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Washington State Ferries Wait Time Analysis and Rider Experience Study

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Washington State Ferries Wait Time Analysis and Rider Experience Study

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16. Abstract

Washington State Ferries' Long-Range Plan, published in 2018, outlines the agency's priorities for the next 20 years. One of the agency's main goals is to improve the passenger experience for Washington State Ferry passengers. This study focuses on determining which terminals are most likely to experience poor wait time experiences, ways to measure vehicle wait times and how to most effectively disseminate wait time information to passengers in vehicles.

The Washington State Ferry (WSF) system allows passengers to drive their vehicle onto the ferry and ride with it to their destination. While a great first-last mile convenience to many, a problem arises when long lines of vehicles queue waiting for the ferry. Currently, vehicles enter the terminal holding area, pay their boarding fee, and wait in line for the next ferry to arrive. WSF is able to calculate the number of vehicles in the holding area based on ticket sales, but when vehicles queue outside the vehicle holding area, the problem of unknown demand arises. Due to this unknown demand, WSF is unable to calculate accurate wait times and convey them to passengers in an efficient manner. This project answers two questions: 1) Which of the twenty WSF terminals are most likely to experience frequent excess demand? and 2) How does the agency measure the excess demand and convey that information to passengers more effectively and equitably?

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Disclaimer

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Washington State Ferries Wait Time Analysis and Rider Experience Study

UCLA Institute of Transportation Studies
By Alexandra Weber

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Executive Summary

Washington State Ferries' Long-Range Plan, published in 2018, outlines the agency's priorities for the next 20 years. One of the agency's main goals is to improve the passenger experience for Washington State Ferry passengers. The deliverables of this goal are open-ended and written with the understanding that over the course of the next 20 years, passenger experience priorities will change. The agency recognizes one of the biggest areas for improvement lie in enhancing the waiting experience for passengers traveling with their vehicles onto the ferries. This study focuses on determining which terminals are most likely to experience poor wait time experiences, ways to measure vehicle wait times and how to most effectively disseminate wait time information to passengers in vehicles.

The Washington State Ferry system allows passengers to drive their vehicle onto the ferry and ride with it to their destination. While a great first-last mile convenience to many, a problem arises when long lines of vehicles queue waiting for the ferry. Currently, vehicles enter the terminal holding area, pay their boarding fee, and wait in line for the next ferry to arrive. WSF is able to calculate the number of vehicles in the holding area based on ticket sales, but when vehicles queue outside the vehicle holding area, the problem of unknown demand arises. Due to this unknown demand, WSF is unable to calculate accurate wait times and convey them to passengers in an efficient manner.

Map of Washington State Ferries Terminals, *Estimating Price Elasticities of Ferry Demand*. Transportation Research Record: Journal of the Transportation Research Board. 2176. 10.3141/2176-07.

Waiting in line makes many people anxious: running late, missing a meeting, not knowing how long you'll be waiting. These feelings are possible wherever lines exist, but this study shows specific steps WSF can take to markedly quell those anxieties and thoroughly improve the passenger experience. WSF provides an incredible service to the Puget Sound Region, and with the improvements outlined in this study, the agency can be well on its way to meeting its passenger experience improvement goals.

To conduct this study, I split my research into two parts:

1. Which of the twenty WSF terminals are most likely to experience frequent excess demand?
2. How does the agency measure the excess demand and convey that information to passengers more effectively and equitably?

Part 1: To determine the priority terminals within this study, I evaluate terminal vehicle holding capacity, individual vessel vehicle holding capacity and internal Best Times to Travel documents created by Washington State Ferries. Of the 20 terminals studied, six are considered priority terminals:

Part 2: For the agency to measure excess demand, I conduct market research as well as speak with WSF personnel and partners to determine the best fit interventions for each of the six terminals. To determine the best way to communicate wait time information, I conduct an equity evaluation and and study existing infrastructure at each of the six terminals.

General findings for the priority terminals of Fauntleroy, Vashon Island North Terminal, Southworth, Clinton, Edmonds and Kingston reveal the following in **Table 1**:

Table 1. Terminal Recommendations Overview

Terminal Name	Recommended Wait Time Collection Method	Recommended Method to Convey Wait Time Information
Fauntleroy	● Painted stripes along the road with cameras positioned above for terminal supervisors to approximate line length based on the number of cars past a particular painted stripe. ● Purchase Streetlight data to measure line length in real time and gather historical line data to help WSF make decisions in the future	● Avoid installing wait time signs along the roadside or overhead ● If using Streetlight data, sync information with WSDOT app for real time wait time information ● Hotline to call for wait times, updated by Terminal Supervisors and Customer Service or automatically through Streetlight Data
Vashon Island North Terminal	● Microwave sensors placed on existing light posts along Vashon Island Highway SW for two miles past the ferry entrance ● Purchase Streetlight data to measure line length in real time and gather historical line data to help WSF make decisions in the future	● Sync information from microwave sensors/ Streetlight data with WSDOT app for real time wait time information ● Hotline to call for wait times, updated by from microwave sensors or Streetlight data
Southworth	● Inductive loops placed in 200' increments along queuing lane	● Sync information from inductive loops with WSDOT app for real time wait time information ● Hotline to call for wait times, updated by from inductive loop information

Clinton	• Inductive loops placed in 200' increments along queuing lane along W-525	• Install live wait time information sign on WSDOT overhead sign structure outside terminal • Sync information from inductive loops with WSDOT app for real time wait time information • Hotline to call for wait times, updated by from inductive loop information
Edmonds	• Microwave vehicle sensors on existing light posts along Terminal Vehicle lanes will provide a low-cost possibility for WSF to measure line length	• Sync information from microwave sensors with WSDOT app for real time wait time information • Hotline to call for wait times, updated by from microwave sensor information
Kingston	• Purchase Streetlight data along terminal queuing lane	• Sync information from Streetlight data with WSDOT app for real time wait time information • Hotline to call for wait times, updated by from Streetlight data

Priority Terminal Recommendations

Washington State Ferries can use the wait time calculation information in the short-run in order to improve the customer experience by reducing passenger anxiety through conveying real wait-time information to passengers in line for the ferry and those trip planning from elsewhere. In the long run, the agency could use data collected from new methods of wait time collection to track traffic patterns more accurately and inform policy decisions and changes in the future surrounding terminal design and line management.

Introduction

Waiting in line is a notoriously frustrating experience. A myriad of factors contribute to the line waiting experience, such as waiting conditions, line length, stress levels and even the company of others. Washington State Ferries is responsible for transporting 24.3 million passengers annually as of 2019, with the projected growth of 32 million passengers annually by 2030. The agency's Long Range Plan released in 2017 outlines the agency's priorities for the future in order to meet demand and better serve the residents and visitors to the Seattle area (*Washington State Ferries Long Range Plan*, n.d.). Customer experience is outlined as a key point of focus for the agency in the coming years, and while "improving the customer experience" can take on multiple meanings, this project seeks to address the issue of line management and its role in the customer experience.

Currently, passengers who wish to travel on a ferry with their vehicle arrive at the terminal, pay the passenger and vehicle fee, and wait in the terminal's vehicle holding area for the next ferry to arrive before they drive their vehicle onto the ferry. Through ticket sales data, WSF is able to capture the current wait time and report it on their website so passengers can better plan their trips. Therefore, wait time for vehicles is currently calculated as follows:

N= Number of vehicles ***inside*** *terminal entrance/vessel capacity*
T= Headway between vessel departures from terminal
W= Wait Time for last vehicle in line

$$W = N*T$$

When demand exceeds the vehicle holding area capacity due to the ferry terminal being particularly busy, an informal line forms on the egress lane outside the terminal and this equation is no longer valid. This situation is referred to as *unknown demand* and makes estimating the wait time for passengers nearly impossible to measure accurately. Passengers use wait time information differently, either to trip plan in advance, calculate their time while already in line or as a way to manage expectations of travel time.

If waiting is inevitable, managing the customer experience must aim to alleviate the stress waiting tends to induce. Two types of wait times exist: actual and perceived. The immediate reaction to addressing a wait time issue is to somehow shorten the line to make the actual waiting time shorter. This can definitely improve the customer experience, if we assume not waiting in line, or waiting in line less, is preferred over waiting in line. However, reducing the *actual* wait times can be a difficult and expensive endeavor as it often involves physical changes to the terminal layout. Some experts in the field express doubt that it's even possible to reduce the actual wait time a meaningful amount. In a conversation with Emily Scott, a Ferry Advisory Committee representative from Vashon Island, she expressed the inability to really reduce much of the actual waiting times. As technology advances, new ticketing streamlining services may become available and vessels may sail faster, but in the near future it may be more advantageous to address the perceived wait time aspect of the customer experience. Research shows passengers overestimate their wait time by 20%-30%, meaning no matter how much the actual length of a line is reduced (but remains greater than zero minutes), passengers will continue to overestimate their wait time. To remove that 20%-30% additional perceived wait time and have actual wait time equal perceived wait time means maximizing the passenger experience. Of the interventions possible to reduce the perceived wait time overestimation, transparency of services and formalization of informal spaces are two of the key ways an agency can improve the customer experience (Fan et al., 2016).

In terms of transparency, this brings us back to the concept of *unknown demand*. WSF has made excellent strides in sharing historical wait time data with the public through the Best Times to Travel charts, which shows how many sailings on average a passenger with a vehicle will wait for the next available sailing based on season, day of the week and time of day for each terminal. Because these are created from historical data however, the accuracy to real-time data may not be reflected in the estimates. The only way to measure the true real-time wait time is to be able to measure how many vehicles are waiting within and outside the terminal vehicle holding area. With the unmeasured informal line forming outside a terminal, WSF is not able to gather real-time data. Each of the 19 domestic terminals are unique, and therefore the chance of experiencing the phenomenon of unknown demand is different in each locale.

Literature Review and Evaluation of Best Practices

Waiting in line can be a miserable experience. Much research surrounds the concept of mitigating and managing this perceived loss of time through interventions before and while a customer is waiting in line. To improve the customer experience, these interventions fall into two categories: changes to the actual wait time and changes to the perceived wait time (Fan et al., 2016).

Decreasing the actual wait time could be achieved through interventions such as physical changes to the queue, precheck systems, or pricing. Changes to the perceived wait time can be achieved through wait time transparency, distractions to those waiting in line and improvement to the line environment, to name a few. Because this study is focused on improving the customer experience, this literature review will review both types of interventions.

The vehicle queuing line for boarding the ferry is a point of focus for this project. In its current form, WSF is able to count the number of cars waiting in line to board the ferry once the cars pass a certain point and enter the ferry terminal vehicle holding center. The line extending outside that space is considered unknown demand, and therefore the length of the line is unable to be conveyed to ferry riders.

Washington State Ferries Existing Conditions Overview

The WSF system is a carefully orchestrated dance providing connectivity throughout the Puget Sound region. With 10 routes and 20 terminals, the system carried nearly 25 million passengers in 2018, with the agency estimating a 30% growth projection by the year 2030. As of 2019, the Washington State Ferry System is the busiest ferry system in the world carrying 24.5 million passengers annually, followed closely by the Staten Island Ferry (23.9 million), British Columbia Ferry Services (22.3 million), and the Star Ferry in Hong Kong (19.7 million) (*News Releases WSDOT,* 2020) (*NYC DOT, Staten Island Ferry Facts,* 2020) (*Investor Relations BC Ferries* (2020) (*Star Ferry Hong Kong* (2019).

Line Management

Vehicle lines can be seen nearly everywhere from drive-thrus to border crossings and are managed through a myriad of interventions. The identification of frequent drivers within a system is, in many cases, an opportunity to reduce waiting times by calculating the “risk” the driver poses to the system. The term risk can mean a driver who will spend more time in line such as one using the system for the first time, or a security risk as determined at border crossings. “Risk” translates to delays in the overall system, aberrations that should be accounted for prior to entering the system. In a 2019 Whatcom Council of Governments study, researchers recognized the level of risk for all trucks crossing the US border from Canada was indiscriminate and because all trucks were funneled into one specific area, this meant an inevitable backup of the line.

By using NII (non-intrusive inspection) before the cars enter the queue, the risk of the truck was evaluated based on the amount of cargo it was carrying. Completely empty trucks did not need to be inspected as their “risk” was low and therefore no longer needed to wait in the line with other full trucks to be inspected (*Improving Border Crossing Planning,* n.d.). By issuing RFID tags to pre-registered cars crossing the border into El Paso, Texas, border control could accurately calculate the current wait times of lines as well as allow certain lines to move faster as they have already been screened.

Reservation systems are another way to evaluate the risk of driver movement (*FHWA Freight Management and Operations, n.d.)*. BC Ferries has 47 terminals and 25 routes, 5 of which are considered “major” routes. Of these five, two are able to accept 100% capacity level of reservations, which discourages travelers from coming to the terminal without a reservation. The other three routes accept anywhere between 45%-75% capacity reservation, meaning while the possibility of being able to drive onto the ferry without a reservation exists, it is discouraged. These reservations along with drivers checked into the terminal are broadcasted on BC Ferries website to show the percentage of a particular sailing available for drive-ons or reservations.

According to a 2008 study in Austin Texas, if a headway between buses is less than 10 minutes, or headway between trains is less than 15 minutes, passengers will arrive randomly at the station without checking to see when the next bus will arrive. This is based on the calculation that perceived estimated waiting time E(W) is half of the headway (HE) time between vessels (Fan & MacHemehl, 2009).

$$E(W)=0.5*HE$$

When a headway exceeds a certain time, passengers begin to plan their trip by timetables and are less likely to show up randomly to the station to wait for the next bus, train, or ferry (Jørgensen & Solvoll, 2018). Therefore, the research concludes that on long trips, such as those by ferry, customers are likely to consult an information source about wait times or departure times to inform their travel behavior.

Queuing Theory

The two most important transportation wait time factors are time savings, or value of time (VOT) and reliability, or value of reliability (VOR). Using these as a guide, we can better understand the investment priorities necessary to improve the passenger experience (Small, 2012). The ferry ride is often the middle of a passenger's journey, and frequently this means driving to the ferry, boarding the ship with the vehicle, and then driving to one's final destination. The vehicle capacity of a ship is more often reached than the passenger capacity, making it the narrowest bottleneck of a ferry service. While often the value of time is considered linear, not every passenger shares the same value. Some commuter passengers have a more stringent time frame while tourists may not mind waiting for the next ferry (Small, 2012). Other domestic ferry services including the Steamship Authority between Cape Cod and Nantucket as well as the Lake Express between Muskeegon, MI and Milwaukee, WI both have vehicle capacity and strongly encourage, or require in the case of the Lake Express, a reservation (*Lake Express,* 2020). A stand-by policy does exist for the Steamship Authority, but on a limited basis (*Travel by Ferry,* 2020).

To understand vehicle line management without a reservation system, we need look no further than the drive-thru. Queuing theory based on empirical evidence gathered from drive thrus in the United States has been applied to transportation planning and congestion theory. Queuing data exists for coffee shops, fast food restaurants, banks and car washes with most of the data being collected through video footage of lines over the course of the day (Spack, 2019). A fast food restaurant in many instances shares similar characteristics to a ferry service: a line of cars must be managed as well as a line of walk-in customers all essentially competing for the same good.

The key difference between a ferry service and a fast food drive-thru is, the ferry service delivers the good in a lump sum to a group of people at the same time with wait times in between groups, whereas a fast food restaurant keeps a steady stream of goods flowing at a rather constant rate. If x is the number of vehicles in the system, y is the arrival rate and z is the service rate, the equation for both vehicle queues as well as passengers queues is:

$$x=y/(z-y)$$

Z, the service rate is determined by dividing the number of spaces available on a boat by the number of boats arriving per hour resulting in a rate of vehicles or passengers per hour being serviced (*Purcellville McDonalds Queuing Analysis, 2019)*.

Queuing discipline refers to the way a line is processed, and in most cases, this means a first-in-first-out system (Fomundam & Herrmann, n.d.). Without reservation systems, a single line forms and is processed in order of arrival. Other methods of determining line processing can be utilized to minimize wait times by sorting out the processing time of individual customers. Those customers who require less time for processing are served more quickly, as seen in the case of the express line of the grocery store (McQuarrie, 1983).

Perceptions of Wait Times

Perceptions of wait times can be just as important to manage as the actual length of the line itself. A 2016 study of transit riders focused on perceptions of safety and waiting times showed riders estimating their wait time to be, on average 1.21 times longer than the actual waiting time, with that number growing to around 1.3 times longer if no amenities, in this case seating, shelter or adequate lighting, to wait for the bus (Fan et al., 2016). This shows while reducing the actual waiting time is a positive improvement, with a 20% overestimation of waiting by customers, interventions to improve the waiting experience are important to reduce that percentage.

Women perceived longer wait times than men in situations where safety seemed to be a concern (Fan et al., 2016). Seawright and Sampson (2007) showed perceived wait times, as they are subjective, can differ vastly between passengers (Seawright & Sampson, 2007). Maister (1985) focused on the psychological aspects of pedestrian waiting experience to produce a guidebook of line management and customer satisfaction (Maister, 1985).

Of these, those relevant to this study is 1) Unexplained Waits Are Longer than Explained Waits 2) Uncertain Waits Are Longer than Known, Finite Waits 3) People Want to Get Started and 4) Anxiety Makes Waits Seem Longer (Maister, 1985). Because many riders on Washington State Ferries are commuters, missing a boat means being late for work, making the anxiety surrounding riding the ferry higher than it would be on, say, a leisure trip. If waiting is considered a waste of time by most customers, long perceived wait times directly correlate with a decrease in passenger's level of service or satisfaction (Tšernov, 2017).

Wu, Lu and Gee studied the statistically significant variables associated with waiting times, divided into personal characteristics of the traveler and the waiting environment. Of the variables evaluated in relation to the waiting environment, the five statistically significant variables that affected waiting time perceptions were weather, facilities, wait time information, interactive elements of the line and the level of crowding (Wu et al., 2013).

Means of Calculating Wait Times

Real-Time Wait Times

Best practices for this detecting car volume according to the FHWA have been outlined by the Traffic Detector Handbook. Traffic sensors are responsible for indicating the "presence or passage of vehicles" along a specific roadway and are categorized as either in-roadway or over-roadway. Today, the most popular type of traffic monitoring sensor is the inductive-loop detector: a piece of wire laid perpendicular to the road that detects vehicles as they pass. These types of sensors allow for axle-type detection and are popular because of their low-maintenance nature. These are insensitive to types of inclimate weather, such as rain or snow. This type of sensor, however, is not considered popular for long line evaluation (*Public Roads—A New Look at Sensors,* 2017). Inductive loop sensors are not seen as ideal for determining an accurate wait time analysis however because of their tendency to recount certain vehicles that have stopped on a particular part of pavement for a period of time (*FHWA Freight Management and Operations,* n.d.).

Video image processors (VIPs) and microwave sensors are more expensive and require more maintenance, but have the potential to be more accurate and give the ability to analyze the type of vehicles in line more effectively. Frequency-modulated waveform microwave sensors "transmit a frequency modulated waveform, which supports measurement of the distance between the sensor and a vehicle" and are able to detect vehicles in a stagnant line. They are able to calculate lane occupancy, vehicle class and vehicle speed. VIPSs capture traffic images and convert them into data. However, Sensors and VIPSs perform poorly in inclimate weather, and conditions such as snow, fog and rain may obstruct the sightline of the camera. Also, some of these sensors are unable to detect stopped vehicles making them ineffective for stagnant line detection (*Public Roads—A New Look at Sensors,* 2017).

In a 2012 study about the Canadian and Mexican border crossings into the United States, the authors outlined technologies for gathering wait time information such as license plate identification, RFID technology, Bluetooth and GPS (SANDAG, n.d.). The clear distinction between types of technologies depends on the amount of information an agency wishes to gather about the vehicles waiting in line. All of the interventions in this study use technology able to gather personal data or payment information in order to monitor the characteristics of those in line and expedite the payment process. RFID technology was used during a pilot border crossing site in Texas and helped gather accurate data for that particular crossing. RFID technology requires an antenna to count vehicles as well as a tag or transponder within a vehicle to answer a radio signal sent by the antenna. This type of intervention works well in states where vehicles have these transponders, such as toll collecting tags, already installed (*FHWA Freight Management and Operations,* n.d.).

Streetlight Data

Streetlight Data relies on location services built into smartphone applications already installed on users' phones (*StreetLight Data,* n.d.). With this information, the powerful algorithm can calculate traffic, parking and pedestrian movement patterns. Cities and companies are able to purchase this data to further analyze for the research and improvement purposes. This type of data collection is becoming increasingly popular among state (Florida, Massachusetts, Maine, Iowa) and city transportation departments (Los Angeles, Toronto, New York City) (*Why StreetLight: How it Works,* n.d.). However, the cost of data extraction zones can become very expensive if an agency is looking to buy large "areas" of data (Schiffer, n.d.). Also, this type of data can be imprecise, particularly for roads with sharp turns or high congestion levels.

These options are summarized in **Table 2.**

Table 2. Wait Time Collection Technology Options, Summarized

Technology	Description	Benefits	Drawbacks
RFID (Radio Frequency Identification Scanners	RFID Scanners are in use today in Washington in the form of a Good To Go Pass , helping drivers use the five toll roads in Washington State. RFID scanners require two pieces: a reader (often installed over a road or bridge) and a transponder (often on the windshield of a car).	● These Good to Go passes could charge drivers their fare automatically when passing through the terminal toll booth.	● Installing readers on terminal egress lanes to scan cars with existing (or newly purchased) responders would lead to data inconsistencies considering not every driver would have or want a transponder. ● If WSF and WSDOT were to issue these transponders to each driver in the state, the capital investment would be politically unpopular.
Inductive Loops	Inductive loops are sensors placed underneath pavement and detect vehicle movement and line length.	● The flexible design of the sensors allows them to be customizable in terms of placement and location ● In terms of cost, the equipment cost is rather inexpensive as compared to other options which could	● Inductive loops have trouble accurately detecting and correctly counting vehicles in long, stationary lines. Considering terminal lines are often stationary, this type of intervention may lead to

		be attractive to WSF from a budgetary perspective ● Inductive loops are insensitive to types of inclimate weather, such as rain or snow. In Seattle, which experiences over 150 days of rain per year, this is a major benefit	inconsistencies in vehicle counts ● Installation and repair mean disruptions in traffic flow in terminal egress lanes ● Road repair may require a re-installation of inductive loops
Streetlight Data	Streetlight Data relies on location services built into smartphone applications already installed on users' phones. With this information, the powerful algorithm can calculate traffic, parking and pedestrian movement patterns.	● Non-invasive "installation" and will not interrupt current terminal egress traffic flow ● Data can distinguish vehicles from trucks, which given the current makeup of traffic could be helpful to determine wait times for WSF ● Streetlight data can easily be converted into trends in order for WSF to further improve service	● Cost of data extraction zones can become very high ● Data can be imprecise, particularly for roads with sharp turns or high congestion levels
Microwave Sensors and	These interventions are mounted above	● Vehicle type (car, truck,	● VIPs and microwave sensors perform poorly

Video Image Processing (VIPs)	or alongside traffic and monitor traffic movement.	delivery truck) detection may be helpful to WSF in order to more accurately calculate line length ● Can be mounted on existing infrastructure such as light posts which are often positioned near egress lanes ●Frequency-modulated waveform microwave sensors are able to detect vehicles in stagnant lines	in inclimate weather conditions, making them not ideal for western Washington ● On the more expensive side on initial investment and upkeep ●Some microwave sensors are unable to detect stationary vehicles, making them not particularly helpful for all types of line detection
Cameras and Painted Stripes	Some terminal operators rely on landmarks to approximate line length, and while this is a rather rudimentary process, it serves as a zero-cost line measurement technique. By painting bright stripes on the road at certain points along the egress lane with cameras	● This intervention would be rather low cost in terms of painting lines on pavement. In terms of cameras, some already exist near terminals and could be repurposed. New cameras for this purpose need not be advanced in terms of image processing.	● This process still requires a WSF employee to watch the cameras and determine line length and call customer service so they are able to update this information ● Historic data will be difficult to derive from this intervention since consistency will be difficult to maintain

	positioned over them to measure if the line is filled to that point with cars.	●Terminal supervisors are familiar with this type of technology vehicles in stagnant lines	● The accuracy of this method will not be as strong as other interventions

Overview of possible technological interventions to measure wait times at ferry terminals

Historic Wait-Time Data

Using historic traffic data to predict and evaluate future traffic patterns is a process used by planners to predict outcomes of changes in the built environment. Ticketing, toll booth, and inductive data can be used to monitor capacity of an area and the general flow of traffic. WSF has data translated to best times to travel based on ticket sales and volume. The use of this type of data will be helpful if seen as relevant in the future of the operation. In 2010, the Minnesota Department of Transportation compared predictions for 2006 traffic based on 1986 and 1996 traffic patterns. Using a predictive model and inductive loop feedback from 2006, the DOT determined 10-year prediction data is much more accurate than 20-year prediction data (*Determination of the Amount of Historical Traffic Volume,* n.d.). Evaluating inaccuracies in travel demand reveal the the inaccuracies have a non-random bias and can be calculated as a percentage with the formula

$$I=[(T_a - T_f) * 100]/ T_f$$

Where I is the percent of inaccuracy, T_a actual travel demand, and T_f forecasted travel demand (Schiffer, n.d.). A 2013 study shows a binary approach to traffic demand forecasting: hubris and humility. The hubris consists of using a multi-decade approach to improve accuracy, and humility comes into play by encouraging planners to understand the inevitable uncertainties tied into demand forecasting and therefore diminishing its role in decision making (Hartgen, 2013). Because this project is not proposing physical changes to the built environment, for this study an assumption can be made that traffic will grow in proportion to the project population growth as stated in WSF's Long-Range Plan (*Washington State Ferries Long Range Plan,* 2017).

How To Best Convey Wait Times: Passenger Communication Techniques

On-Site Information

Transparency contributes to the safety and efficiency of passenger travel. The New York City Subway, a system of rather short headways between trains, is in the process of ubiquitously installing countdown clocks in stations to keep people from leaning over the tracks to spot the headlights of an oncoming train and also give passengers the opportunity to avoid waiting on a deserted subway platform for 15 minutes for the next train (Marshall, 2016). Improving transparency will assist with travel pattern adjustments and reduce the chances of missing the ferry because of it being over capacity or the parking lot being full. Over a long-time horizon, it is possible for travelers to adjust their behavior based on data trends based on the theory of triple convergence. This theory states travelers if met with congestion will over time find another route to work, change the time of the commute, or shift travel modes entirely (Downs, 2013).

Smartphone Interventions

Over a short-term horizon, however, travelers may not be able to perform the logistical gymnastics to reach their trip destination on time. As of this year, 83% of urban and 71% of rural Americans have a smartphone (*Mobile Fact Sheet,* 2018). While smartphone usage is not ubiquitous, using its system to transmit traveler information can be effective. While many transit agencies have used apps to convey information, a lack of streamlining the reservation, ticketing, and scheduled arrival or departure can mean disjointed information and a less-than-positive user experience. The Chicago Transit Authority's app known as Ventra combined three of their user apps onto one platform allowing passengers to add value to their transit pass, check account balances and track the location of buses and trains (*Ventra Mobile App,* 2014).

Cell Phone/Landline Interventions

The border crossing in Tijuana, drivers are able to call a toll free number, updated hourly, that recites a recording of wait times both from San Diego and Tijuana (*The Border Commuters,* n.d.). This low-cost, highly accessible option could improve wait time transparency for those without smartphones or internet access.

These types of interventions are summarized in **Table 3**.

Table 3. Passenger Communication Techniques, Summarized

Technology	**Description**	**Benefits**	**Drawbacks**
App-Based Solutions	WSDOT's app is quite extensive and could add data gathered by wait time measurement interventions.	● Providing customers with real-time wait time data is possible to include on the existing app platform. ● Building a new app is not necessary and	● Information on an app not accessible to passengers without a smartphone will not have access to wait time data ● Requires a bundling of wait time measurement

		therefore the cost will be low ● Travelers already familiar with this application platform	technology and the app
Queuing Lane Wait Time Automated Signs along Queuing Lane Outside Terminal	A digital sign placed next to egress lanes or existing overhead signage connected to wait time measurement and updated based on the current length of the line.	● Visible to all drivers in line and does not require any personal technology ● Can be mounted to existing infrastructure at certain terminals ● Information can easily interpreted by drivers	● Some communities, such as Fauntleroy according to Sue Lowery, are not interested in having infrastructure placed in their community ● Cumbersome and potentially unattractive ● Must be placed where the historic end of the line can see the sign
Wait Time Hotline	A hotline such as WSF's customer information line could provide the real-time wait time for a particular terminal. By providing a phone number for passengers to call, a real-time updated recording will play	● Accessible to anyone with a landline or cell phone ● The consumer interface side of the intervention would be easy to interpret by passengers	● The agency must purchase an ever-updating recording to convey wait times ● May be seen as regressive technology

	and say the number of minutes until the last car in line will board the next available ferry		

Means of communicating wait times to WSF passengers

Methodology

It is not particularly difficult to identify where long lines tend to queue, and Seattle's 20 ferry terminals are no exception. However, formalizing the process to identify these priority terminals is important to maintain consistency for policy recommendations. To improve the customer experience by changing the waiting experience, recall the two types of waiting: actual and perceived.

While changes to actual wait times often involve physical infrastructure changes, something outside the scope of this project, changes to the perceived wait time are achieved through, as discussed in the literature review, a mix of behavioral incentives as well as technological interventions. Again, the five statistically significant variables that affected waiting time perceptions were weather, facilities, wait time information, interactive elements of the line and the level of crowding (Fan et al., 2016).

To choose which of these variables to focus this research on, we first considered the conditions of the line. Since riders are waiting inside their vehicles, weather is less of a concern than if the line were outdoors and uncovered. Also, the level of crowding is not relevant because the line is single file, but is tangentially related because the length of that line may play into a customer's level of stress. Facilities refers to the amenities related to line, often translated to levels of comfort such as availability of seating, shelter and light; again because riders are waiting in their cars, this isn't particularly relevant.

We are left to operate with two variables: wait time information and interactive elements of the line. The perceived length of a line with a known wait time is less than that of a line with an unknown wait time (Wu et al., 2013). By addressing these two elements in our overall study, we hope to decrease customer's perceived wait time and in turn improve the customer experience. Another positive of using these two variables is that by improving wait time information, WSF has the potential to decrease not only the perceived wait time in the short term, but also the actual wait time by encouraging customers to trip plan more effectively using this information in the long term.

WSF has extensive wait time evaluations based on historical ticket sales data. Real-time wait time information can improve the customer experience at priority terminals. Currently, as displayed on WSF's website and the WSDOT mobile app, the real-time wait time is based on the numbers of cars and passengers inside the terminal vehicle holding area who have paid for their passage at the ticketing tollbooth. This combined with information about the next ferry arrival provides passengers with a sense of the general wait time, if the line of vehicles is completely contained in the terminal vehicle holding area.

Inaccuracies of real-time wait times occur when the line extends past the ticketing booth onto the egress lane leading up to the terminal. Terminal operators have a series of cameras producing publicly-available live footage of the egress lane to help evaluate the line and inform customer service of delays. However, this method is not always precise and is subject to interpretation. Further, if the line extends past the camera's view, the number of vehicles will be impossible to estimate. This **unknown demand** is the weakest point in the queuing system and standing in the way of creating an entirely accurate real-time wait time analysis.

With varying terminal holding capacities across the system, ferry capacities, and popularity, no two terminals are alike. For a less frequented terminal with high holding capacities, the chances of the line extending beyond the tollbooth is much lower than an incredibly popular terminal with a low vehicle holding capacity.

This study aims to identify the latter types of terminals where unknown demand is standing in the way of capturing an accurate wait time.
The second piece of this research is determining the best way to capture and convey these wait times. This will be completed through a series of interviews, market research of technological solutions, and an equity evaluation to decide which types of personal technological interventions are the best fit for the particular terminal area.

Terminal Identification

By identifying priority terminals for intervention, WSF will be able to use this information to improve line length determining technologies. To identify these priority terminals, this study uses terminal vehicle holding capacity, ferry vehicle capacity, the potential of mode shift, and historic ticket sales in the form of Best Time to Travel Documents to evaluate the probability of a terminal experiencing unknown demand.

Route Type

Two-Destination Routes

Most ferry routes make round trips between two destinations. The Best Times to Travel documents, terminals vehicle holding capacities and vessel vehicle capacity work in concert to calculate priority terminals for terminals serving two-destination routes.

Multi-Destination Routes

Because on these routes, a single ferry will make multiple stops to both pick up and drop off passengers and their vehicles, the mode frequency of vehicle capacities is slightly different. For the Anacortes-San Juan Islands route, the Best Times to Travel documents show the average vehicle spaces available on the ferry during different weekly sailings. For those routes and the Fauntleroy-Vashon-Southworth routes, I averaged these to find the average daily vessel vehicle capacity.

Classified by terminal, by dividing the terminal's vehicle capacity by the mode vessel vehicle capacity, the data provides the number of sailings able to be held in the vehicle holding area. This provides a key piece of information as even if the ratio of highly congested sailings is high, if the terminal holding capacity is large, the risk of having a line form outside the terminal representing unknown demand is less likely.

Best Times to Travel Documents and Congestion Ratio

Washington State Ferries generates the Best Times to Travel Documents to assist passengers in planning their trips. Organized by season, route, day of the week, and time of day, the document classifies average wait times based on ferry departures throughout the day. Each sailing is color-coded as symbolized:

Gray: No sailing
Green: Least Congested: Vessels typically not full
Yellow: Moderate Congestion: Vessels can fill close to sailing time
Red: Most Congested: Likely to wait one sailing or more

Because this study is focused on the busiest sailing times, the next step found the percentage of sailings throughout the day (unique to each route) as compared to the number of Most Congested vessels to create the ratio:

Congestion Ratio = Most Congested sailings : Total number of sailings

Using this congestion ratio will allow me to determine natural break between those with high congestion ratios and lower congestion ratios in order to continue with the analysis of priority terminals.

Vessel's Vehicle Holding Capacity

The final step in determining the possibility of unknown demand occurring at any particular terminal is determining ferry capacity. Each vessel is responsible for carrying passengers, cars and other cargo from one terminal to another between the ten routes. Seven classes of ferries exist with 21 total vessels in WSF's fleet. Each class denotes a passenger and vehicle capacity unique to that particular class of vessel. Vessels are not completely tied to any specific route, however, patterns in vessel usage appear throughout WSF VesselWatch History portal, a function that compiles this data in three-month periods dating back to 2010.

To determine which class of vessel frequents which route and therefore how many vehicles are able to board a particular vessel, I use the VesselWatch History portal available through WSF to evaluate three summer's (June-August) of 2017, 2018, 2019. By linking vessel class with its vehicle capacity, I determine the mode vehicle capacity for each terminal based on the classes of vessels that used that route over the course of the three summers.

By downloading the VesselWatchHistory, the name of each vessel is given for a route over the course of a season. I truncate these vessels into each of their classes to calculate vessel vehicle holding capacity for each of specific vessels for each route. I analyze this data by calculating the mode vessel type serving a particular route over the summers of 2017, 2018 and 2019. I use mode instead of average because of the stagnant nature of a vessel's vehicle holding capacity.

Terminal's Vehicle Holding Capacity

The terminal vehicle holding space consists of the formal area inside the terminal and past the toll booth dedicated to holding vehicles prior to their departure on the ferry. Holding capacities for terminals are measured by WSF upon construction. While a variety of vehicle lengths exist, the calculations are based on a 20' vehicle length, the average length of a vehicle with 2' buffer. Therefore, these calculations are considered the number of personal vehicle lengths available at a given terminal. Trucks and longer vehicles can be counted as multiple vehicles. This information is created from an internal Washington State Ferries document noting the layout of individual terminals and their passenger/vehicle holding capacities.

If a terminal has a large enough vehicle capacity, a line will not often extend past the terminal booth. The terminal holding capacity is considered large enough if two vessel's worth of vehicles are able to fit inside the terminal holding area. This is determined through this equation:

Vehicle Holding Capacity Ratio

*terminal vehicle holding capacity <= 2*mode vessel vehicle holding capacity*

Determine Possibility of Mode Shift

In some instances, although the ferry is often the faster option, driving between two terminals is possible. Drivers can circumvent six of the ten ferry routes by driving rather than taking the ferry. With unknown wait times due to unknown demand at certain terminals, drivers may decide to drive to their destination. Driving offers what the ferry often cannot: a means to calculate nearly the exact amount of time between origin and destination. With the ease of driving time calculations with navigation services like Google Maps, drivers may be lured into leaving the ferry terminal line. Even if ferry travelers do not actually make the switch and abandon the route, the stress caused by knowing they could drive to their destination in less time than the ferry will take makes for a decreased customer satisfaction.

To determine which ferry routes drivers are able to circumvent, I will input the two ferry terminal locations (route origin and destination) into Google Maps, opt to avoid ferry routes, and observe the potential driving route. If one exists, this route will be flagged as higher risk simply because there is the possibility for mode shift. Research like this for specific terminals has been conducted in more depth by the Washington State Transportation Center and will be evaluated based on priority terminals (*Fauntleroy Ferry Study,* 2018).

Calculations for Priority Terminal Identification

To show which terminals would benefit most from technological interventions, I use the Congestion Ratio of 0.28 as a natural break in the data for highly congested sailings. Again, this is the ratio of highly congested sailings to total sailings. With the terminals sorted by Congestion Ratio, I grouped the terminals with a Congestion Ratio of greater than 0.28 (more than 28% of the daily sailings are congested), and of those, noted the terminals with a vehicle capacity less than twice the mode vessel vehicle capacity. Terminals that met both those criteria are considered priority.

Terminals under construction or those with routes using reservation systems will be removed from final recommendations simply because proper data does not exist to make an evaluation using this methodology. If one terminal on a route is included but the other(s) terminal(s) is not, both terminals will be considered priority terminals.

Wait Times and the Customer Experience

Measuring Wait Times, Recommending Specific Terminal Interventions

Research from the literature review gives a general overview of the technologies available to measure vehicle line length. These findings will be reiterated in the Findings section along with comments on their potential efficacy within a particular terminal area. I take into consideration weather conditions, existing signage, and queuing lane conditions as displayed in **Table 4**.

Table 4. Wait Time Collection Technologies and Recommendation Conditions

Technology	Under What Conditions is it Recommended?
RFID (Radio Frequency Identification Scanners	This type of intervention is not recommended for investment by WSF and WSDOT.
Inductive Loops	Inductive loops may be recommended in situations of particularly difficult weather conditions or where installing another type of line detection technology is impossible, but given the disruption of traffic upon their installation and repair, they are not recommended for all situations in all terminals.

Streetlight Data	If this type of intervention is in the budget for WSF, the long-term access to data to more accurately assess traffic trends across time may be very valuable to the agency.
Microwave Sensors and Video Image Processing (VIPs)	Because the effect of weather is so great on these types of sensors, they will be recommended in places where other interventions are unable to be implemented or where WSF is hoping to collect extremely specific vehicle data.
Cameras and Painted Stripes	This type of rudimentary intervention will be recommended where no other interventions are possible due to existing conditions or community hesitancy for new infrastructure.

Recommendations overview for technological interventions to measure vehicle line

Interviews

Ferry Advisory Committee Members

I conducted a series of formal and informal interviews to better understand the Seattle ferry landscape and its interactions with local communities. I interviewed members of the Ferry Advisory Committee Executive Committee, a group appointed by local officials to better communicate with communities where ferry terminals are located (*Community Participation,* n.d.). The FACs have a variety of responsibilities as liaisons between WSF and their specific communities, making its members uniquely positioned to speak on the actual conditions of the terminals and their opportunities for growth and change.

Terminal Supervisors

Terminal supervisors are responsible for terminal operations, and many are well versed in the history of specific terminals as well as able to give insights into interventions that could make traffic onto the terminal site more efficient and measurable. Among their many duties, terminal supervisors are responsible for watching the camera feed of the terminal egress lane and calling customer service to report the perceived wait time. These terminal operators are a wealth of information when it comes to potential helpful technological interventions to better measure unknown demand. While each of these interventions is different for each terminal, using themes from these interviews will form parts of future recommendations.

Conveying Wait Times to Passengers

Equity Evaulation

Equity plays into possible consumer-facing technological intervention recommendations. Washington State Ferries carries around 25 million annually, showing the use of the ferries as a major means of public transportation in the Puget Sound area. For reference, the King County Metro, serving a similar geography, carries just over 121 million riders annually (*Accountability Center Ridership,* n.d.). While WSF carries around one fifth the passengers of the Metro, some of its services reach island areas unable to be reached by the Metro. WSF's commitment to equity as laid out in the Long-Range Plan, creating the best means of communicating wait time information will be based on the percentage of low-income residents within a 2.5-mile boundary of the centroid of each priority terminal, classified by census tract.

A digital divide persists throughout the country, and access to smartphones is directly correlated with income (*Digital Divides in Lower-Income America,* n.d.). Therefore, by evaluating poverty and reliance on public transit as a means of commuting in the area, policy recommendations can be made to dictate which type of technological intervention would be most accessible to terminal communities. Because I have focused this study on vehicle wait times, information about the amount of vehicle owners in Seattle who do not have access to a smartphone is pertinent information. However, this information has not yet been collected.

This evaluation is a proxy measure for Washington State Ferries passengers who are in need of real-time wait time information and do not have access to a smartphone. More research is needed, perhaps in the form of a ridership survey to determine how many WSF passengers do not have access to a cell phone or are otherwise unable to access the WSDOT app to see real time information.

If this study's evaluation shows a non-zero result of residents below the poverty line who use public transit to commute to work, alternative technologies to convey wait times will be recommended.

How Best to Convey Wait Times in WSF Terminals

Table 5 shows the three options for conveying wait times to passengers, as well as when they are most likely to be recommended.

Table 5. How Best to Convey Wait Times to Passengers and Recommendation Conditions

Technology	**Under What Conditions is it Recommended?**
App-Based Solutions	App-based solutions could be part of the solution, but based on the access to that information, it should not be the only way to access wait times.

Automated Signs along Queuing Lane Outside Terminal	These signs could be placed along terminal egress lanes unless certain terminal communities resist their presence. These will be recommended for terminals with existing signage infrastructure.
Wait Time Hotline	A hotline, considering its low cost and nearly-ubiquitous accessibility, should be implemented in all terminals as an option for passengers.

Findings

The priority terminals were determined through a series of calculations described in the Methodology Section of this report. While all of the 20 terminals inherently have some room for improvement, by prioritizing terminals based on a calculation concerning terminal vehicle holding capacity as well as vessel holding capacity, Washington State Ferries will be able to focus their immediate efforts on six terminals and evaluate their performance accordingly before investing in other terminals. These findings are summarized in **Appendix A**.

Priority Terminal Calculation Results

I originally identified nine terminals using the calculations described in the methodology (Fauntleroy, Edmonds, Lopez, Clinton, Southworth, Kingston, Port Townsend, Coupeville, and Mukilteo), by removing four terminal either under construction or using a reservation system (Port Townsend, Mukilteo, Edmonds and Lopez) and adding one terminal along the routes of another priority terminal (Vashon Island, North), six priority terminals are determined as seen in **Table 6**.

Table 6 Priority Terminals

Terminal Name	Congested Sailings Per Day	Sailings Per Day	Congestion Ratio	Mode Ferry Vehicle Capacity	Terminal Vehicle Capacity	Vehicle Holding Capacity Ratio	Drive Around Possibility
Vashon	n/a	n/a	n/a	124	45	0.3629	No
Fauntleroy	50	135	0.37	124	88	0.7097	Yes, unlikely
Southworth	n/a	n/a	n/a	124	171	1.379	Yes, unlikely
Edmonds	63	165	0.38	202	188	0.9307	Yes
Kingston	69	165	0.41	202	292	1.4455	Yes
Clinton	78	268	0.29	144	163	1.1319	Yes

Priority Terminal chart, see Appendix A for more detail

Equity Results

The equity evaluation showed low numbers of residents living below the poverty line who also reported using transit as a means of commuting to work. This again does not show an exact relationship between car ownership, WSF passengers and smartphone usage. However an imperfect measure, access to an alternative form of wait time information is something WSF should provide to passengers. The results from the equity study shows a non-zero result, giving WSF investing in strategies to convey wait time information other than only improving the WSDOT mobile app.

Menu of Options for Wait Time Measurement

Radio Frequency Identification Scanners

RFID Scanners are in use today as highway transponders by WSDOT in the form of a Good to Go. RFID scanners require two pieces: a reader (often installed over a road or bridge) and a transponder (often on the windshield of a car).

Due to the high cost of implementation because of the necessity for all vehicles using the ferry system to possess an RFID scanner, this is not seen as a viable option for measuring the unknown demand outside the terminal toll booth.

Inductive Loops

Inductive loops are sensors placed underneath pavement and detect vehicle movement and line length. Inductive loops may be recommended in situations of particularly difficult weather conditions or where installing another type of line detection technology is impossible, but given the disruption of traffic upon their installation and repair, they are not recommended for all situations in all terminals.

Streetlight Data

Streetlight Data relies on location services built into smartphone applications already installed on users' phones (*StreetLight Data raises $15 million to bring big data analytics to city transport, n.d.)*. With this information, the powerful algorithm can calculate traffic, parking and pedestrian movement patterns. Cities and companies are able to purchase this data to further analyze for the research and improvement purposes.

If this type of intervention is in the budget for WSF, the long-term access to data to more accurately assess traffic trends across time may be very valuable to the agency for real-time wait time analysis as well as long-term data collection.

Microwave Sensors and Video Image Processing

These interventions are mounted above or alongside traffic and monitor traffic movement through microwave sensors reflecting off vehicles or video footage captured and processed concerning street conditions.

Because the effect of weather is so great on these types of sensors, they will be recommended in places where other interventions are unable to be implemented or where WSF is hoping to collect extremely specific vehicle data.

Cameras and Painted Stripes

Some terminal operators rely on landmarks to approximate line length, and while this is a rather rudimentary process, it serves as a zero-cost line measurement technique. By painting bright stripes on the road at certain points along the egress lane with cameras positioned over them to measure if the line is filled to that point with cars.

This type of rudimentary intervention will be recommended where no other interventions are possible due to existing conditions or community hesitancy for new infrastructure.

Menu of Options for Passenger Communication Techniques

App-Based Solutions

WSDOT's existing app is quite extensive and could add data gathered by wait time measurement interventions. Making the wait time feature more accurate using information gathered from improved wait time analysis technologies, the WSDOT app could become more reliable as a source of real-time data. App-based improvements should be part of the solution, but based on the access to that information, they should not be the only way to access wait times.

Egress Wait Time Signs at Terminal

A digital sign placed next to egress lanes or existing overhead signage connected to wait time measurement and updated based on the current length of the line. These signs could be placed along terminal egress lanes unless certain terminal communities resist their presence. These will be recommended for terminals with existing signage infrastructure.

Real-Time Hotline

A hotline such as this would provide the real-time wait time for a particular terminal. By providing a phone number for passengers to call, an real-time updated recording will play and say the number of minutes until the last car in line will board the next available ferry. A hotline, considering its low cost and nearly-ubiquitous accessibility, should be implemented in all terminals as an option for passengers.

Recommendations

Fauntleroy

A fascinating case study, the Fauntleroy terminal has a notoriously small vehicle holding area leading to lines often extending past the terminal toll booth. In conversations with Ferry Advisory Committee members and Terminal Supervisors, the tension around making physical changes to the terminal area is high, and therefore the suggestions are created to be as minimal as possible.

For line detection, the recommendations are painting stripes along the road with cameras positioned above them for terminal supervisors to approximate line length based on the number of cars past a particular painted stripe. This option does not allow for historic data to be recorded in an official manner and requires terminal supervisors to monitor the cameras in order to determine line length. Another option for Washington State Ferries is to purchase Streetlight data, but considering the egress lane also services a popular public park, the data received from this may be imperfect.

Given conversations with Ferry Advisory Committee members and Terminal Supervisors, the Fauntleroy terminal should avoid installing wait time signs along the roadside or overhead, and instead focus on implementing and then marketing both a hotline and improved app wait time feature.

Vashon

The Vashon Island North-End Terminal is not equipped with a toll booth, and passengers must purchase tickets on one of the mainland terminals part of the triangle route. Vashon residents and visitors have no alternative way to leave the island other than by boat, so many passengers are resigned to the fact of a ferry line, according to Emily Scott Vashon Island's FAC representative.

For line detection, because the alternate road to the ferry terminal is only two-lanes, disrupting traffic for installation would be detrimental. Therefore, microwave sensors are recommended to be placed on existing light posts along Vashon Island Highway SW for two miles past the ferry entrance. WSF could also purchase Streetlight data to observe travel trends on Vashon Island near the ferry terminal.To make this information accessible by passengers, WSF will publish this data in real time to the WSDOT app and make that information available on the Hotline.

Southworth

The Southworth population is growing quickly due to its housing affordability and proximity to transportation (S. Lowery, D. Wea, personal communication, March, 8, 2021) . Traffic to the terminal comes in on SE Southworth Dr, but can be rerouted onto WA-160 if installation disrupts the traditional traffic flow. No existing lamp/camera poles exist along SE Southworth Dr, and therefore for cost sake, the conditions of this terminal are positive for an inductive loop system.

By determining the length of a historic line, inductive loops should be placed in certain segments of the road to represent wait time brackets. This information is recorded and can be exported to provide a wait time approximation. This information, for Southworth, should be available on a hotline as well as on the WSDOT app.

Edmonds

The Edmonds terminal is equipped with a dedicated terminal vehicle lane, making installation of recommendations much more manageable. Microwave vehicle sensors on existing light posts along Terminal Vehicle lanes will provide a low-cost possibility for WSF to measure line length. Without existing signage along the terminal egress lane, installing signage infrastructure on which to display wait time information is possible but may be expensive. The WSDOT app as well as a hotline would be helpful to convey this information to passengers.

Clinton

The Clinton terminal is a candidate for inductive loops, because the road, WA-525 extending from the ferry terminal is only 0.2 miles. The terminal has a large WSDOT overhead sign that could be equipped with wait time information for the back of the line. The Clinton terminal should also use a hotline with terminal wait time information.

Kingston

No alternative road exists for rerouting traffic to the Kingston terminal, and therefore interrupting traffic to install inductive loops or other sensors may be too disruptive to ferry service. Streetlight data could be the most efficient and effective way to measure wait times entering the terminal. This information should be shared on the WSDOT as well as a hotline.

Conclusion

By focusing on wait times throughout this study, the reduction of perceived wait times is addressed through the concept of improved transparency. Through data analysis and interviews with ferry personnel, this study has pinpointed the six priority WSF terminals where technological interventions would be most useful.

Fauntleroy, Vashon, Southworth, Clinton, Edmonds and Kingston have vehicle holding capacities less than two times an average sailing vessel's vehicle holding capacity and have 28% or more *very congested* sailings (meaning passengers will wait one or more sailings) during the summer months. Recommendations are based on conditions of the terminal area and conversations with ferry personnel and are specific to each of the six terminal areas.

In addressing these six terminals, WSF can assess the impacts of the recommended interventions and employ them when retrofitting other terminals in the future. With projected growth in the Puget sound region over the next 20 years, it is paramount WSF makes the ferry system more accessible and able to be used as part of trip planning. In many conversions over the course of this project, people expressed the accepting nature of a region relying on ferries for transportation.

There are delays, lack of alternatives, and other complications that come with carrying 25 million people, some with dogs, cars, trucks, and bicycles, over the course of a single year. WSF is making excellent strides in laying out future changes such as terminal replacements and new vessels. Focusing efforts on customer transparency would be the last piece in the puzzle making WSF more reliable to passengers.

One of Washington State Ferries' goals through its Long Range Plan is to improve the customer experience, and these types of recommendations are just the first step. In finding ways to increase wait time transparency, the agency will have a more consistent means of collecting wait time data and be better equipped to convey wait times to passengers and track excess demand above current capacity. This study shows potential steps to achieve WSF's goals for a more efficient and equitable service for the Puget Sound Region.

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Appendix A

Terminal Name	Congested Sailings Per Day	Sailings Per Day	Congestion Ratio	Mode Ferry Vehicle Capacity	Terminal Vehicle Capacity	Vehicle Holding Capacity Ratio
Talequah	29	134	0.2164179104	64	5	0.0781
Vashon	n/a	n/a	n/a	124	45	0.3629
Fauntleroy	50	135	0.3703703704	124	88	0.7097
Edmonds	63	165	0.3818181818	202	188	0.9307
Friday Harbor	10	50	0.2	120	118	0.9844
Lopez	21	53	0.3962264151	87	93	1.0672
Clinton	78	268	0.2910447761	144	163	1.1319
Bainbridge	37	160	0.23125	202	250	1.2376
Bremerton	12	105	0.1142857143	144	190	1.3194
Southworth	n/a	n/a	n/a	124	171	1.379
Orcas	8	54	0.1481481481	116	162	1.3914
Kingston	69	165	0.4181818182	202	292	1.4455
Port Townsend	52	109	0.4770642202	64	98	1.5313
Point Defiance	30	134	0.223880597	64	100	1.5625
Coupeville (Keystone)	46	109	0.4220183486	64	101	1.5781
Seattle-Bainbridge	39	159	0.2452830189	202	325	1.6089
Mukilteo	84	268	0.3134328358	144	245	1.7014