delays are very frustrating.

Considering our data and comments from riders, inconsistencies or delays in the arrival and departure times of buses has diminished the convenience of pulses. Responses to our survey showed that the most common reason that passengers found transfers at pulse stations to be inconvenient was that buses arrived late, causing passengers to miss the bus they had planned on transferring to. Our data about bus arrival times confirmed that a significant percentage of buses arrive late (as many as 20% of all buses at Ártún in the period we examined in 2019) and that this problem is not isolated to a single route or station, but rather affects routes across Strætó's network. This matched our observations from the field while collecting data at each station. Our data also indicated that lateness is becoming more common, particularly during the afternoon rush hour. From 2018 to 2019, each station we studied showed an increase in the total percentage of buses that arrived late, and during the afternoon rush hour, more than 25% of buses at each station arrived late. While the team initially hypothesized that this increase in late buses was mostly due to increasing traffic congestion, this may not be the case. Data from Vegagerðin, the Icelandic Road and Coastal Administration, shows only a 1% increase in the total number of vehicles on the road in August and September (the time period during which we collected data) in 2019 versus the same period in 2018 (Vegagerðin, 2019). It was not until we examined Strætó's ridership data that we found a potential explanation. The total number of passengers using Strætó's system in August and September increased 9% from 2018 to 2019, which may help explain the increased delays we observed. In our own experience riding buses, the team observed that passengers paying with cash or asking the driver questions when boarding could take as long as fifteen to twenty seconds each. Factors aside from traffic and number of passengers, such as construction, could also be contributing to bus lateness. The specific causes of the delays we observed was not a focus for our work but could be an area for future research teams to investigate.

Pulses may also be causing these delays to spread beyond individual routes. A fleet manager at Strætó commented in an interview that pulses sometimes cause delays in the system to propagate as buses on a pulse wait for a straggling bus to catch up. As **Figure 25** shows, sometimes buses become stuck in traffic and cannot make their connections on time. Removing the need for buses to wait for each other could help to alleviate the scheduling issues caused by traffic and by other factors. In this way, the removal of pulses would not prevent buses from falling behind schedule but might isolate delays to improve the efficiency of the overall system. An added benefit of this isolation could be the better clarity with which Strætó can identify problematic routes in the future.

Figure 25. A bus stuck in traffic (Iceland Monitor, 2016).

The general sentiment expressed by riders was that when pulse scheduling works as intended it facilitates convenient transfers, but that increasing delays in Strætó's system have resulted in buses often not being on time. Part of the frustration experienced by riders may be due to their expectations not being met rather than from the time they have to wait. People plan their schedules assuming they will be able to catch all of their transfers, and when buses become delayed it makes them late. One rider commented during an interview that he does not care what the bus schedule is as long as it is consistent and does not make him late. Other riders echoed the sentiment that pulses are not a requirement for convenient transfers; responses to the rider survey showed that waiting a few minutes for a bus to make a connection was the least commonly cited reason for transfer inconvenience at all three pulse stations in question. In the team's own experience and observations, waiting a few minutes for a bus is in fact already quite common. Based on this information and discussions in our informal rider interviews, a schedule without pulses in which popular routes arrive only a few minutes apart (but do not necessarily wait for each other) would keep transfers mostly convenient for riders while saving Strætó significant money. Transfer convenience would be further improved by frequencies of fifteen minutes or higher by limiting the maximum time riders need to wait for connecting buses. We believe this would be of interest to riders, whose third most common comment in the survey free response was a desire for increased frequency of buses.

Strætó can also focus on the quality of their customer service and how they communicate with their rider base as another way to improve rider satisfaction. While riders will at times experience frustrating travel delays, there are steps that Strætó could take to ensure that riders still have a positive experience with the system. In our informal interviews and survey, we were surprised by how many riders mentioned that they experienced negative driver behavior or aggressive driving. Other topics riders often mentioned included that the schedules posted at the stations sometimes do not match the ones on Strætó's website and mobile app, and that real-time information about bus arrivals would be useful. Additionally, overcrowding concerns have been voiced from both Strætó employees and riders, which is consistent with the crowded buses the team witnessed during rush hours.

5.0 Recommendations and Conclusions

5.1 Recommendations

Based on our analysis, we developed the following recommendations for Strætó to consider moving forward. The team recommended that Strætó remove pulses across all times of day. We also developed three additional recommendations based on observations made during the project.

1. Remove pulse scheduling across all times of day

Due to increases in schedule delays since the introduction of pulse scheduling to Strætó's network, as well as rider feedback regarding long wait times between buses, pulse scheduling may no longer be the best strategy for Strætó. Strætó employees stated that it is often not possible for buses to make their connections due to traffic, and riders indicated that they are frustrated by the recurring delays in the system. For these reasons, we recommend that Strætó work to remove pulse scheduling from their system across all times of day. Removing pulses will prevent the propagation of delays as buses wait for each other at pulses, making the system timelier overall. In addition, the money Strætó will save from eliminating waiting periods and layover costs from pulse routes can be used to help offset the costs of increasing bus frequency for popular or overcrowded routes. Furthermore, based on the results of our survey and informal interviews, we believe riders will not mind waiting short times for their connection as long as they expect to do so, and that transfers will remain convenient.

Removing pulses could address one of the most common rider complaints. In our interviews and surveys, riders frequently mentioned negative driver behavior or aggressive driving, echoing common feedback received at the call center. Our interview with a Strætó bus driver revealed that drivers sometimes feel time pressure because of pulse scheduling and may drive more aggressively to catch up. We reason that if the time pressure to keep up with pulses was removed, drivers might experience less stress.

If Strætó chooses to remove pulses, there are several important things to consider when implementing the change. First, we recommend that Strætó remove pulses during the least busy season of the year, potentially in June or July based on ridership numbers from Strætó. This will allow riders who use the system seasonally to learn how the new schedule operates before the changes immediately affect them. Strætó can also either remove all pulse connections at once, or slowly phase them out by time of day. Removing pulse connections all at once could make communication of the new schedule easier, while removing them slowly may give riders a chance to adjust to the new schedule and provide feedback. Throughout the process of removing pulse scheduling, Strætó should also consider that some buses are commonly transferred between when planning the new routes and schedules.

The common connections we observed are listed below:

- Ártún: 5 and 6, 5 and 15, 5 and 18, 6 and 15, 6 and 18
- Mjódd: 3 and 4, 3 and 12, 4 and 12
- Hamraborg: 1 and 2, 1 and 4, 1 and 28, 1 and 35, 2 and 4

Regardless of how, when, or if these changes are made, it should be noted that the clear communication of any schedule changes to the riders is important to avoid confusion and potential backlash.

Additional recommendations:

2. Improve communication channels with riders

Improving communications between Strætó and its users will increase rider satisfaction. In informal interviews and the survey, some riders expressed frustration with the Strætó mobile app, which reportedly sometimes displays inaccurate times or impossible transfers. Riders also mentioned discrepancies between schedules posted at stations and those available online. We suggest that Strætó work to improve the clarity and consistency of schedules, whether online, or in the Strætó app. In addition, an interview with Strætó's data specialist revealed that Strætó is planning to implement digital displays at bus stops that will give riders information regarding bus arrival times and potential delays. The team supports this decision because if riders have more access to real-time data about bus systems, they will be able to plan their schedules more effectively.

We also found from rider interview and survey results that some people who used to take buses currently do not take the bus because of negative experiences with Strætó years ago. Since then, Strætó has made continuous improvements, and we suggest that Strætó take this opportunity to renew their image as they make significant changes. The appearance of new, passenger-focused improvements can be marketed to attract new riders as well as those who have not given the system a chance in recent years.

3. Pursue additional priority bus lanes

While Strætó's existing designated bus-only lanes allow buses to bypass traffic, they are too disconnected to be fully effective. By adding additional bus-only priority lanes and connecting more of the existing lanes together, delays and inconsistencies caused by heavy traffic can be mitigated. We acknowledge the expensive nature of this improvement but recommend ongoing consideration for designated lanes as larger city projects such as the proposed bus rapid transit system develop in the future. **Figure 26**, below, shows one of Strætó's priority bus lanes.

Figure 26. One of Strætó's priority bus lanes.

4. Implement AFC systems on all buses and fully utilize AVL data

Strætó is planning to add AFC systems to their buses in the future. The team encourages this decision for two main reasons: AFC will reduce passenger boarding delays by speeding up passenger payment and will generate additional data for analysis. These data gathered from AFC will be similar to the data about bus transfers collected during this project but will be much more thorough and could help to verify the findings of this project. Additionally, while we only analyzed two three-week periods from 2018 and 2019, Strætó has years' worth of archived AVL data for every bus in the network. We learned from our interviews with Strætó's data analyst that they do some evaluation, but typically focus on individual routes rather than the whole system. Performing the same type of analysis that our team did with this larger dataset could further establish patterns in bus timeliness or expose new ones. Finally, combining AFC and AVL data will provide Strætó with a more complete picture of the end-to-end travel patterns of individual passenger as well as how delays affect the travel behaviors of passengers, which will be useful for future route planning.

5.2 Conclusion

The purpose of our research was to evaluate pulse scheduling in the overall context of Strætó's route network. Our research showed that increasing schedule delays in the Capital Region have made pulse scheduling less feasible. As Reykjavík grows, Strætó will continue to play a major role in how people navigate the city. By reorganizing their network and schedules Strætó could increase convenience for riders, save money, and ultimately increase their ridership. An increase in ridership will improve mobility in the Capital Region and thus promote economic growth, social equality, and environmental friendliness. By taking steps toward implementing a more sustainable public transit system, Strætó will contribute to the United Nations' sustainability goals.

There were some limitations in our research that are important to acknowledge. Due to the short amount of time we had to work on this project, we were only able to gather data about bus transfers for some of the buses at each station we observed, and only at some times of day. There were also other pulse stations, such as Fjörður, for which we did not collect any transfer data. We also would have liked to have conducted more interviews with Strætó employees and riders.

During this project, we identified two potential areas for future research. Firstly, an investigation into the reasons for the delays we observed may reveal specific actions Strætó could take to improve bus timeliness. Our data showed that although there was not a major increase in traffic, there was a significant increase in delays, suggesting that other factors may be causing delays. Secondly, we believe that more data regarding how passengers make transfers at pulse stations would be beneficial to Strætó. Collecting data from different bus routes and at different times of day could yield a more complete picture of how riders make transfers. The AFC system Strætó plans on implementing in the coming years will also provide similar data to what we collected manually but in much larger volume, which could be used to verify our findings and to pose new research questions for improvement of the system.

We would like to thank Strætó for the opportunity to work with them to improve their service. The staff we had the pleasure of working with were generous with their time and provided guidance for the team throughout the project. We hope that our research and recommendations have provided Strætó with valuable insights regarding the logistics and perceptions surrounding pulse scheduling and can inform future work regarding modifications to the system.

Works Cited

Bamwesigye, D. & Hlavackova, P. (2019). Analysis of Sustainable Transport for Smart Cities [PDF file]. https://doi.org/10.3390/su11072140

Bartolini, F., Cappelini, V., & Mecocci, A. (1994). Counting people getting in and out of a bus by real-time image-sequence processing. *Image and Vision Computing*. *12*(1), 36-41. https://doi.org/10.1016/0262-8856(94)90053-1

Beebe, J. (2014). *Rapid qualitative inquiry: A field guide to team-based assessment* (ed.2). Lanham, MD: Rowman & Littlefield

COWI. (2017). Borgarlína - High Class Public Transport in Reykjavík Capital Area [PDF file]. Retrieved from https://ssh.is/images/stories/svaedisskipulag/Borgarlína/Borgarl-High_class_pub_transport_Reykjav_area.m.pdf

Department of Planning and Environment. (2014). Reykjavík Municipal Plan 2010-2030 [PDF file]. Retrieved from https://Reykjavík.is/sites/default/files/Reykjavík-municipal-plan-2010-2030.pdf

Hawas, E.Y., Hassan, M. N., and Abulibdeh, A. (2016). A multi-criteria approach of assessing public transport accessibility at a strategic level. *Journal of transport geography*, *57*, 19-34. https://doi.org/10.1016/j.jtrangeo.2016.09.011

Iceland Monitor. (2016). *Bus stuck in traffic* [Digital image]. Retrieved from https://icelandmonitor.mbl.is/news/politics_and_society/2016/10/14/three_parties_in_iceland_pass_the_climate_change_te/

Iceland Review. (2017). Cityline to cost up to ISK 70 billion. Retrieved from https://www.icelandreview.com/news/cityline-cost-up-isk-70-billion/

Institute for Transportation & Development Policy. (2014). Bus Rapid Transit Nearly Quadruples Over Ten Years. Retrieved from https://www.itdp.org/2014/11/17/bus-rapid-transit-nearly-quadruples-ten-years/

Institute for Transportation & Development Policy. (n.d.). What is BRT? Retrieved from https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/

International Association of Public Transport. (2017). Urban public transport in the 21st century [PDF file]. Retrieved from https://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP_Statistic%20Brief_national%20PT%20stats.pdf

Jónsdóttir, H. (2007). Coffee, buses, and laptops: a good mix?. *The Reykjavík grapevine*. Retrieved from https://grapevine.is/mag/column-opinion/2007/08/10/coffee-buses-and-laptops-a-good-mix/

Luxembourg Times (2016). 30 cars or a bus? [Digital image]. *Luxembourg Times*. Retrieved from https://luxtimes.lu/archives/5262-30-cars-or-a-bus.

MacKechnie, C. (2018). How do bus routes and schedules get planned?. Retrieved from https://www.thoughtco.com/bus-routes-and-schedules-planning-2798726

Noone, D. R., Bergman, A. S., & Lynch, R. K. (2015). *United States Patent Number US9183686B2.* Retrieved from https://patents.google.com/patent/US9183686B2/en

Nulty, D. D. (2008). The adequacy of response rates to online and paper surveys: What can be done?. *Assessment and evaluation in higher education, 33*(3), 301-314. Retrieved from: https://www.uaf.edu/files/uafgov/fsadmin-nulty5-19-10.pdf

OpenStreetMap. (n.d.). *Capital Region of Iceland* [Digital image]. Retrieved from https://www.openstreetmap.org/#map=10/64.0698/-21.7207

Rubiano, L. C. & Darido, G. (2019). The ticket to a better ride: how can automated fare collection improve urban transport? [Blog post]. Retrieved from https://blogs.worldbank.org/transport/ticket-better-ride-how-can-automated-fare-collection-improve-urban-transport

Section 14. SWOT Analysis: Strengths, Weaknesses, Opportunities, and Threats. (n.d.). Retrieved from https://ctb.ku.edu/en/table-of-contents/assessment/assessing-community-needs-and-resources/swot-analysis/main

Strætó bs. (2019a). Frequently Asked Questions. Retrieved from https://www.Strætó.is/en/upplysingar/spurt-svarad

Strætó bs. (2019b). Human Resources. Retrieved from https://www.Strætó.is/en/um-Strætó/mannaudur

Strætó bs. (2019c). Route planner. Retrieved from https://www.Strætó.is/

Strateo bs (2019d). Strætó's route network. Retrieved from https://www.Strætó.is/en/um-Strætó/leidakerfi

Stræto bs. (2018) Stræto bs (5.11.1) [Mobile application software]. Retrieved from https://itunes.apple.com/us/app/str%C3%A6t%C3%B3-bs/id573475820?mt=8

Stræto bs. (n.d.). Retrieved from https://appgrooves.com/ios/573475820/str%C3%A6t%C3%B3-bs/str%C3%A6to-bs

Sveinbjörnsdóttir, E. (2002). What is the Greater Reykjavík Area as a percentage of the entire country? Retrieved from https://www.visindavefur.is/svar.php?id=2245

Taxi. (n.d.). Retrieved from https://visitReykjavík.is/city/taxi

Trumm, D. (2019). Tacoma's Pacific Avenue Hybrid Bus Rapid Transit Advances [Digital image]. Retrieved from https://www.theurbanist.org/2019/04/16/tacomas-pacific-avenue-hybrid-bus-rapid-transit-advances/

United Nations. (n.d.). Goal 11: Make cities inclusive, safe, resilient and sustainable. Retrieved from https://www.un.org/sustainabledevelopment/cities/

Vegagerðin. (2019). 3 lykilteljarar á höfuðborgarsvæðinu [PDF file] Retrieved from http://www.vegagerdin.is/vefur2.nsf/Files/Hb_netid_2019/$file/Hb_%C3%A1_neti%C3%B0_2019.pdf

Viriyinci, Oran. (2009, May 10). *ORCA Tap out Tacoma Sounder* [Digital image]. Retrieved from https://www.flickr.com/photos/viriyincy/3520015658/in/album-72157630706010570/

Walker, J. (n.d.). The Transit Ridership Recipe [Blog post]. Retrieved from https://humantransit.org/basics/the-transit-ridership-recipe#ridershipcoveragetradeoff

Wilson, N.H., Zhao, J., & Rahbee, A. (2009). The potential impact of automated data collection systems on urban public transport planning. Schedule-based modeling of transportation networks, *46*. https://doi.org/10.1007/978-0-387-84812-9_5

Wei-Hua, L., & Jian, Z. (1999). Experimental Study of Real-Time BusArrival Time Prediction with GPS Data. *Transportation Research Record: Journal of the Transportation Research Board*, *1666*(1), 101-109, https://doi.org/10.3141%2F1666-12

Appendix A: Strætó Employee Interview Questions

INFORMED CONSENT: You are invited to participate in this survey, conducted by students at Worcester Polytechnic Institute in Worcester, Massachusetts, USA as part of a research project. Your participation in this survey is entirely voluntary. Your responses will be confidential and anonymous. The purpose of this research is to help Strætó improve the efficiency of their bus network.

If you have any questions about this survey, the researchers can be contacted at gr-a19Strætó@wpi.edu. This research project is advised by Fred Looft (fjlooft@wpi.edu) and Ingrid Shockey (ishockey@wpi.edu). Please contact irb@wpi.edu if you have ethical concerns about the content of this interview.

Fleet Manager

- Can you describe your position at Strætó and your experience with Strætó?
- What do you think works well in the bus system and why do you think it works well?
- What are the advantages and disadvantages of the pulse system?
- What are some challenges of the pulse system?
- What kind of things can you do if the buses become delayed?
- Have any changes been made recently to deal with issues and what effect did they have?
- How do you get feedback from passengers?
- Who makes planning decisions?
- Do you think removing the pulses would be helpful?

Data Specialist

- Can you describe your role at Strætó?
- What data do you have about the buses?
- How do you use this data?
- Have you noticed the impact of traffic congestion in your data analysis?
- What percentage of buses have GPS trackers?
- Does Strætó do analysis or look at the times that buses actually arrive at stop versus the schedule?
- Is there any data that you wish you had that you do not have currently?

Call Center Project Manager

- Could you start off by quickly describe your position here with Strætó?
- What kinds of calls do you receive?
- Or callers usually pretty frustrated or more reasonable?
- How much immediate power does your center have to kind of respond to what the callers are asking for or complaining about?
- What does the feedback process look like?
- After route changes are made, do you usually receive more calls?
- Do people take changes well?
- What kind of communication is done ahead of time to inform people of route changes?
- Do you mostly receive calls from locals or from tourists as well?

Bus Driver

- Can you start of by quickly describing what it is you do here at Strætó?
- What do you think works well in the system and what does not work well?
- What factors cause the buses to become delayed?
- If you ever do get behind schedule, can you do anything to catch up?
- What would you think of a system without pulses?
- What kind of feedback do bus drivers receive?

Appendix B: Rider Informal Interview Questions

- Is it helpful when the buses come at the same time?
- How often do you ride the bus?
- Which bus transfers do you make?
- Do you often have to wait a long time for buses?
- How would you feel about buses coming more often, but not at the same time?
- Do you like riding the bus?
- What could be better about the bus system?

Appendix C: Rider Surveys

Rider Survey (English)

You are invited to participate in this survey, conducted by students at Worcester Polytechnic Institute in Worcester, Massachusetts, USA as part of a research project. Your participation in this survey is entirely voluntary. Your responses will be confidential and anonymous.

If you have any questions about this survey, the researchers can be contacted at gr-a19Strætó@wpi.edu. This research project is advised by Fred Looft (fjlooft@wpi.edu) and Ingrid Shockey (ishockey@wpi.edu). Please contact irb@wpi.edu if you have ethical concerns about the content of this interview.

The purpose of this research is to help Strætó improve the efficiency of their bus network.

Are you 18 years of age or older?

(you must be 18 years or older to participate)

Yes, No

What is your age?

18 - 24, 25- 34, 35- 44, 45 - 54, 55 - 64, 65+, I prefer not to answer

Please select your gender.

Male, Female, Other, I prefer not to answer

How often do you make transfers at Ártún?
Never, Less than once a month, 1-3 times a month, 1-2 times per week, 3 - 6 times per week, Daily

How convenient is it for you to transfer between bus routes at Ártún?
Not at all convenient, Not very convenient, Somewhat convenient, Very convenient

If not convenient, why?
Bus is late so I miss transfers, Bus I’m transferring to is late so I have to wait, Difficult to figure out where the connecting bus is, Inconvenient to walk between buses, Other: (free response)

How often do you make transfers at Mjódd?

Never, Less than once a month, 1-3 times a month, 1-2 times per week, 3 - 6 times per week, Daily

How convenient is it for you to transfer between bus routes at Mjódd?

Not at all convenient, Not very convenient, Somewhat convenient, Very convenient

If not convenient, why?

Bus is late so I miss transfers, Bus I'm transferring to is late so I have to wait, Difficult to figure out where the connecting bus is, Inconvenient to walk between buses, Other: (free response)

How often do you make transfers at Hamraborg?

Never, Less than once a month, 1-3 times a month, 1-2 times per week, 3 - 6 times per week, Daily

How convenient is it for you to transfer between bus routes at Hamraborg?

Not at all convenient, Not very convenient, Somewhat convenient, Very convenient

If not convenient, why? (select multiple)

Bus is late so I miss transfers, Bus I'm transferring to is late so I have to wait, Difficult to figure out where the connecting bus is, Inconvenient to walk between buses, Other: (free response)

How satisfied are you with Strætó's bus system overall?

Very dissatisfied, Somewhat dissatisfied, Neutral, Somewhat satisfied, Very satisfied

Do you have any additional comments?

(free response)

Your response has been recorded. Thank you for your time!

Rider Survey (Icelandic)

Þér er boðið að taka þátt í þessari könnun sem gerð er af nemendum við Worcester Polytechnic Institute í Massachusetts, Bandaríkjunum. Könnunin er hluti af rannsóknarverkefni nemendanna. Ekki verður hægt að rekja einstök svör og könnunin er nafnlaus.

Ef þú hefur einhverjar spurningar varðandi þessa könnun er hægt að hafa samband við nemendurna í gegnum netfangið gr-a19Strætó@wpi.edu . Leiðbeinendur nemendanna eru Fred Looft (fjlooft@wpi.edu) og Ingrid Shockey (ishockey@wpi.edu).

Tilgangur þessarar rannsóknar er að rannsaka leiðakerfi Strætó og koma með tillögur að bætingum.

Ertu 18 ára eða eldri?

Já, Nei

Aldur

18 - 24, 25- 34, 35- 44, 45 - 54, 55 - 64, 65+, Vil ekki svara

Kyn

Karl, Kona, Annað, Vil ekki svara

Hversu oft skiptir þú um vagn í Ártúni að jafnaði?

Aldrei, Sjaldnar en einu sinni í mánuði, 1-3 sinnum í mánuði, 1-2 sinnum í viku, 3-6 sinnum í viku, Daglega

Hversu hentugt er fyrir þig að skipta um vagn í Ártúni?

Mjög hentugt, Frekar hentugt, Frekar óhentugt, Mjög óhentugt

Ef það er óhentugt, hver er ástæðan?

Strætó er seinn þannig að ég missi af skiptingu, Vagninn sem ég þarf að skipta í er seinn þannig að ég þarf að bíða, Það er erfitt að átta sig á því hvar maður skiptir um vagn, Það er erfitt/óhentugt að ganga á milli vagna, Annað (free response)

Hversu oft skiptir þú um vagn í Mjódd að jafnaði?

Aldrei, Sjaldnar en einu sinni í mánuði, 1-3 sinnum í mánuði, 1-2 sinnum í viku, 3-6 sinnum í viku, Daglega

Hversu hentugt er fyrir þig að skipta umvagn í Mjódd?

Mjög hentugt, Frekar hentugt, Frekar óhentugt, Mjög óhentugt

Ef það er óhentugt, hver er ástæðan?

Strætó er seinn þannig að ég missi af skiptingu, Vagninn sem ég þarf að skipta í er seinn þannig að ég þarf að bíða, Það er erfitt að átta sig á því hvar maður skiptir um vagn, Það er erfitt/óhentugt að ganga á milli vagna, Annað (free response)

Hversu oftskiptir þú um vagn í Hamraborg að jafnaði?

Aldrei, Sjaldnar en einu sinni í mánuði, 1-3 sinnum í mánuði, 1-2 sinnum í viku, 3-6 sinnum í viku, Daglega

Hversu hentugt er fyrir þig að skiptaum vagn í Hamraborg?

Mjög hentugt, Frekar hentugt, Frekar óhentugt, Mjög óhentugt

Ef það er óhentugt, hver er ástæðan?

Strætó er seinn þannig að ég missi af skiptingu, Vagninn sem ég þarf að skipta í er seinn þannig að ég þarf að bíða, Það er erfitt að átta sig á því hvar maður skiptir um vagn, Það er erfitt/óhentugt að ganga á milli vagna, Annað (free response)

Hversu ánægð/ur ert þú með leiðakerfi Strætó

Mjög ánægð/ur, Frekar ánægð/ur, Hvorki né, Frekar óánægð/ur, Mjög óánægð

Ert þú með einhverjar frekari athugasemdir?

Appendix D: Bus Counting Data Charts

ÁRTÚN BUS 6

Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center

	Bus Number	Bus 5	Bus 12	Bus 15	Bus 16	Bus 18	Bus 24	Bus 57	No transfer	Total Responses	No Response	Response Rate
ENTERING	Morning rush	48	1	18	0	33	0	0	12	112	22	83.58%
	Midday	5	1	2	0	0	1	0	2	11	1	91.67%
	Afternoon rush	5	1	5	2	5	2	0	1	21	8	72.41%
	All Entering Times	58	3	25	2	38	3	0	15	144	42	77.42%
EXITING	Morning rush	22	2	6	0	5	0	0	0	35	6	85.37%
	Midday	6	1	7	0	12	0	0	0	26	13	66.67%
	Afternoon rush	33	1	26	1	23	0	5	6	95	24	79.83%
	All Exiting Times	61	4	38	7	40	0	5	6	156	19	89.14%

ÁRTÚN BUS 5

Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center

	Bus Number	Bus 6	Bus 12	Bus 15	Bus 16	Bus 18	Bus 24	Bus 57	No transfer	Total Responses	No Response	Response Rate
ENTERING	Morning rush	5	0	2	0	24	0	0	3	34	24	58.62%
	Midday	8	0	2	0	2	1	0	1	14	2	87.50%
	Afternoon rush	33	0	6	0	6	0	0	2	47	16	74.60%
	All Times	46	0	10	0	32	1	0	6	95	42	69.34%
EXITING	Morning rush	32	0	5	0	3	0	0	0	40	12	76.92%
	Midday	4	0	0	0	2	0	0	0	6	0	100.00%
	Afternoon rush	9	0	3	0	7	0	3	3	25	7	78.13%
	All Times	45	0	8	0	12	0	3	3	71	19	78.89%

MJÓDD BUS 4

Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center

	Bus Number	Bus 2	Bus 3	Bus 4	Bus 11	Bus 12	Bus 17	Bus 21	Bus 24	Bus 51	Bus 57	No transfer	Total Responses	No Response	Response Rate
ENTERING	Morning rush	1	11			10	2		1			2	27	12	69.23%
	Midday		9		3			5	2			2	21	9	70.00%
	Afternoon rush		4		1	5		1	1			5	17	20	45.95%
	All Entering Times	1	24	0	4	15	2	6	4	0	0	9	65	41	61.32%
EXITING	Morning rush		27		7	6			1			1	42	5	89.36%
	Midday		1	1		1			1			1	5	12	29.41%
	Afternoon rush		9	3	2	3	2	5	3			4	31	23	57.41%
	All Exiting Times	0	37	4	9	10	2	5	5	0	0	6	78	40	66.10%

MJÓDD BUS 12

Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center

	Bus Number	Bus 2	Bus 3	Bus 4	Bus 11	Bus 12	Bus 17	Bus 21	Bus 24	Bus 51	Bus 57	No transfer	Total Responses	No Response	Response Rate
ENTERING	Morning rush	1	1	13			1	3		2	1	5	27	17	61.36%
	Midday		1		1								2	6	25.00%
	Afternoon rush		2	2	1	2			3			1	11	21	34.38%
	All Entering Times	1	4	15	2	2	1	3	3	2	1	6	40	44	47.62%
EXITING	Morning rush	1	14	6	3								24	10	70.59%
	Midday							1	4			7	12	11	52.17%
	Afternoon rush	1	3	2					2			1	9	31	22.50%
	All Exiting Times	2	17	8	3	0	0	1	6	0	0	8	45	52	46.39%

MJÓDD BUS 3

Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center

	Bus Number	Bus 2	Bus 3	Bus 4	Bus 11	Bus 12	Bus 17	Bus 21	Bus 24	Bus 51	Bus 57	No transfer	Total Responses	No Response	Response Rate
ENTERING	Morning rush	6	4	24	1	10			1	5		11	62	22	73.81%
	Midday	1	1	4		1		1				3	11	2	84.62%
	Afternoon rush		2	2	1	4		2	2			4	17	8	68.00%
	All Times	7	7	30	2	15	0	3	3	5	0	18	90	32	73.77%
EXITING	Morning rush	0		3	1	1		1	1				7	9	43.75%
	Midday	1	1	6		3		2	3	2		1	19	17	52.78%
	Afternoon rush	2	3	6		2			1	3		2	19	52	26.76%
	All Times	3	4	15	1	6	0	3	5	5	0	3	45	78	36.59%

HAMRABORG BUS 1

Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center

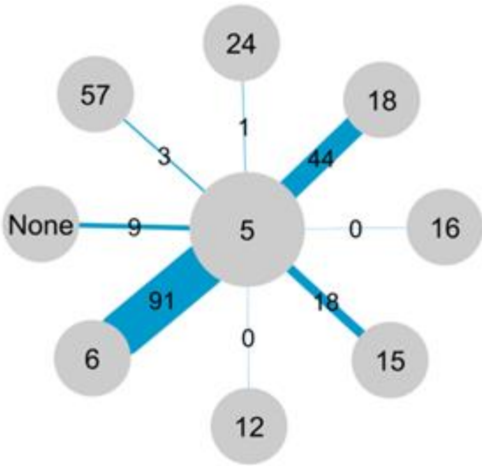
	Bus Number	Bus 1	Bus 2	Bus 4	Bus 28	Bus 35	Bus 36	No transfer	Total Responses	No Response	Response Rate
ENTERING	Morning rush		26	9	19	14	5	56	129	41	75.88%
	Midday		3	8				8	19	6	76.00%
	Afternoon rush	12	8	22	1	1		12	56	8	87.50%
	All Times	12	37	39	20	15	5	76	204	55	78.76%
EXITING	Morning rush	1	0	19	1	0	1	11	33	41	44.59%
	Midday		6	2	3		1		12	27	30.77%
	Afternoon rush		13	4	9	2	1	3	32	84	27.59%
	All Times	1	19	25	13	2	3	14	77	152	33.62%

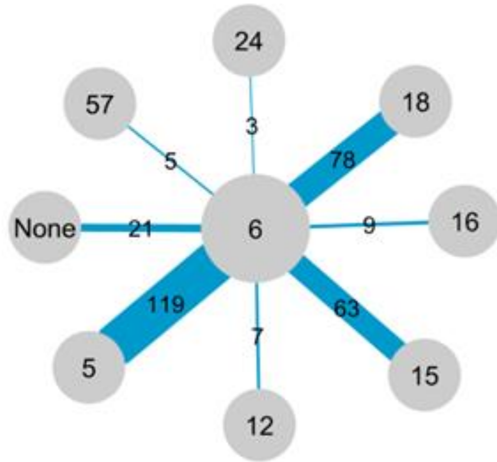
	HAMRABORG BUS 4										
	Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center										
	Bus Number	Bus 1	Bus 2	Bus 4	Bus 28	Bus 35	Bus 36	No transfer	Total Responses	No Response	Response Rate
ENTERING	**Morning rush**	12	8	4		1	1	9	35	18	66.04%
	Midday	3	1		1			1	6	9	40.00%
	Afternoon rush	20	2	1		1	2	3	29	13	69.05%
	All Entering Times	35	11	5	1	2	3	13	70	40	63.64%
EXITING	**Morning rush**	16	4			1		1	22	30	42.31%
	Midday	3	2		1	2	1	5	14	6	70.00%
	Afternoon rush	14	1	3	2	1	3	1	25	22	53.19%
	All Exiting Times	33	7	3	3	4	4	7	61	58	51.26%

	HAMRABORG BUS 2										
	Morning rush: headed into the city center, Midday: headed out of the city center, Afternoon rush: headed out of the city center										
	Bus Number	Bus 1	Bus 2	Bus 4	Bus 28	Bus 35	Bus 36	No transfer	Total Responses	No Response	Response Rate
ENTERING	**Morning rush**	3	4	3	2		1	2	15	29	34.09%
	Midday	16		2				11	29	6	82.86%
	Afternoon rush	16		7				9	32	19	62.75%
	All Entering Times	35	4	12	2	0	1	22	76	54	58.46%
EXITING	**Morning rush**	38		9		1	1	2	51	8	86.44%
	Midday	2				2		5	9	2	81.82%
	Afternoon rush	3	2	2	3			16	26	21	55.32%
	All Exiting Times	43	2	11	3	3	1	23	86	31	73.50%

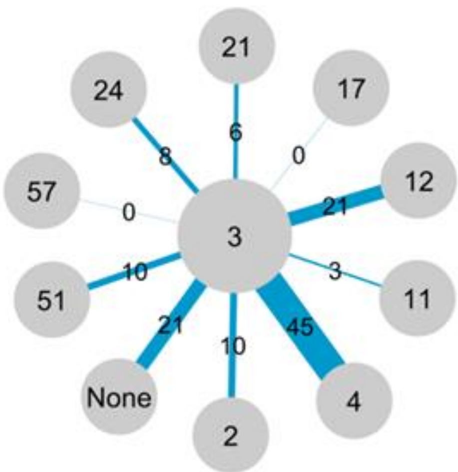
Appendix E: Bus Transfer Web Charts

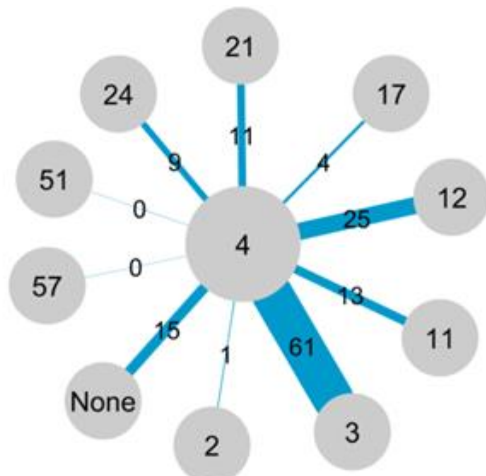
Ártún:

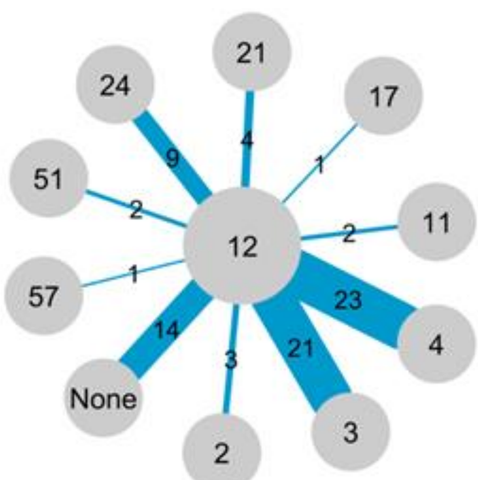




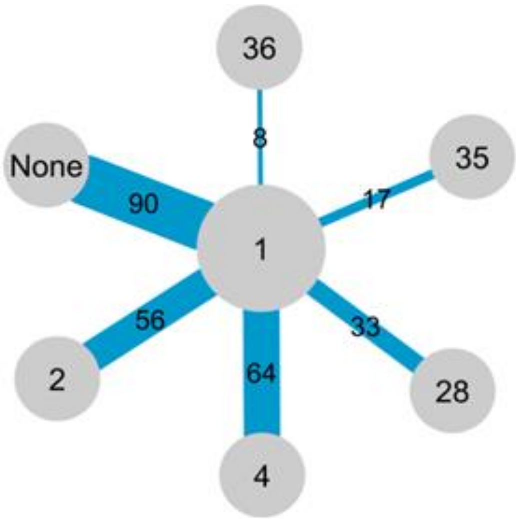
Mjódd:

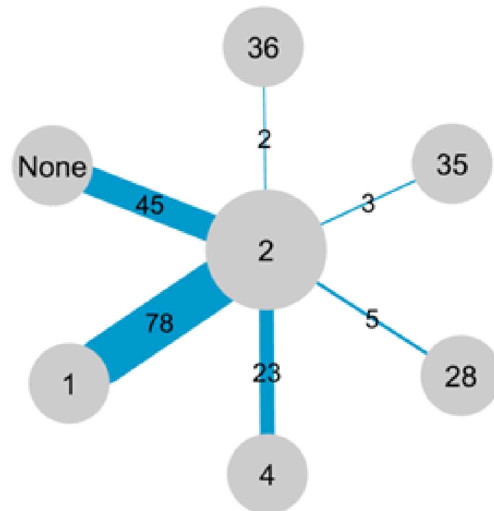


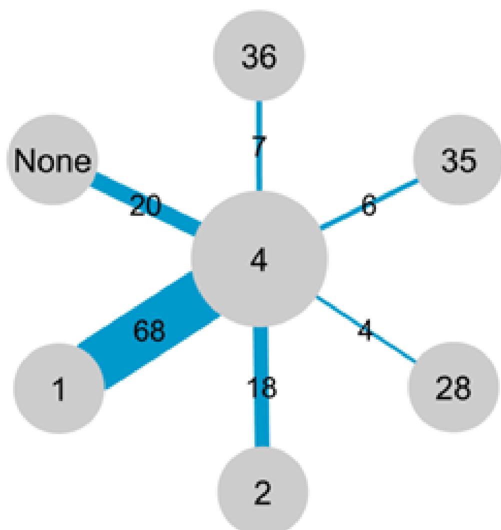




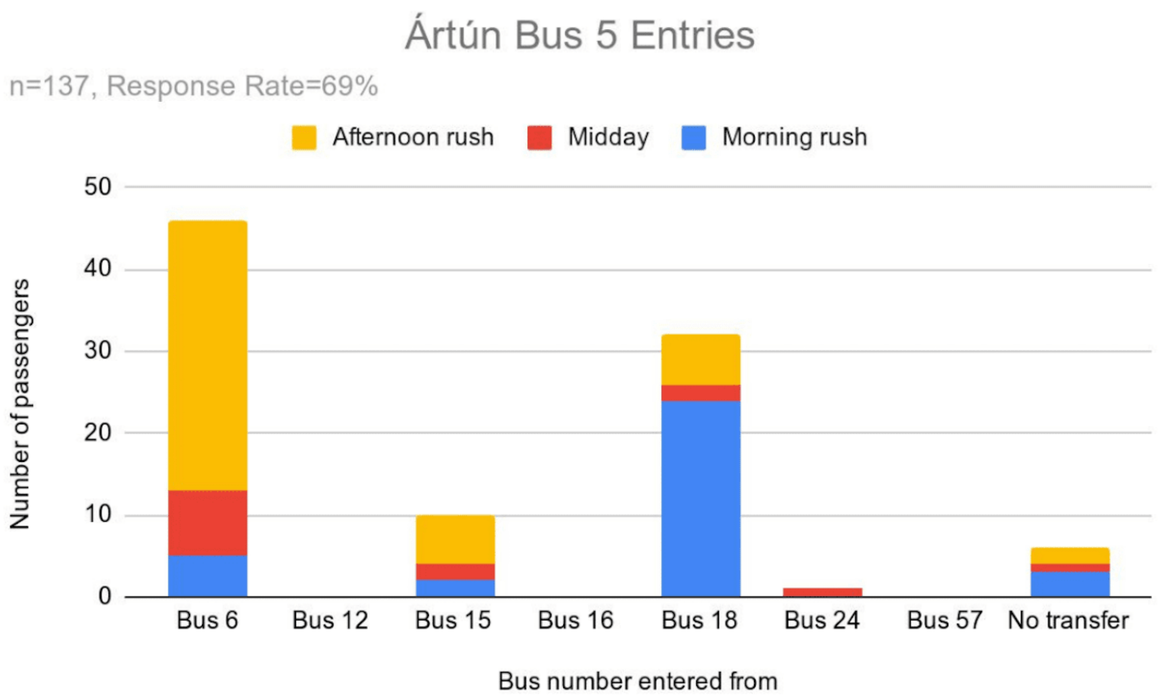
Hamraborg:

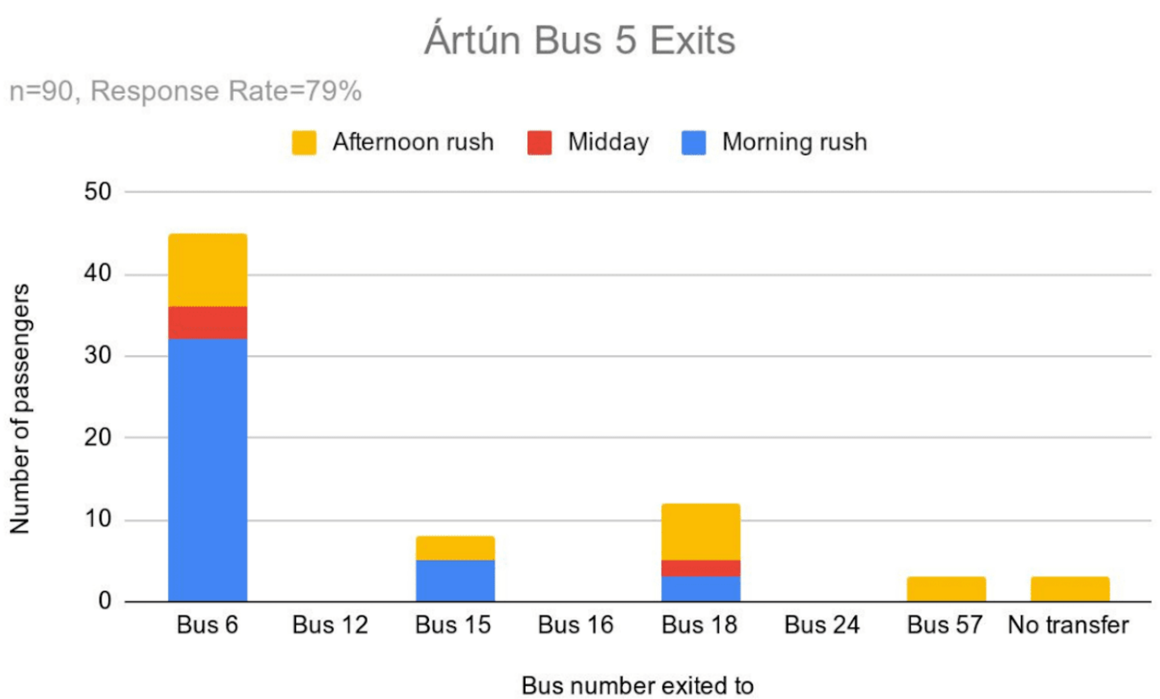

36
8
None
90
35
17
1
56
33
2
64
28
4

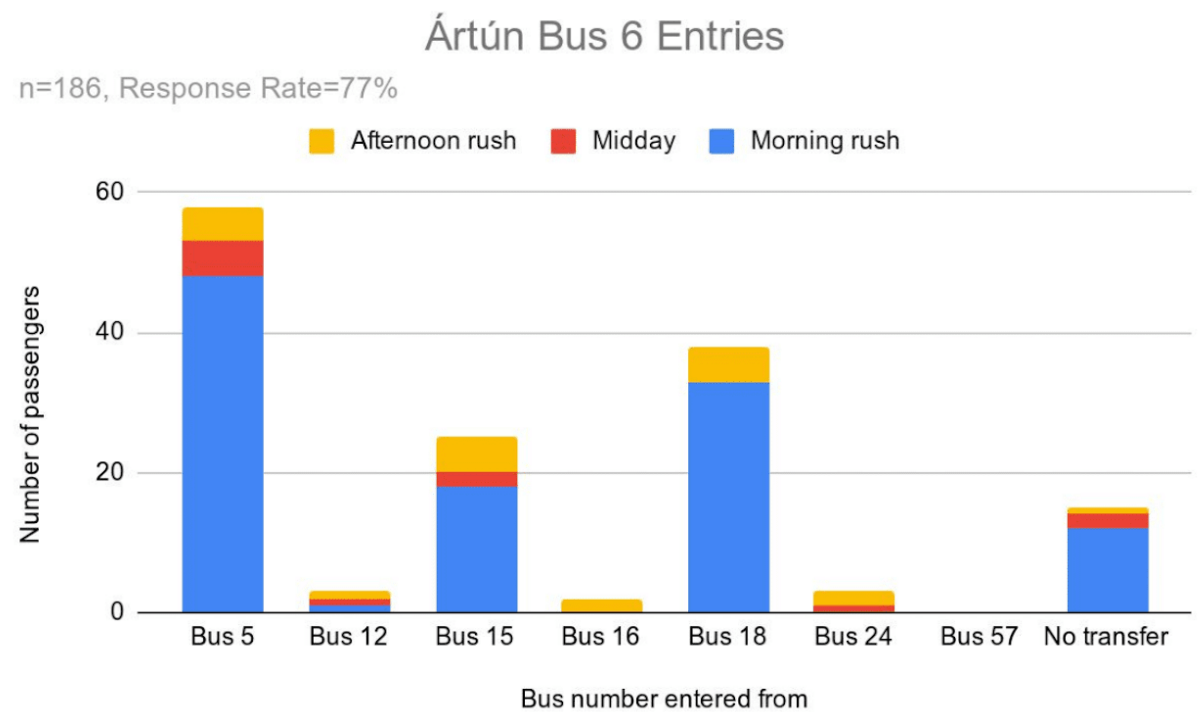

36
2
None
45
35
3
2
78
5
1
23
28
4

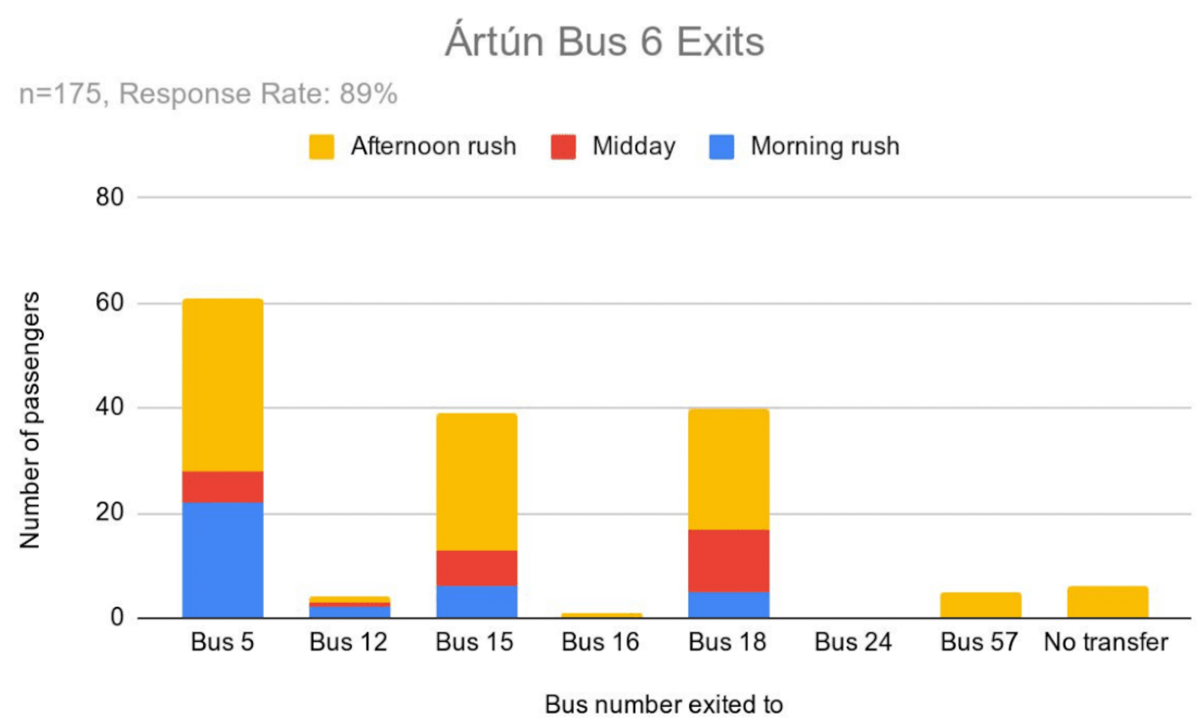

36
7
None
20
35
6
4
68
4
1
18
28
2

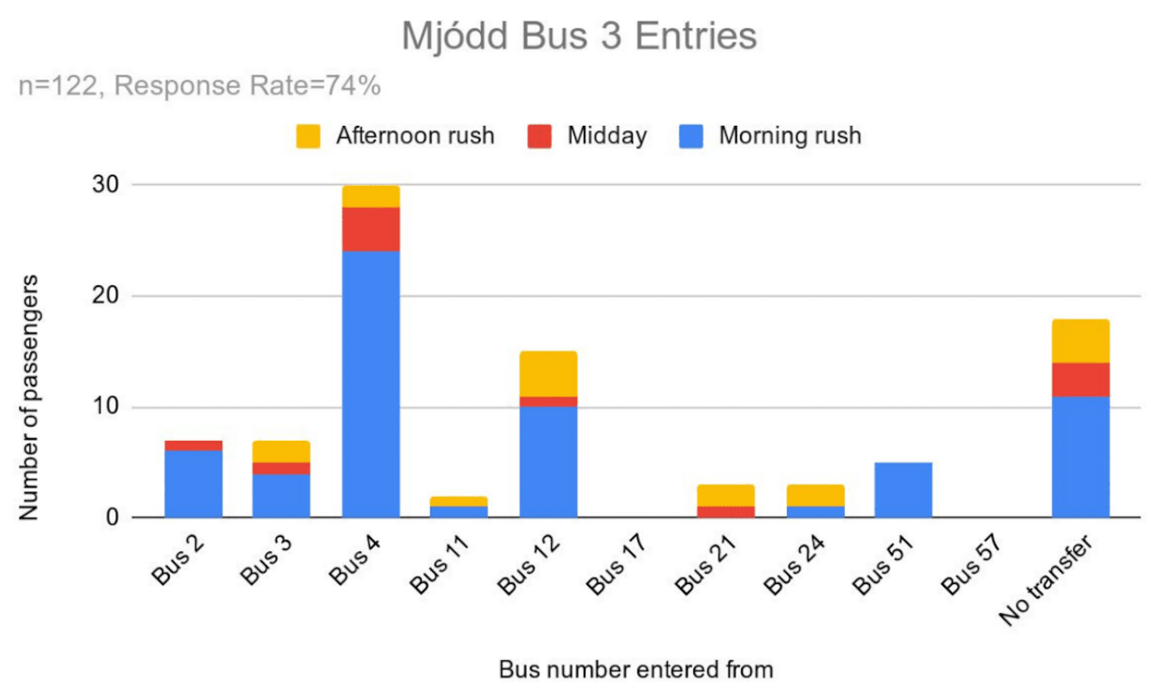
Appendix F: Bus Counting Data Bar Graphs

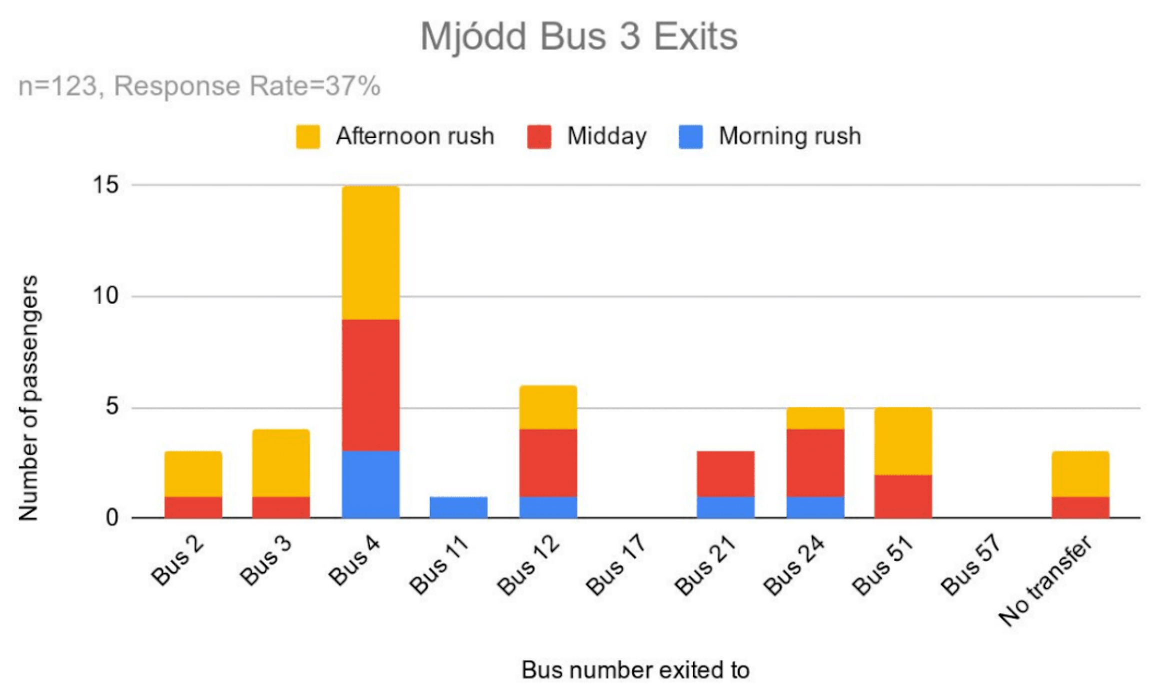


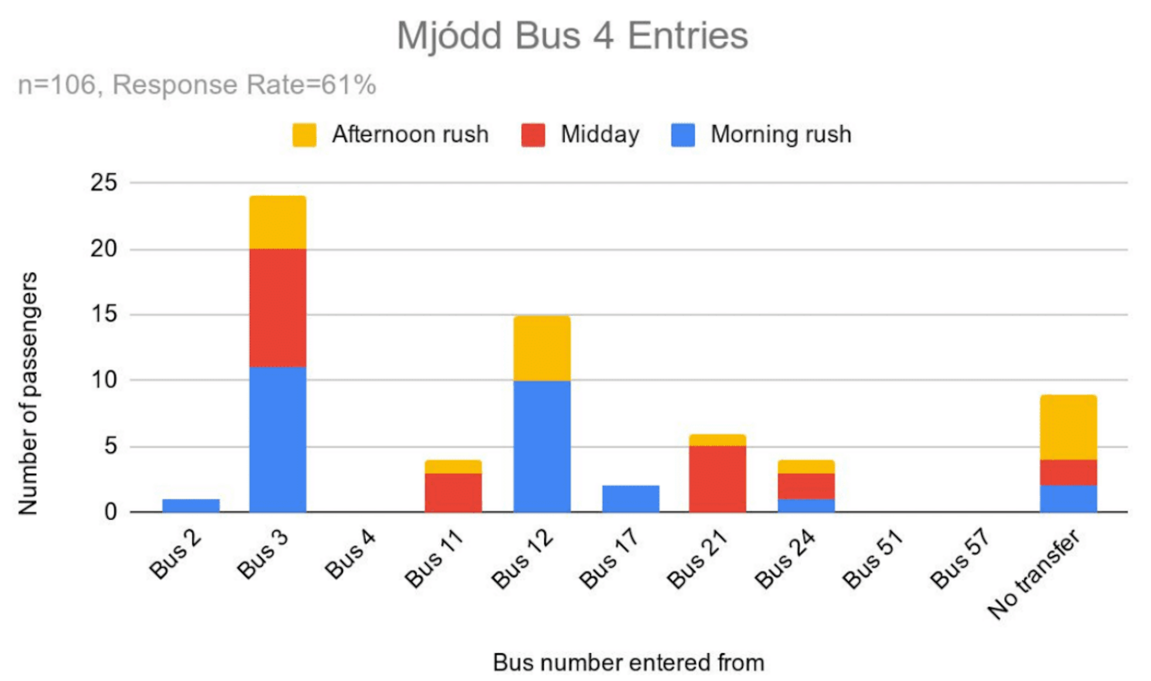


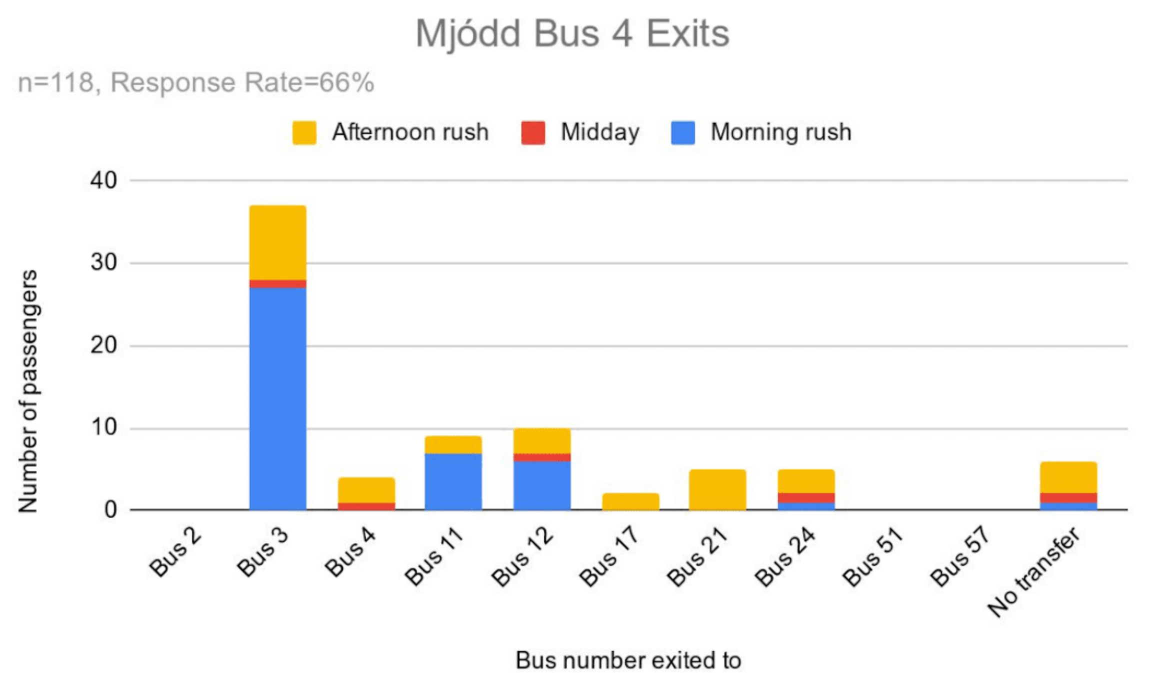

Ártún Bus 6 Entries
n=186, Response Rate=77%
Afternoon rush
Midday
Morning rush
60
40
20
0
Number of passengers
Bus 5
Bus 12
Bus 15
Bus 16
Bus 18
Bus 24
Bus 57
No transfer
Bus number entered from

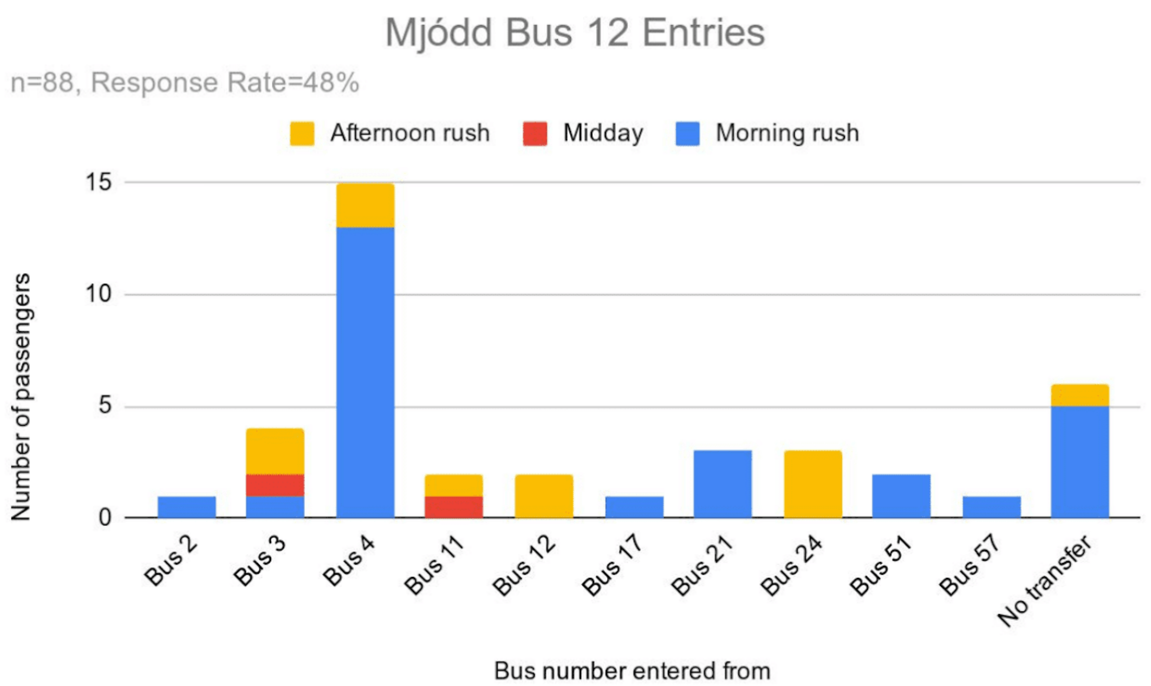

Ártún Bus 6 Exits
n=175, Response Rate: 89%
Afternoon rush
Midday
Morning rush
80
60
40
20
0
Number of passengers
Bus 5
Bus 12
Bus 15
Bus 16
Bus 18
Bus 24
Bus 57
No transfer
Bus number exited to

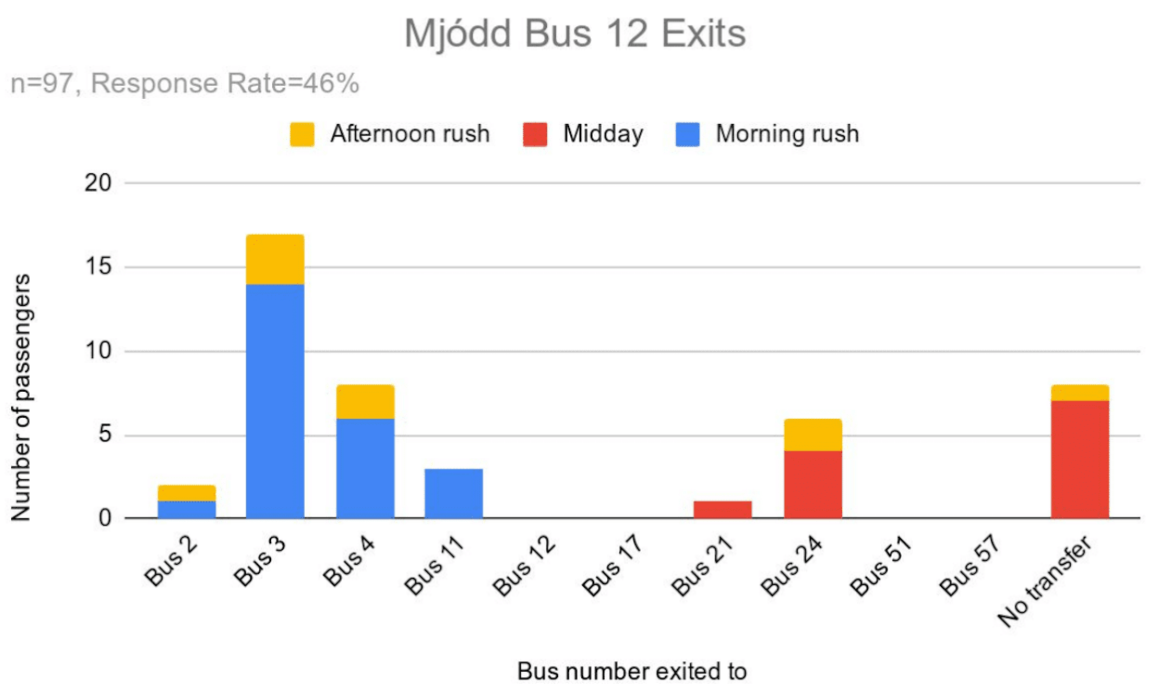

Mjódd Bus 3 Entries
n=122, Response Rate=74%
Afternoon rush
Midday
Morning rush
30
20
10
0
Number of passengers
Bus 2
Bus 3
Bus 4
Bus 11
Bus 12
Bus 17
Bus 21
Bus 24
Bus 51
Bus 57
No transfer
Bus number entered from

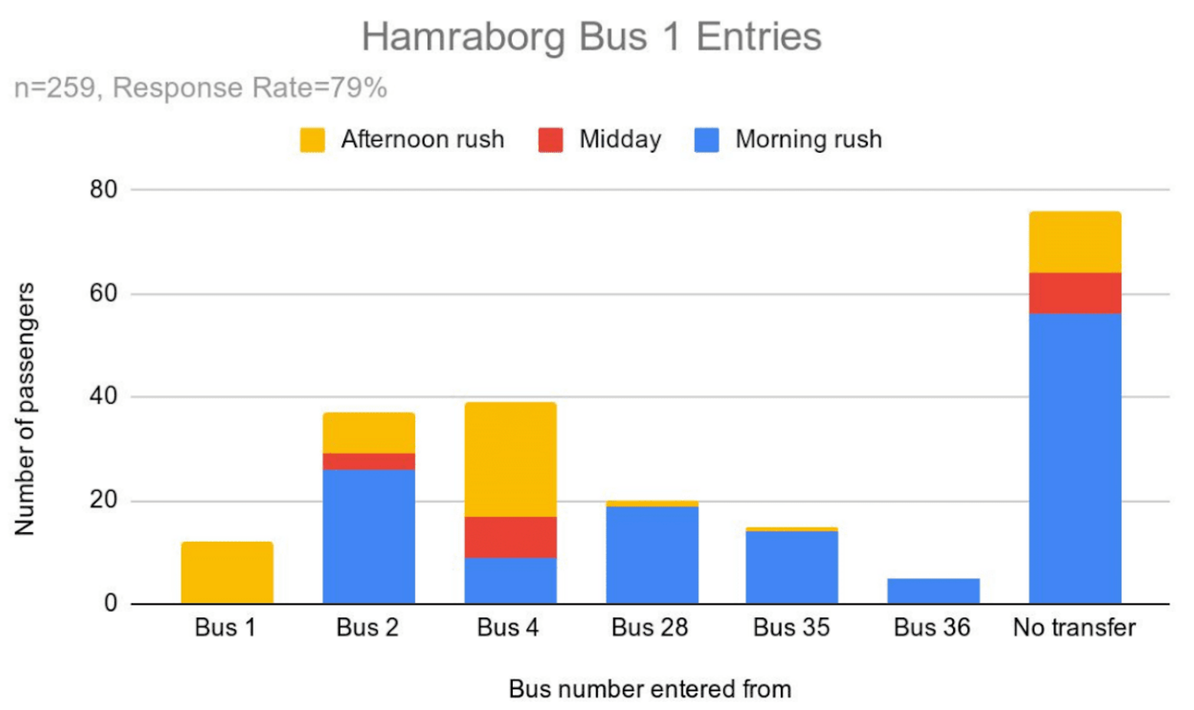

Mjódd Bus 3 Exits
n=123, Response Rate=37%
Afternoon rush
Midday
Morning rush
15
10
5
0
Number of passengers
Bus 2
Bus 3
Bus 4
Bus 11
Bus 12
Bus 17
Bus 21
Bus 24
Bus 51
Bus 57
No transfer
Bus number exited to

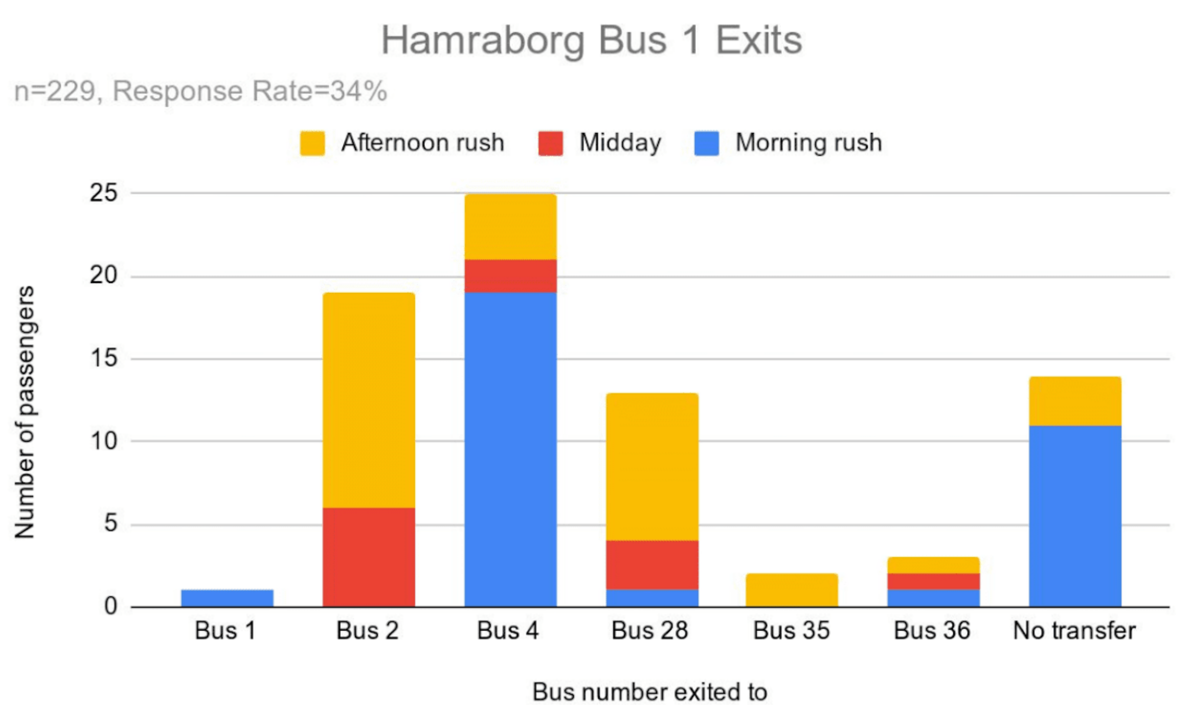

Mjódd Bus 4 Entries
n=106, Response Rate=61%
Afternoon rush
Midday
Morning rush
25
20
15
10
5
0
Number of passengers
Bus 2
Bus 3
Bus 4
Bus 11
Bus 12
Bus 17
Bus 21
Bus 24
Bus 51
Bus 57
No transfer
Bus number entered from

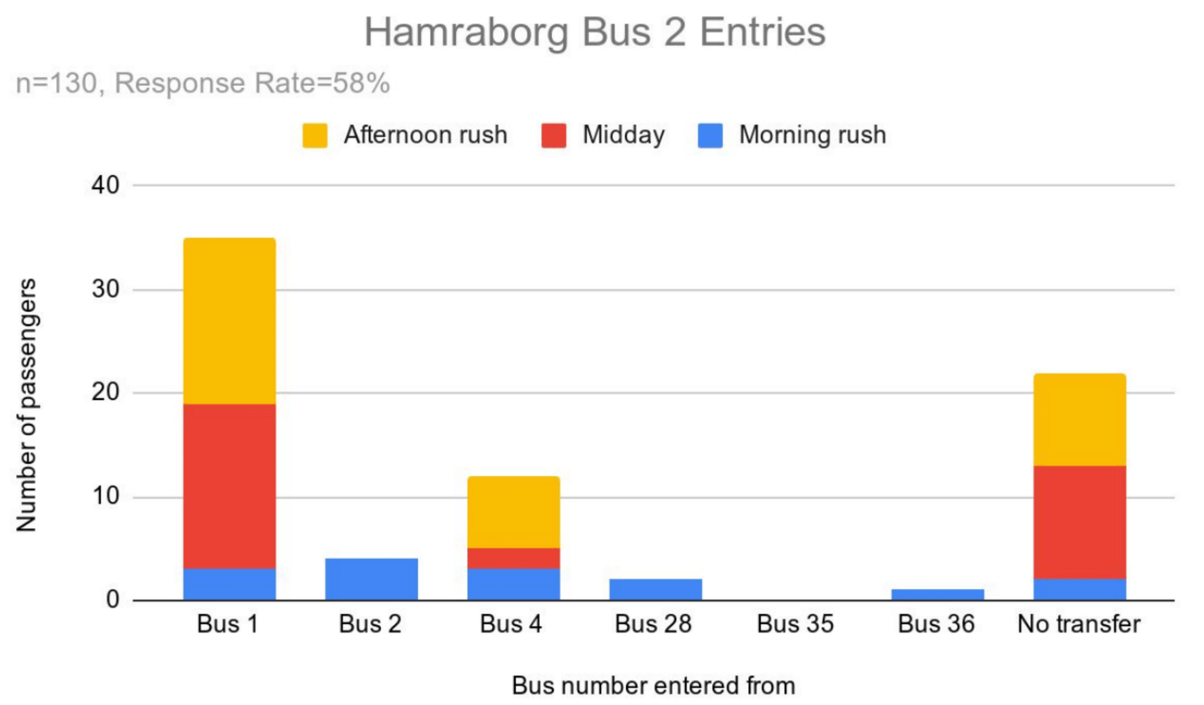

Mjódd Bus 4 Exits
n=118, Response Rate=66%
Afternoon rush
Midday
Morning rush
40
30
20
10
0
Number of passengers
Bus 2
Bus 3
Bus 4
Bus 11
Bus 12
Bus 17
Bus 21
Bus 24
Bus 51
Bus 57
No transfer
Bus number exited to


Mjódd Bus 12 Entries
n=88, Response Rate=48%
Afternoon rush
Midday
Morning rush
15
10
5
0
Number of passengers
Bus 2
Bus 3
Bus 4
Bus 11
Bus 12
Bus 17
Bus 21
Bus 24
Bus 51
Bus 57
No transfer
Bus number entered from

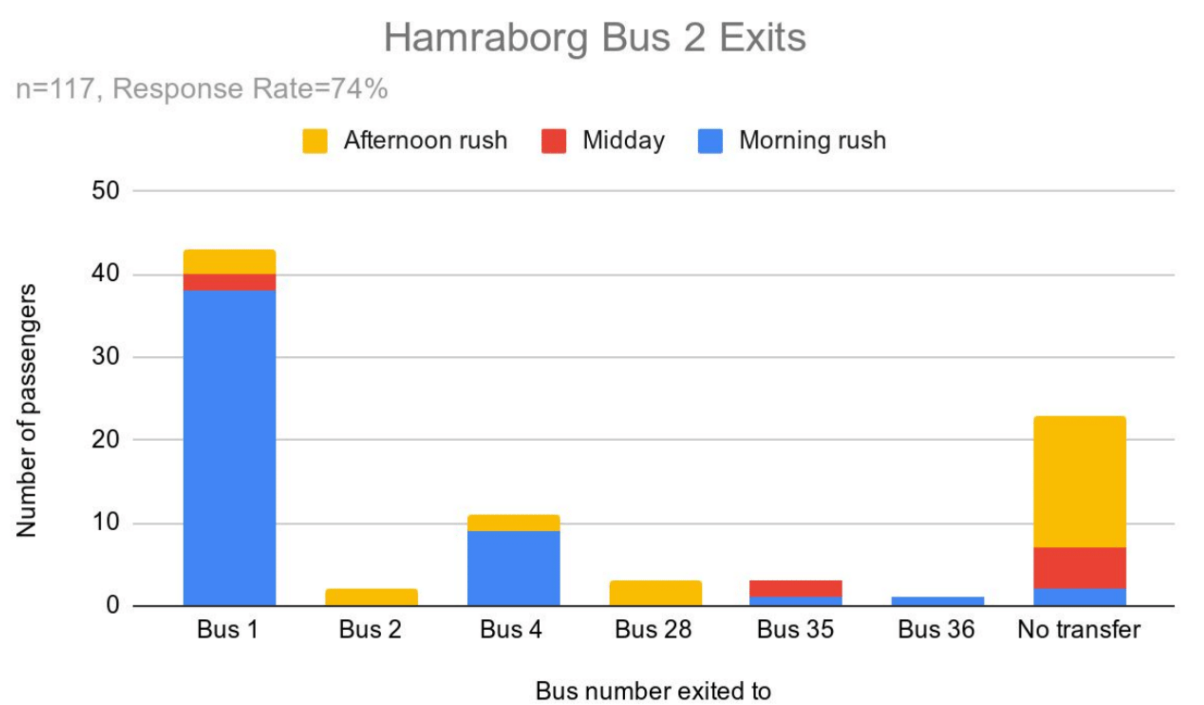

Mjódd Bus 12 Exits
n=97, Response Rate=46%
Afternoon rush
Midday
Morning rush
20
15
10
5
0
Number of passengers
Bus 2
Bus 3
Bus 4
Bus 11
Bus 12
Bus 17
Bus 21
Bus 24
Bus 51
Bus 57
No transfer
Bus number exited to


Hamraborg Bus 1 Entries
n=259, Response Rate=79%
Afternoon rush
Midday
Morning rush
80
60
40
20
0
Number of passengers
Bus 1
Bus 2
Bus 4
Bus 28
Bus 35
Bus 36
No transfer
Bus number entered from

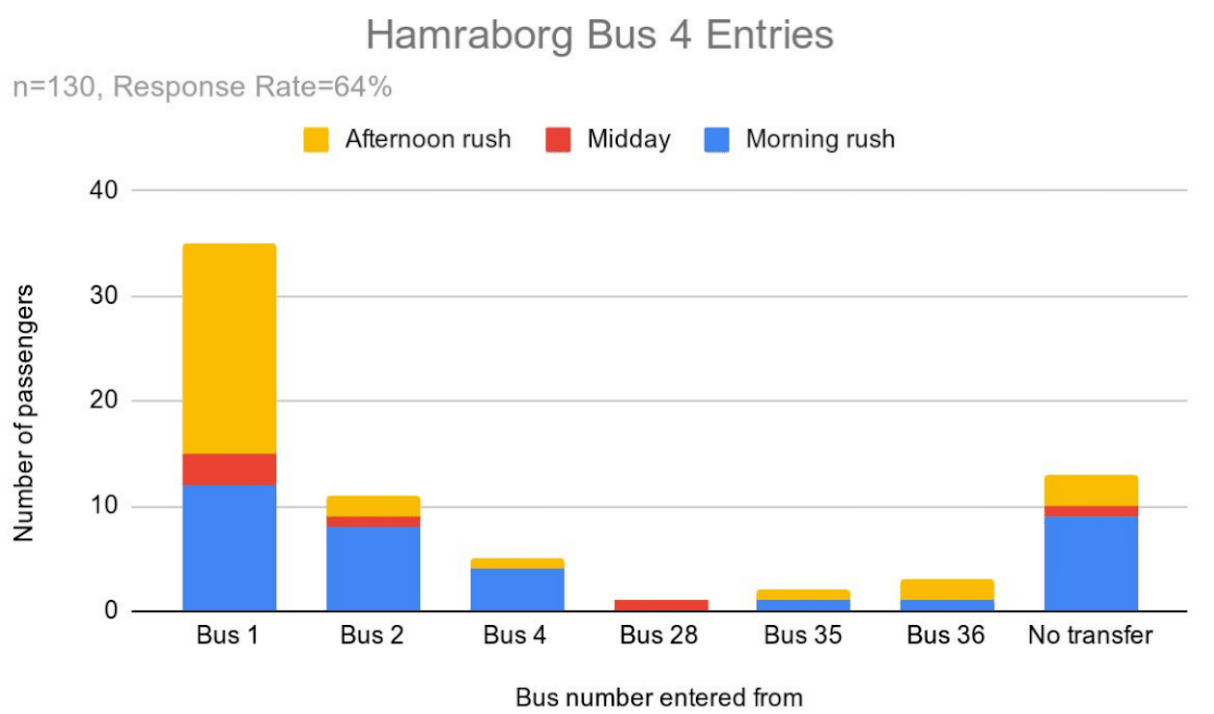

Hamraborg Bus 1 Exits
n=229, Response Rate=34%
Afternoon rush
Midday
Morning rush
25
20
15
10
5
0
Number of passengers
Bus 1
Bus 2
Bus 4
Bus 28
Bus 35
Bus 36
No transfer
Bus number exited to



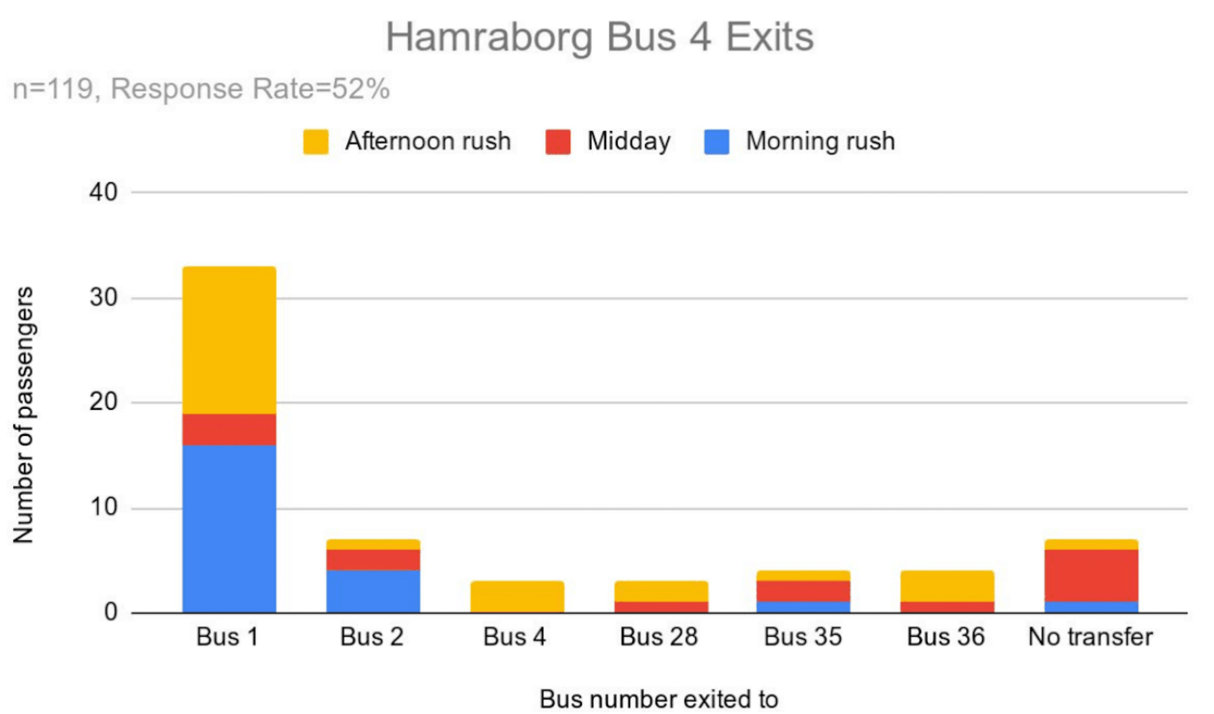
Hamraborg Bus 2 Entries
n=130, Response Rate=58%
Afternoon rush
Midday
Morning rush
40
30
20
10
0
Number of passengers
Bus 1
Bus 2
Bus 4
Bus 28
Bus 35
Bus 36
No transfer
Bus number entered from



Hamraborg Bus 2 Exits
n=117, Response Rate=74%
Afternoon rush
Midday
Morning rush
50
40
30
20
10
0
Number of passengers
Bus 1
Bus 2
Bus 4
Bus 28
Bus 35
Bus 36
No transfer
Bus number exited to



Hamraborg Bus 4 Entries
n=130, Response Rate=64%
Afternoon rush
Midday
Morning rush
40
30
20
10
0
Number of passengers
Bus 1
Bus 2
Bus 4
Bus 28
Bus 35
Bus 36
No transfer
Bus number entered from



Hamraborg Bus 4 Exits
n=119, Response Rate=52%
Afternoon rush
Midday
Morning rush
40
30
20
10
0
Number of passengers
Bus 1
Bus 2
Bus 4
Bus 28
Bus 35
Bus 36
No transfer
Bus number exited to

Appendix G: Bus Timeliness Data

	Ártún, 2018, both directions			
Morning rush	Bus Number	Early	On Time	Late
	5	77	109	4
	6	8	248	15
	15	25	125	44
	18	16	138	37
	Total arrivals analyzed:		846	
Afternoon rush	Bus Number	Early	On Time	Late
	5	49	173	96
	6	44	188	243
	15	95	163	90
	18	94	232	26
	Total arrivals analyzed:		1493	
All times	Bus Number	Early	On Time	Late
	5	683	988	124
	6	168	1852	419
	15	467	1166	244
	18	578	1147	76
	Total arrivals analyzed:		7912	
	Ártún 2018	% early	% on time	% late

	Morning	14.89%	73.29%	11.82%
	Afternoon	18.89%	50.64%	30.48%
	All	23.96%	65.13%	10.91%

	Mjódd, 2018, both directions			
Morning rush	Bus Number	Early	On Time	Late
	2	2	82	25
	3	71	105	1
	4	45	155	1
	11	35	34	25
	12	70	110	9
	17	22	76	0
	21	28	19	0
	24	28	149	10
	Total arrivals analyzed:		1102	
Afternoon rush	Bus Number	Early	On Time	Late
	2	1	52	136
	3	70	165	80
	4	85	227	24
	11	16	65	97
	12	160	114	73
	17	9	119	37
	21	37	60	0

	24	46	268	42
	Total arrivals analyzed:		1983	
All times	Bus Number	Early	On Time	Late
	2	34	577	301
	3	703	860	129
	4	682	1060	52
	11	217	503	235
	12	861	728	150
	17	183	691	42
	21	366	200	0
	24	387	1250	70
	Total arrivals analyzed:		10281	
	Mjódd 2018	% early	% on time	% late
	Morning	27.31%	66.24%	6.44%
	Afternoon	21.38%	53.96%	24.66%
	All	33.39%	57.09%	9.52%

	Hamraborg, 2018, both directions			
Morning rush	Bus Number	Early	On Time	Late
	1	86	135	57
	2	19	132	41

	4	1	95	65
	28	8	74	3
	35	6	53	9
	36	4	36	12
	Total arrivals analyzed:		836	
Afternoon rush	Bus Number	Early	On Time	Late
	1	70	311	83
	4	46	207	65
	28	37	113	9
	35	15	96	14
	36	7	95	4
	Total arrivals analyzed:		1172	
All times	Bus Number	Early	On Time	Late
	1	631	1558	202
	2	126	1451	221
	4	84	1301	248
	28	231	580	24
	35	131	539	36
	36	91	553	23
	Total arrivals analyzed:		8030	

	Hamraborg 2018	% early	% on time	% late
	Morning	14.83%	62.80%	22.37%
	Afternoon	14.93%	70.14%	14.93%
	All	16.11%	74.50%	9.39%

	Ártún, 2019, both directions			
Morning rush	Bus Number	Early	On Time	Late
	5	35	110	34
	6	9	223	46
	15	24	116	58
	18	14	153	19
	Total arrivals analyzed:		841	
Afternoon rush	Bus Number	Early	On Time	Late
	5	54	143	134
	6	23	154	276
	15	80	154	109
	18	39	203	90
	Total arrivals analyzed:		1459	
All times	Bus Number	Early	On Time	Late
	5	573	940	243

	6	116	1509	677
	15	397	1081	314
	18	285	1233	156
	Total arrivals analyzed:		7524	
	Ártún 2019	% early	% on time	% late
	Morning	9.75%	71.58%	18.67%
	Afternoon	13.43%	44.83%	41.74%
	All	18.22%	63.30%	18.47%

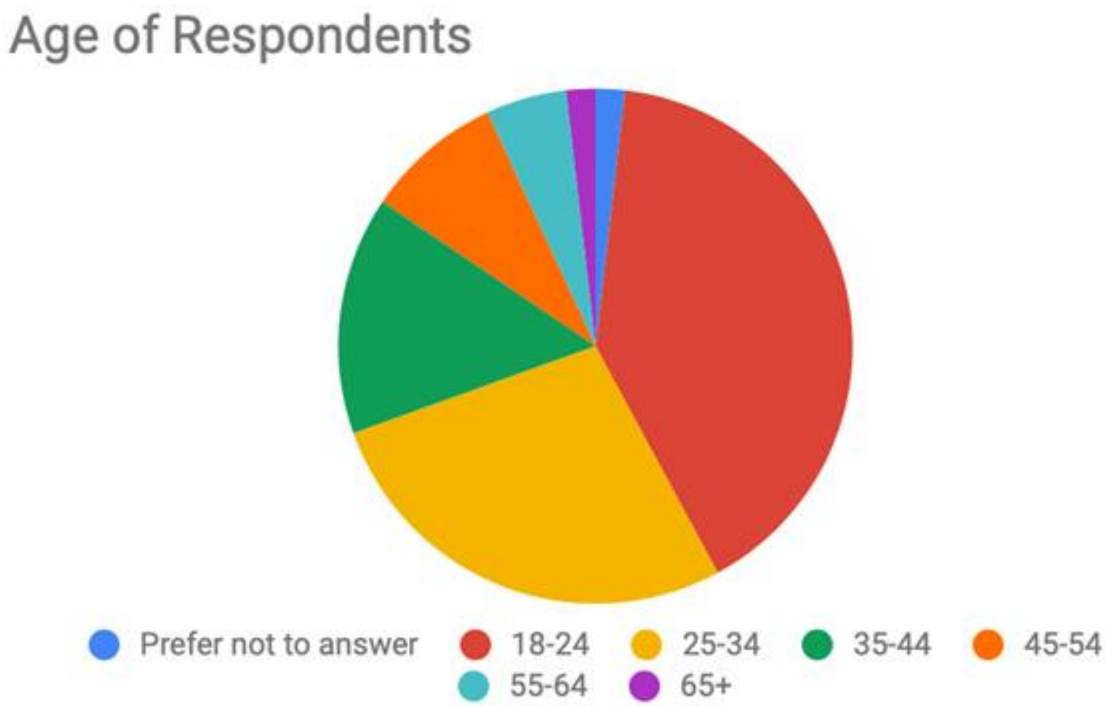
	Mjódd, 2019, both directions			
Morning rush	Bus Number	Early	On Time	Late
	2	1	67	28
	3	59	127	4
	4	45	128	5
	11	32	32	30
	12	59	120	13
	17	19	80	1
	21	23	28	0
	24	18	167	6
	Total arrivals analyzed:		1092	
Afternoon rush	Bus Number	Early	On Time	Late
	2	4	45	131

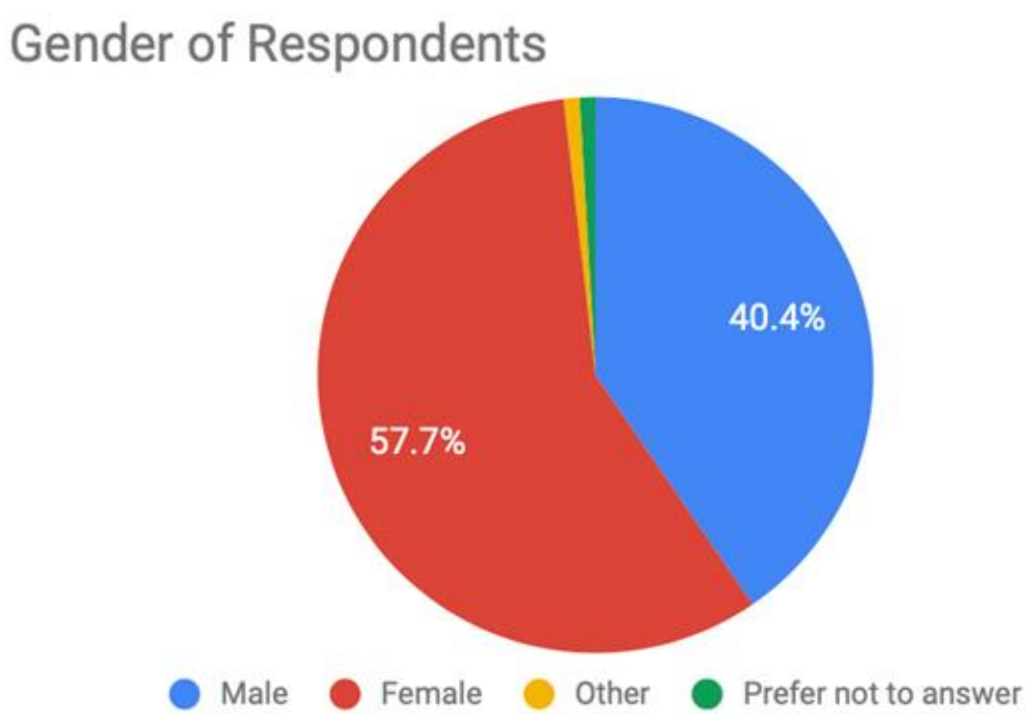
	3	41	118	179
	4	74	204	53
	11	13	39	121
	12	117	112	118
	17	10	97	64
	21	36	65	3
	24	36	257	63
	Total arrivals analyzed:		2000	
All times	Bus Number	Early	On Time	Late
	2	29	505	312
	3	585	879	308
	4	627	1037	75
	11	207	396	272
	12	742	752	235
	17	173	674	92
	21	348	251	4
	24	296	1327	96
	Total arrivals analyzed:		10222	
	Mjódd 2019	% early	% on time	% late
	Morning	23.44%	68.59%	7.97%
	Afternoon	16.55%	46.85%	36.60%
	All	29.42%	56.95%	13.64%

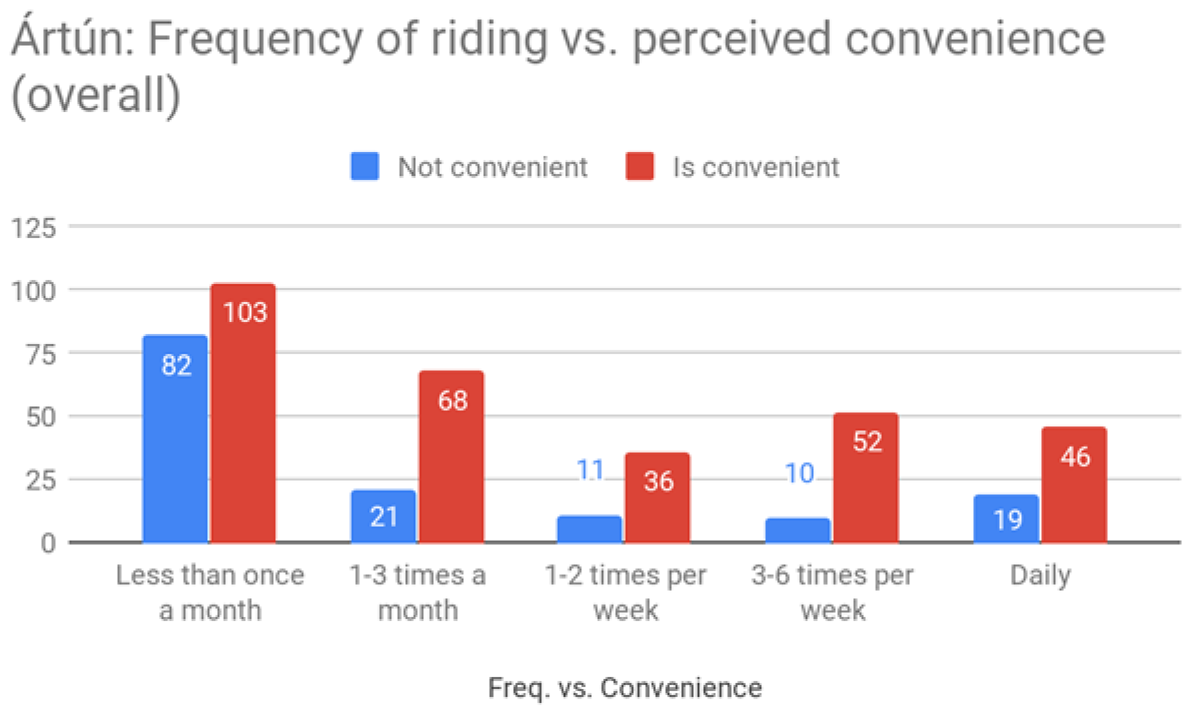
	Hamraborg, 2019, both directions			
Morning rush	Bus Number	Early	On Time	Late
	1	47	165	61
	2	22	124	39
	4	0	98	46
	28	22	68	2
	35	5	60	4
	36	0	40	13
	Total arrivals analyzed:		816	
Afternoon rush	Bus Number	Early	On Time	Late
	1	35	248	181
	2	18	221	106
	4	15	204	94
	28	21	123	15
	35	8	103	14
	36	15	91	4
	Total arrivals analyzed:		1516	
All times	Bus Number	Early	On Time	Late
	1	371	1529	393
	2	165	1316	238
	4	39	1304	234

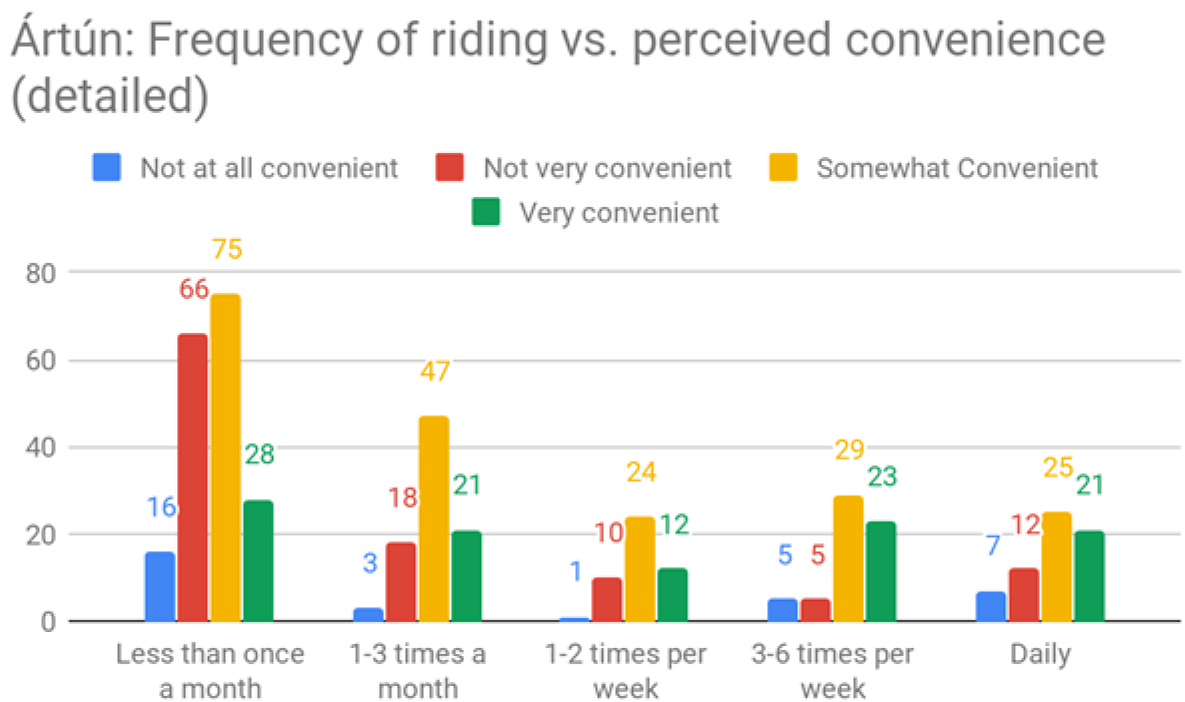
	28	237	551	38
	35	84	579	26
	36	126	516	26
	Total arrivals analyzed:		7772	
	Hamraborg 2019	% early	% on time	% late
	Morning	11.76%	68.01%	20.22%
	Afternoon	7.39%	65.30%	27.31%
	All	13.15%	74.56%	12.29%

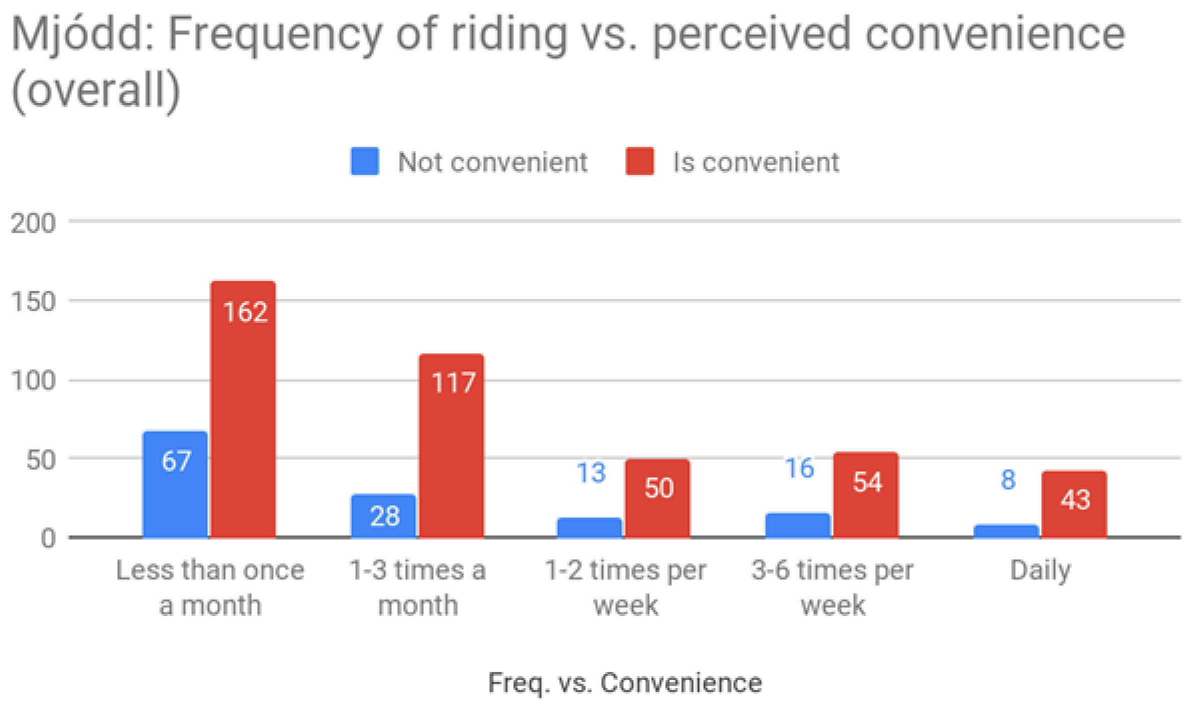
Appendix H: Survey Results

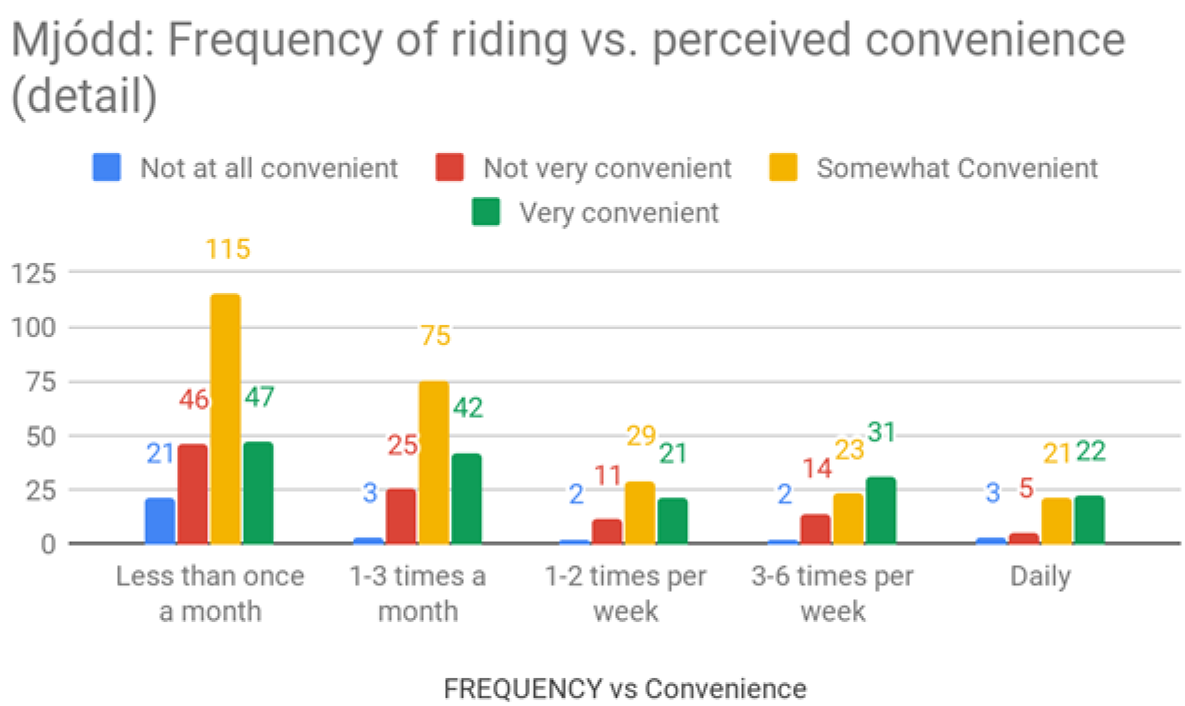


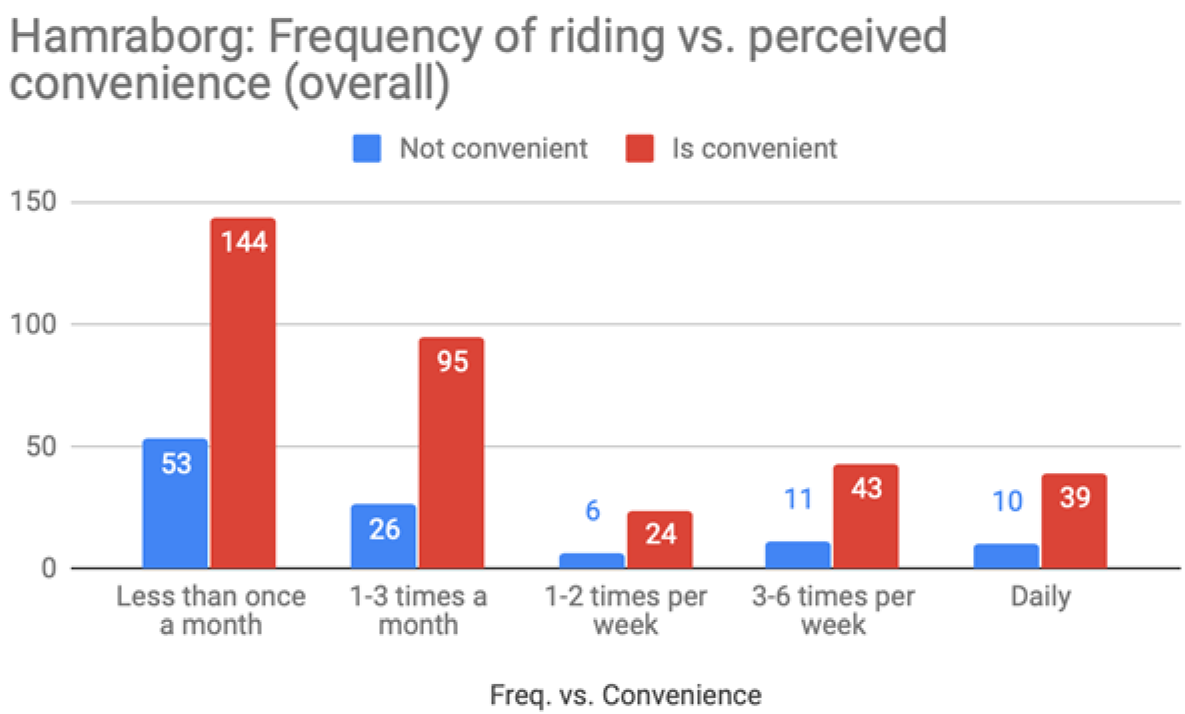



Ártún: Frequency of riding vs. perceived convenience (overall)
Not convenient
Is convenient
125
100
75
50
25
0
82
103
21
68
11
36
10
52
19
46
Less than once a month
1-3 times a month
1-2 times per week
3-6 times per week
Daily
Freq. vs. Convenience

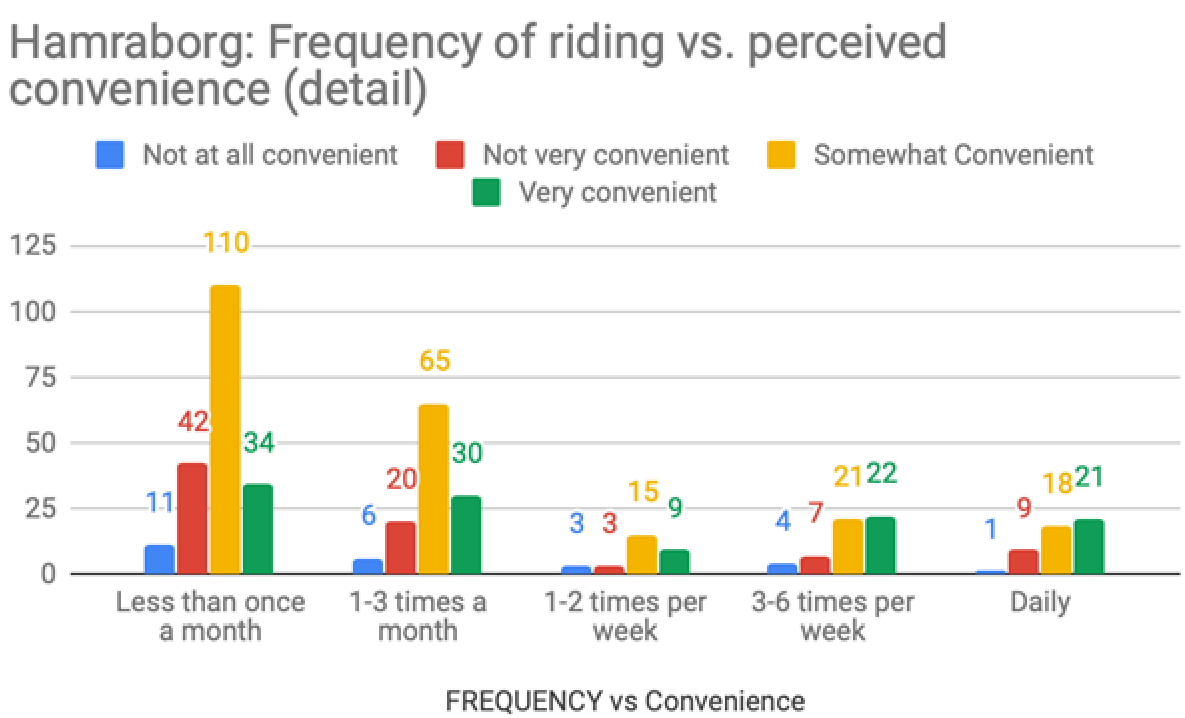

Ártún: Frequency of riding vs. perceived convenience (detailed)
Not at all convenient
Not very convenient
Somewhat Convenient
Very convenient
80
60
40
20
0
16
66
75
28
3
18
47
21
1
10
24
12
5
5
29
23
7
12
25
21
Less than once a month
1-3 times a month
1-2 times per week
3-6 times per week
Daily


Mjódd: Frequency of riding vs. perceived convenience (overall)
Not convenient
Is convenient
200
150
100
50
0
67
162
28
117
13
50
16
54
8
43
Less than once a month
1-3 times a month
1-2 times per week
3-6 times per week
Daily
Freq. vs. Convenience

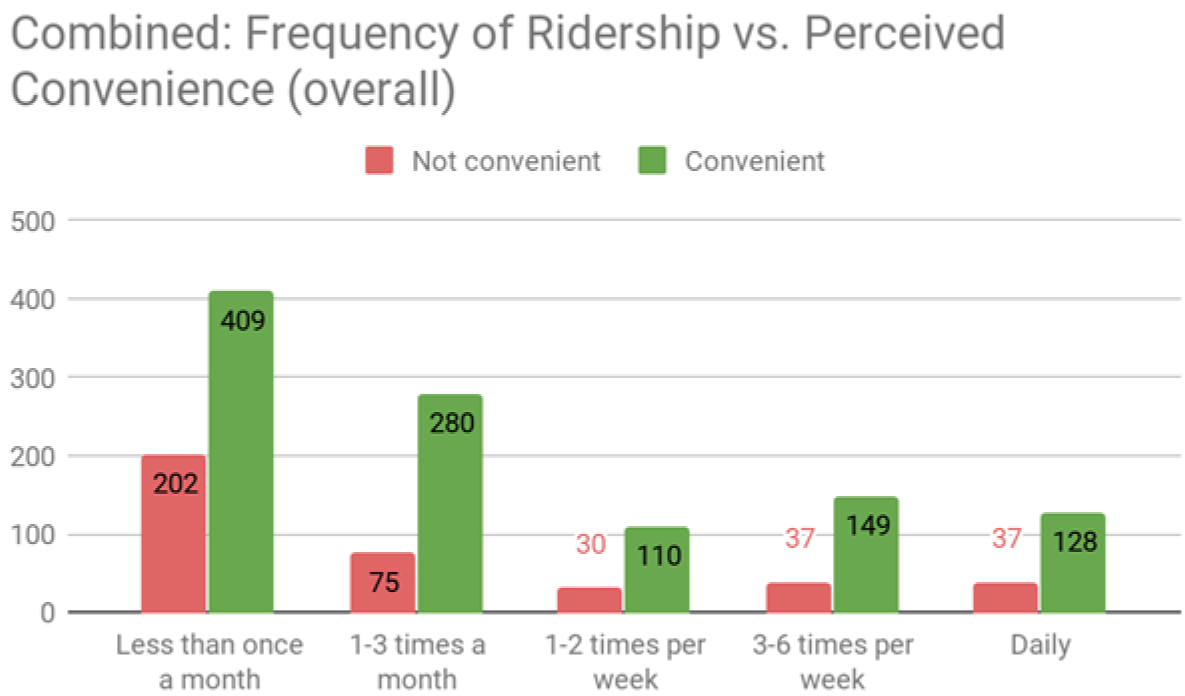

Mjódd: Frequency of riding vs. perceived convenience (detail)
Not at all convenient
Not very convenient
Somewhat Convenient
Very convenient
125
100
75
50
25
0
21
46
115
47
3
25
75
42
2
11
29
21
2
14
23
31
3
5
21
22
Less than once a month
1-3 times a month
1-2 times per week
3-6 times per week
Daily
FREQUENCY vs Convenience

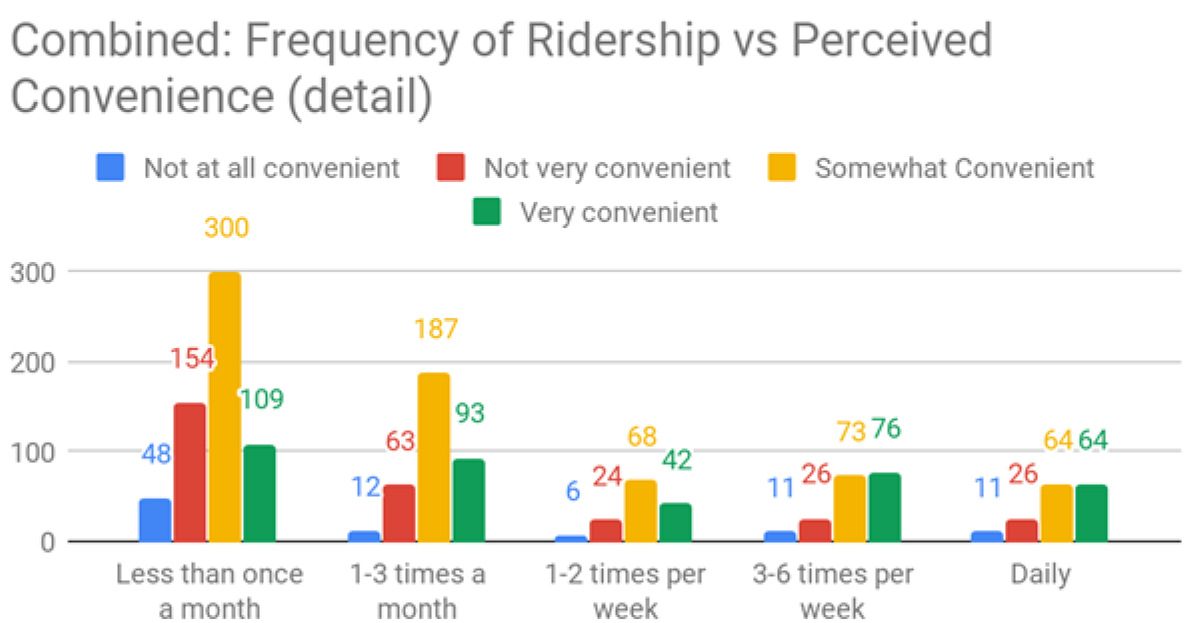


Hamraborg: Frequency of riding vs. perceived convenience (overall)
Not convenient
Is convenient
150
100
50
0
53
144
26
95
6
24
11
43
10
39
Less than once a month
1-3 times a month
1-2 times per week
3-6 times per week
Daily
Freq. vs. Convenience

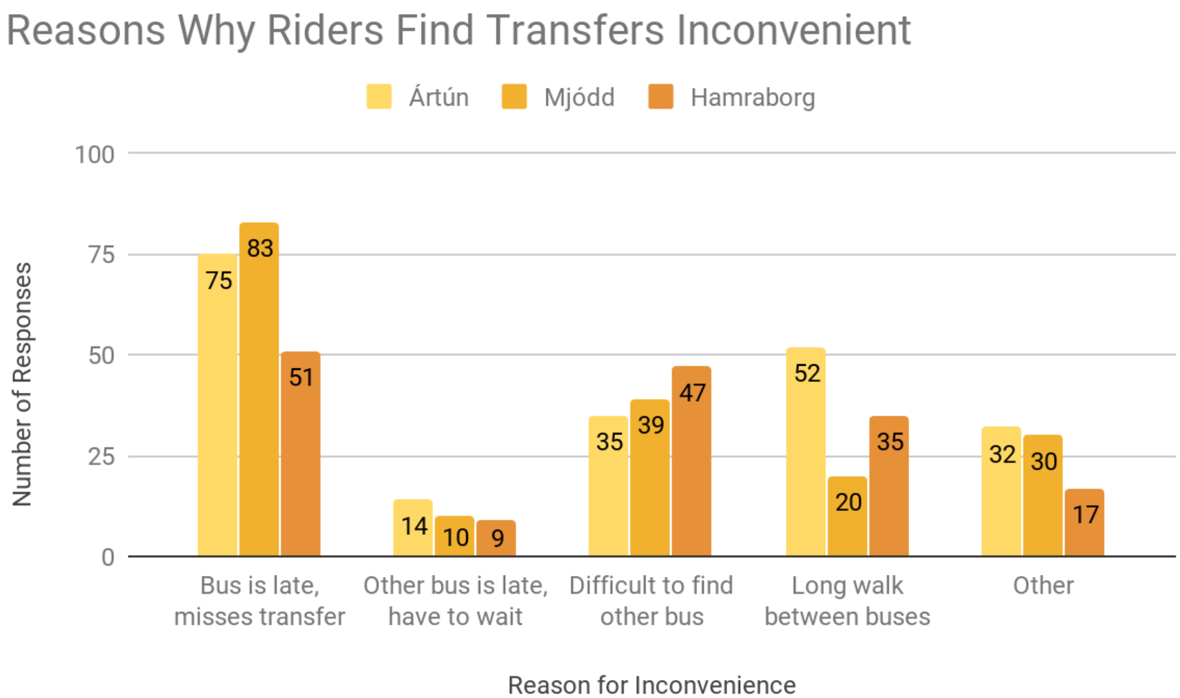


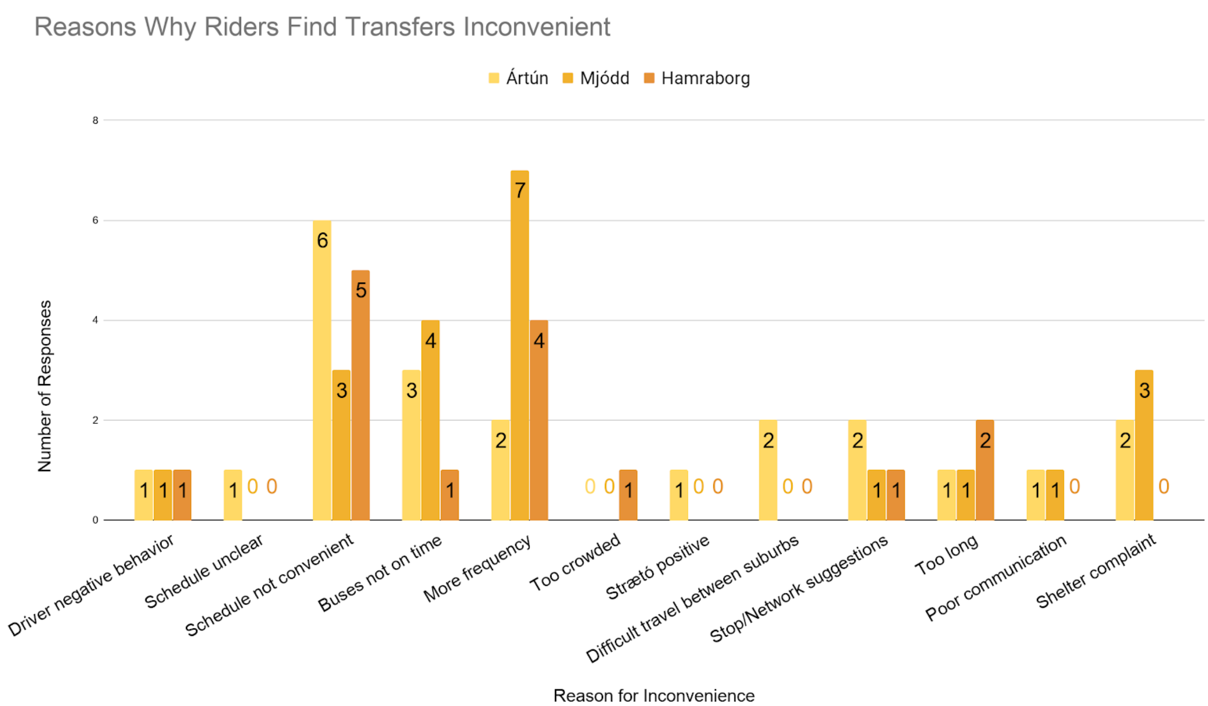
Hamraborg: Frequency of riding vs. perceived convenience (detail)
Not at all convenient
Not very convenient
Somewhat Convenient
Very convenient
125
100
75
50
25
0
11
42
110
34
6
20
65
30
3
3
15
9
4
7
21
22
1
9
18
21
Less than once a month
1-3 times a month
1-2 times per week
3-6 times per week
Daily
FREQUENCY vs Convenience

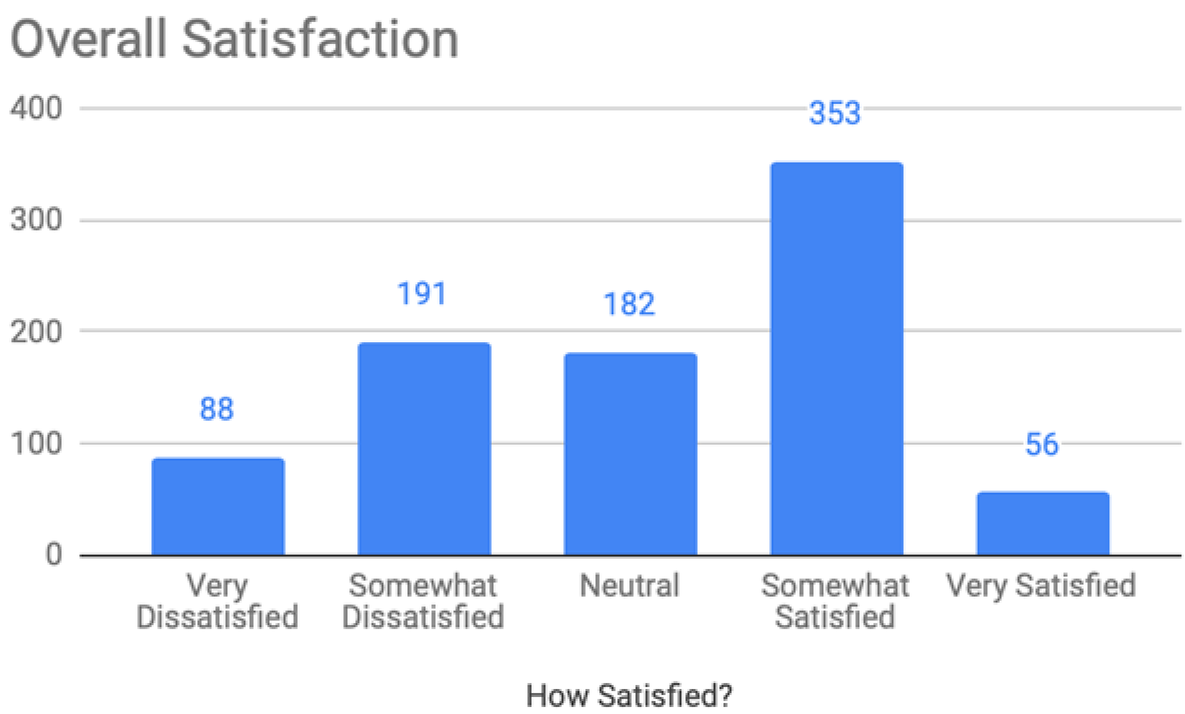


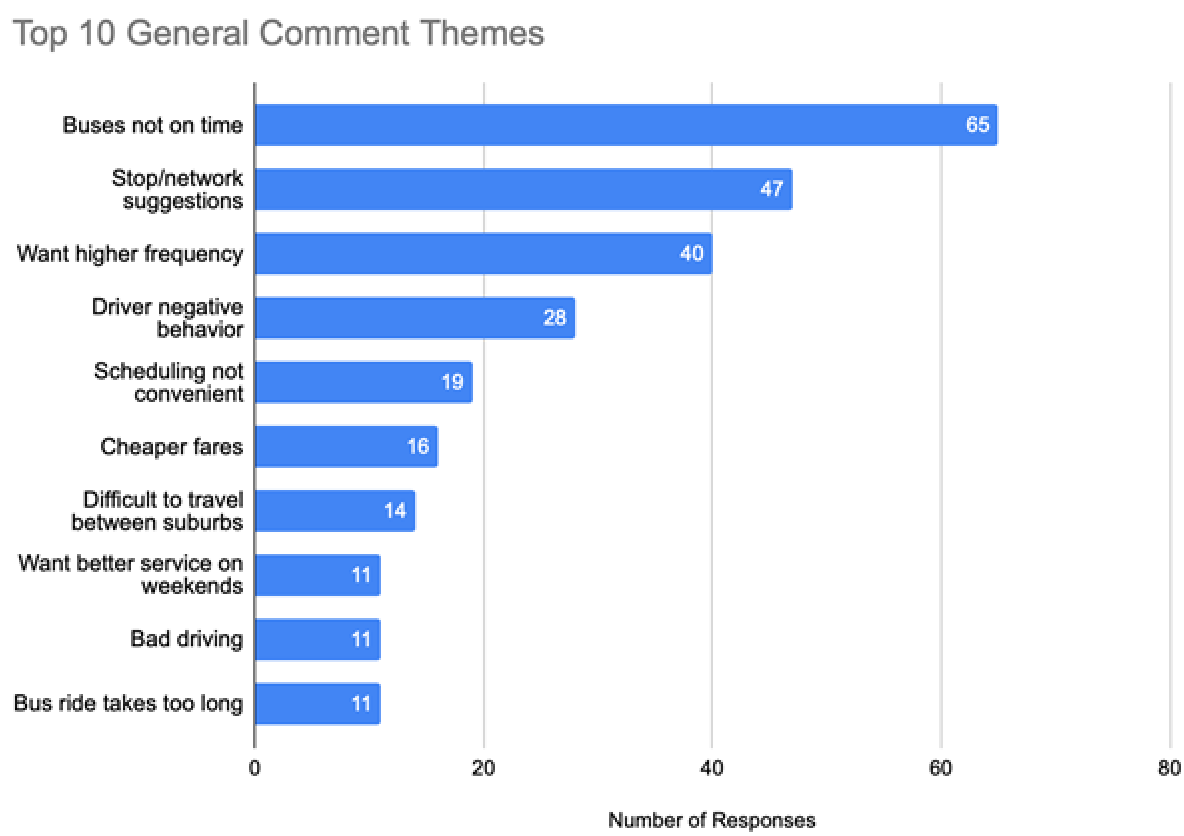


Frequency vs. Convenience


Reasons Why Riders Find Transfers Inconvenient
Ártún
Mjódd
Hamraborg
Number of Responses
100
75
50
25
0
75
83
51
14
10
9
35
39
47
52
20
35
32
30
17
Bus is late, misses transfer
Other bus is late, have to wait
Difficult to find other bus
Long walk between buses
Other
Reason for Inconvenience


Reasons Why Riders Find Transfers Inconvenient
Ártún
Mjódd
Hamraborg
Number of Responses
8
6
4
2
0
Driver negative behavior
Schedule unclear
Schedule not convenient
Buses not on time
More frequency
Too crowded
Strætó positive
Difficult travel between suburbs
Stop/Network suggestions
Too long
Poor communication
Shelter complaint
Reason for Inconvenience


Overall Satisfaction
400
300
200
100
0
88
191
182
353
56
Very Dissatisfied
Somewhat Dissatisfied
Neutral
Somewhat Satisfied
Very Satisfied
How Satisfied?


Top 10 General Comment Themes
Buses not on time
Stop/network suggestions
Want higher frequency
Driver negative behavior
Scheduling not convenient
Cheaper fares
Difficult to travel between suburbs
Want better service on weekends
Bad driving
Bus ride takes too long
65
47
40
28
19
16
14
11
11
11
0
20
40
60
80
Number of Responses