Bit by Bit: Developing a Concept Design for Bus Priority for Route 73, in Portland, Oregon, USA.

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McGill

Developing a Concept Design for Bus Priority for Route 73

Executive summary

1. What is bus priority?

Bus Priority Interventions, also known as Enhanced Transit, are small-scale changes that improve bus speed and reliability. These include changes to street geometry, bus stops, and traffic signals. This project used Automated Vehicle Location and Automated Passenger Counter (AVL-APC) data to propose a concept design for enhancing Route 73 on 122nd Avenue between Powell Street and Halsey Street, in Portland, Oregon.

2. Why study this corridor?

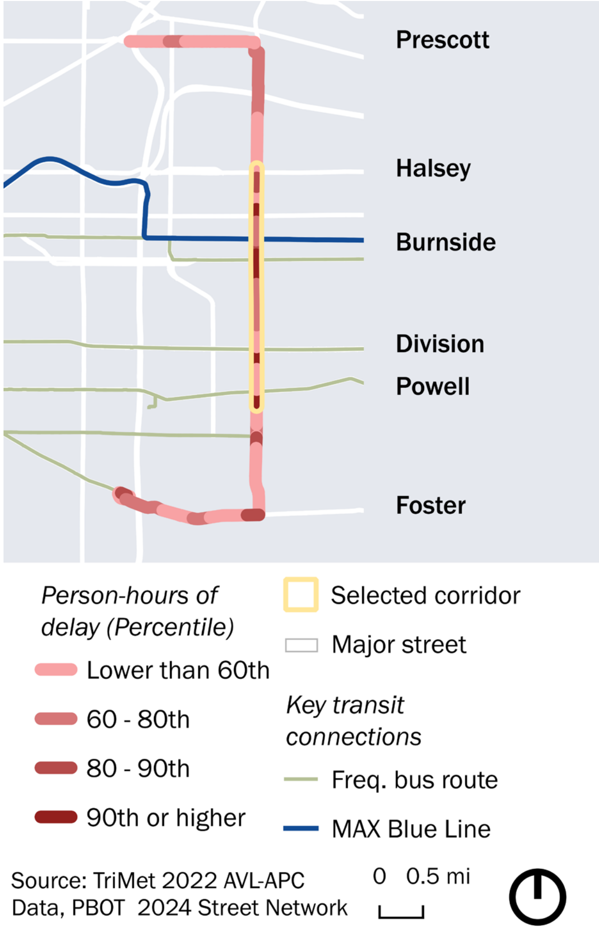
This stretch of Route 73 was chosen because many segments of it had high levels of travel delay and passenger demand. Several additional considerations affected the choice:

- Bus priority interventions are feasible, since 122nd Avenue is 76 feet wide and entirely owned by the city of Portland.
- The city recently received a $20M US DOT grant to make 122nd Avenue safer, and released a new transportation plan for the street in January 2024.
- The equity impact of enhancing Route 73 is especially high, as the route serves areas with concentrations of low-income and racialized groups.
- Bus priority on 122nd Avenue has been considered by the city, but not extensively studied.

3. Where is delay concentrated?

Quantitative data analysis and on-site visits found that delays were concentrated at major intersections, rather than between them. Delays were most notable where 122nd Avenue crosses Powell Street, Stark Street, and Burnside Street. Stop delay was also an issue, particularly at the stops serving Burnside, Division, and Powell. These delays and passenger demand were highest during the PM peak, between 3-6PM.

Major points of delay on Route 73



Source: TriMet 2022 AVL-APC Data, PBOT 2024 Street Network

Developing a Concept Design for Bus Priority for Route 73

4. What is recommended?

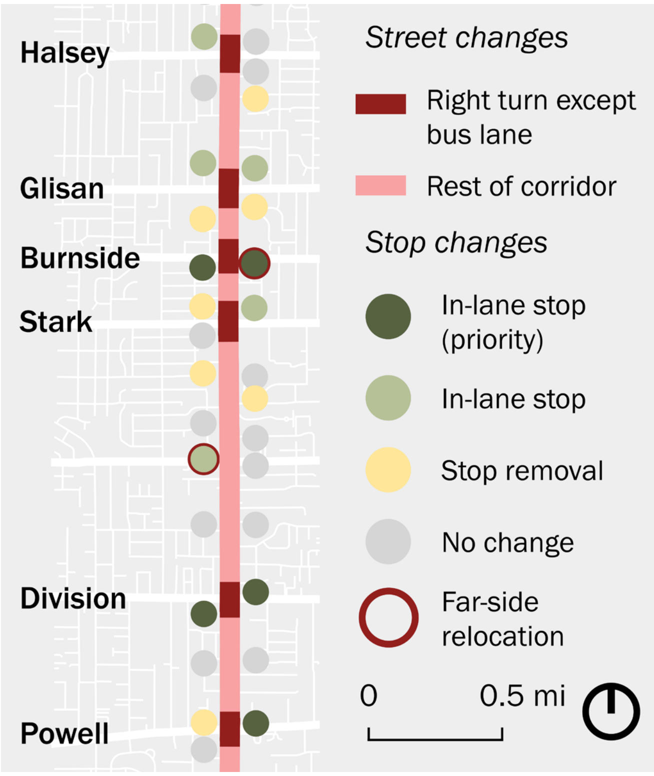
1. **Right-turn except bus lanes** at 6 intersections, to let buses use right-turn lanes to get past queuing traffic
2. **Next-generation Transit Signal Priority** at 6 intersections
3. **In-Lane Bus Stops**, particularly at Burnside, Division, and Powell
4. **Bus stop consolidation** at 7 stops

5. What impact is expected?

Breadcrumb Automated Vehicle Location (AVL) data was used to predict each intervention's impact. Historical trips were analyzed to calculate how buses are currently affected by different types of delay, including red light and stop delay. The suggested changes could create upto 7.5 minutes in savings — 3.1 minutes northbound and 4.4 minutes southbound. These interventions would reduce travel times from one end of the corridor to the other by 20%.

Intervention	Exp. savings
Right-turn except bus lanes	0.5 minutes
Next-gen TSP	4.2 minutes
In-lane bus stops	1.1 minutes
Stop consolidation	1.8 minutes
Total	**7.5 minutes**

Proposed interventions for corridor



6. Are financial savings possible?

The savings alone are not enough to reduce the number of buses servicing Route 73 during the PM peak. This is partially since layovers on Route 73 are relatively high — they currently make up 24% of the total cycle time. If layovers were reduced by four minutes each way, they would make up 19% of the total cycle time — still a higher percentage than other frequent service routes. Coupled with the travel time savings from the bus priority interventions, this reduction in layover time would enable TriMet to service the route with one fewer bus during peak hours, generating an annual savings of upto $150,000.

Beyond Route 73, this project demonstrated an end-to-end methodology for how bus priority programs could be efficiently and thoughtfully planned across an entire bus network.

Acknowledgments

First and foremost, I would like to thank my supervisor Prof. Ahmed El-Geneidy for his constant guidance throughout my degree. He has played an essential role in the completion of this project and in my development as a transportation planner.

I would also like to thank Miles Crumley from TriMet for sharing the detailed AVL-APC data, providing valuable feedback on which route to study in detail, and connecting me with other transportation experts in Portland. Thank you to Peter Koonce and Mark Haines from the Portland Bureau of Transportation and A.J. O'Connor from TriMet for providing detail on how the LYT TSP system and the associated traffic signals function.

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Source: TriMet

PART 1: INTRODUCTION

Part 1: Introduction

This project demonstrates a methodology for using bus data to identify bus priority interventions that can improve bus speed and reliability.

Increasing public transportation ridership has become an important tactic to reduce congestion and achieve sustainability goals.

Despite this, the sight of a packed bus stuck in traffic is common. This is an issue since bus speed and reliability are two key determinants of bus ridership (El-Geneidy et al., 2009; Taylor et al., 2009). Slow-moving buses put financial pressure on transit agencies. As they take longer to complete their routes, more buses are required to achieve the desired headway. Since many cities and transit agencies are in poor financial situations due to low ridership post-COVID-19, cities and agencies cannot afford to improve transit by building capital-intensive infrastructure like subways, light-rail, or even bus rapid transit (Association of Public Transit, 2023).

Bus Priority Interventions (BPIs) are promising policies for transit agencies and cities looking for a low-cost tool to improve operational efficiency.

BPIs are small-scale changes to street geometry, bus stops, and traffic signals that improve bus speed and reliability. These include dedicated bus lanes, curb extensions, and transit signal priority. BPIs help minimize traffic delay by reducing buses' interactions with other road users, particularly at intersections. BPIs can be rolled out across an entire transit corridor, or targeted at specific intersections that demonstrate an elevated need. Their smaller scope makes them cost and time-effective to implement, because they require less coordination and physical infrastructure to deploy.

Source: Portland Bureau of Transportation

This project seeks to use bus data to support the design and prioritization of Bus Priority Interventions.

Research question:	How can bus data help identify opportunities for bus priority and predict the benefits of specific interventions?
Project Phases	**Phase 1:** Analysis of Portland, Oregon's bus network to identify a transit corridor with high delays and passenger demand. **Phase 2:** Quantitative and qualitative analysis of chosen corridor to identify most appropriate BPIs.
Result of project	Data-driven plan for improving bus speed and reliability on a high-priority transit corridor.
Why it matters	Demonstrates an end-to-end methodology for efficiently and thoughtfully implementing bus priority programs

Source: City of Portland

PART 2: LITERATURE REVIEW

Part 2: Literature Review

Academic and industry research highlights different ways to define, measure, and reduce bus delays.

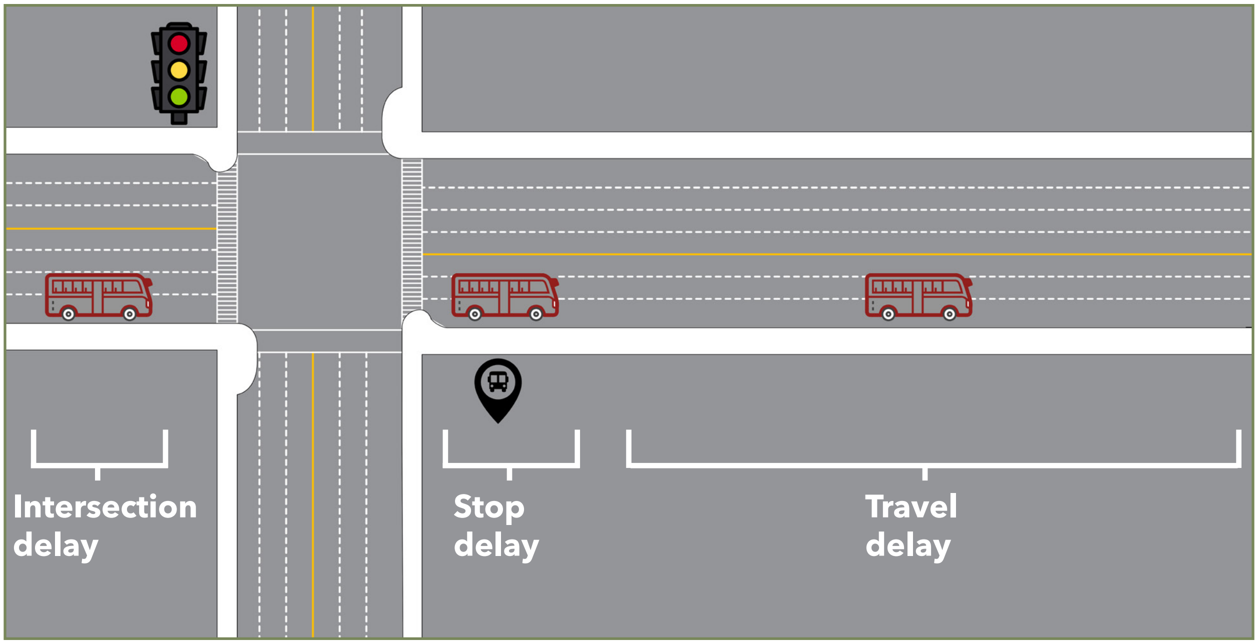
Types of delay

Bus delays can be grouped based on where they occur: near bus stops, at intersections, or while travelling in between two stops.

Bus stop delays occur when the bus is picking up or dropping off passengers. These can include delays that take place while passengers are boarding or alighting, often referred to as dwell time delays. Bus stop delays include acceleration and deceleration time during a stop, such as time lost when the bus must wait to merge back into traffic as it pulls out of a bus stop (Ryus, 2013). Bus stop delays tend to be driven by passenger demand and bus stop location.

Intersection delays happen when a bus must wait at an intersection. This could be because it stopped at a red light (signal delay) or because it is stuck behind a vehicle waiting to turn. Intersection delays increase as the traffic volume approaches the street's vehicle capacity and when there are many cross streets (National Association of City Transportation Officials, 2016). Travel delays occur between stops, when congestion or curbside activity (e.g., parking) reduces vehicle travel speed. Different BPIs are best suited for different delay types, so bus routes must be carefully observed to ascertain which type of BPI is most needed.

Where do different bus delays occur

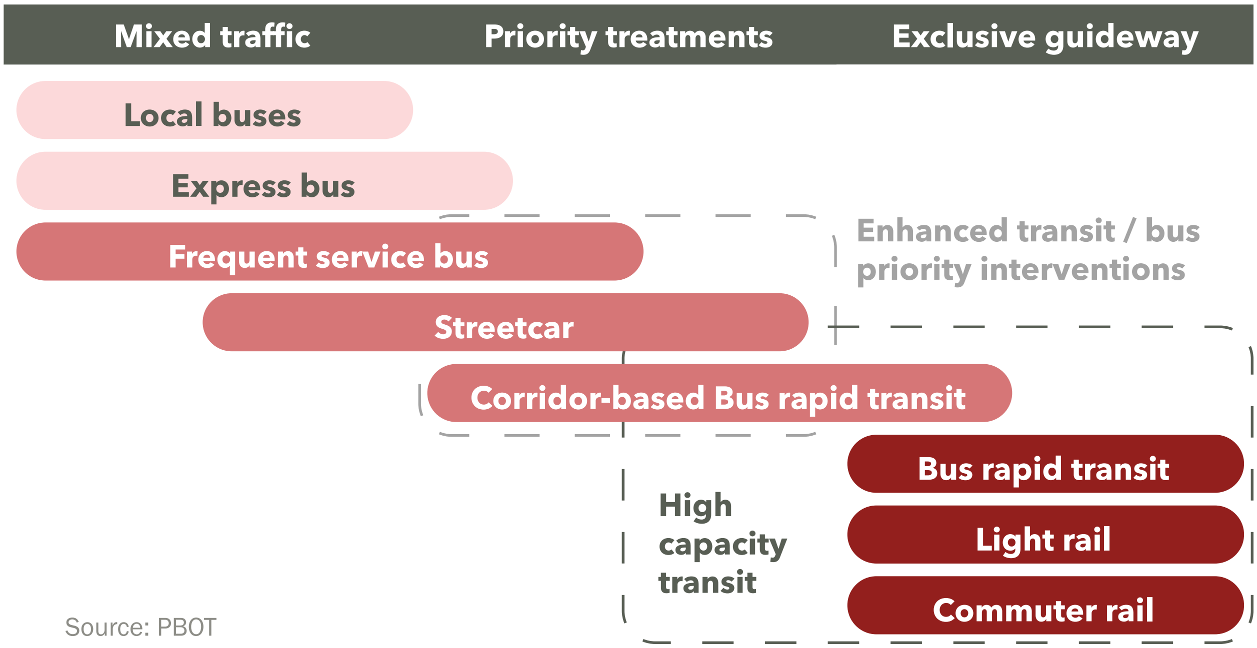


Broader transportation context

Bus Priority Interventions occupy a middle ground between giving buses no priority and building rapid transit.

To understand BPIs, it helps to place them within the broader transit context. The transit spectrum includes different vehicle types which are separated from traffic to differing degrees (Portland Bureau of Transportation, 2018). At one extreme are local buses operating in mixed traffic with no priority. These are the slowest, lowest capacity form of transit. At the other extreme are high-capacity transit modes, such as commuter rail, subways or light rail. These systems are often grade separated, meaning they do not interact with other road users or even stop at traffic signals. BPIs, known as Enhanced Transit in Portland, sit in the middle. Road geometry, bus stops, and traffic signals are tuned to give transit vehicles some separation or priority over car traffic. However, this separation is not continuous and not physically enforced.

Regional transit spectrum



Source: PBOT

Types of Bus Priority Interventions

BPIs can be split into three major categories: bus stop management, street design, and signal priority.

Bus stop management refers to interventions that reduce the number of bus stops or adjust their placement to allow buses to clear intersections more rapidly. Street design can give buses dedicated right-of-way to ensure they are not inhibited by vehicles.

Signal priority changes traffic signal timing to minimize the length of time a bus spends waiting at red lights. This section provides detail on each type of BPI, and where it is most appropriate.

Key BPIs discussed in this section

BPI group	Name of BPI	Delay targeted	Cost to implement
Bus stop management	Stop relocation	Stop delay	$-$$
	Stop consolidation		$
	In-lane stops		$-$$$
Street design	Dedicated lanes	Travelling delay	$$-$$$$
	Turn pocket	Intersection delay	$
	Queue jump		$
Signal priority	Passive TSP		$-$$
	Active TSP		$$-$$$$

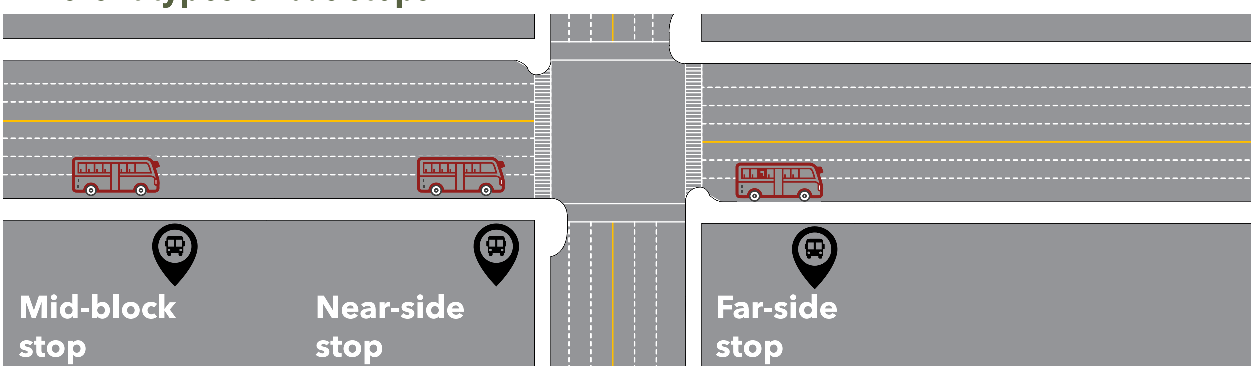
Source: TransLink Transit Priority Toolkit

Bus stop management

Bus stop relocation

Bus stop delay is partially driven by the location of bus stops, which can be situated at the far-side of an intersection (i.e., after the bus has cleared the intersection), near-side, or mid-block. Far-side bus stops typically provide the greatest benefits. They make it easier for buses to benefit from signal priority, increasing the likelihood that a bus can get through the intersection before stopping (TransLink, 2023b). They also eliminate the risk of triple-stopping, which can happen with near-side stops. In a triple stop, the bus stops in traffic that is queuing at a red-light, then stops again to pick up passengers, and then stops a third time at the red light. The traffic signal located immediately behind a far-side stop also gives an opportunity for the bus to re-enter traffic smoothly once it is ready to leave. A 2015 study in Montréal, Québec and Portland, Oregon found that far-side stops were 4.2 to 5.0 seconds faster than near-side stops (Diab & El-Geneidy, 2015). Costs associated with bus stop relocation are relatively low, although they rise if the stop infrastructure is more complex (i.e., a stop with a more sophisticated shelter or station).

Different types of bus stops



Bus stop consolidation

Since each stop slows the bus down and has the potential to create delay, reducing the number of bus stops provides another way to reduce bus stop delay. Wider stop spacing allows vehicles to go faster, with a 2005 study in Portland, Oregon finding that bus stop consolidation reduced running times by 6% (El-Geneidy et al., 2006). Stop consolidation can reduce bus stop maintenance costs and improve the customer experience by reducing the number of stops and starts (Stewart & El-Geneidy, 2016). However, consolidation does increase access/egress time to the bus. This is most impactful for riders with mobility challenges, including older adults, those with strollers, and those with disabilities. To minimize these harms, stop removal must consider bus stops' immediate surroundings, such as connections to other transit lines or the presence of healthcare facilities. Cost to implement stop consolidation are low, however it may be politically challenging to eliminate certain stops.

In-lane stops

Bus stop delay decreases when a bus can access a bus stop in the lane it is travelling in (i.e., an in-lane stop), rather than having to pull over into the parking lane. This is because, after using an in-lane stop, the bus does not need to merge back into traffic but rather just needs to accelerate forward. This avoids the bus having to wait for a gap in traffic, and makes deceleration and acceleration faster and simpler. This saves time, and also reduces bus and pavement maintenance costs (National Association of City Transportation Officials, 2016).

The most common way to create an in-lane stop is via a bus bulb, also known as a curb extension. With a bus bulb, the sidewalk is extended into the parking lane at the location of the bus stop. As such, the bus stop meets the transit vehicle where it is travelling. A study in New Jersey estimated that bus bulbs saved 15-30 seconds per stop in high traffic corridors (Daniel & Konon, 2005). In Vancouver, TransLink found that travel times decreased by 14% when bus bulbs were deployed along a busy shopping street (TransLink, 2023a). Beyond their improvements to bus speed and reliability, bus bulbs also improve the customer boarding experience, by creating a dedicated space for passengers to wait for the bus (National Association of City Transportation Officials, 2016). By narrowing the street, they can also reduce the time required for pedestrians to cross the street (Fitzpatrick et al., 2001). These benefits are especially meaningful for passengers who use mobility aids, like wheelchairs. Bus bulbs are best suited for streets with low traffic speed, and at least two available travel lanes (Ryus, 2013). When they are located at far-side stops, care must be taken to ensure vehicles do not queue behind the bus and occupy the intersection. One drawback of implementing bus bulbs is that they prevent the installation of a peak-hour bus lane, because the curb extensions make it impossible to drive down the parking lane.

On streets with cycling lanes, an in-lane stop may be achieved via what is known as an island stop.

In this configuration, the bike lane is routed in between the sidewalk and the island stop. The bike lane is raised to the level of the sidewalk at the point where it crosses behind the bus stop. This ensures that pedestrians crossing the bike lane to get from the sidewalk to the stop have an even platform on which to walk. Cyclists have the responsibility for yielding to pedestrians that are accessing or leaving the stop. The advantage of this configuration is that it avoids conflicts between buses and cyclists, by ensuring that the bus does not have to cross the bike lane at any point. However, it does create the potential for conflicts between bus riders and bikers. To ensure safety, cyclists' obligation to stop for pedestrians must be clearly defined. For example, in Portland, cyclists must wait at the start of the bus stop whenever is using it (see below). In-lane stops are relatively costly to implement, particularly island stops. This is partially because they may require modifications to the street to allow for proper drainage (National Association of City Transportation Officials, 2016).

Island stop on new FX bus route in Portland, Oregon

Source: City of Portland

Street design

Dedicated/peak lanes

Travelling delay can be mitigated by installing dedicated or peak-only bus lanes, which prevent non-transit vehicles from using specific lanes.

Exceptions may be made to allow non-transit vehicles to temporarily enter bus lanes to turn, park, or access driveways. Lanes may be located in the middle of the roadway, in the lane next to the parking lane, or along the curb (on streets that do not allow street parking). To ensure compliance, lanes must be well defined, using either red paint or clear signage. The efficacy of dedicated lanes is limited on streets with high right-turn volumes, as the buses may be stuck behind vehicles waiting to turn (National Association of City Transportation Officials, 2016). To mitigate this challenge, bus lanes may be paired with turn pockets to further segregate buses from general traffic.

While some lanes are in effect 24-hours a day, in some cases cities may choose to implement the bus lane only during peak hours. A peak-only bus lane may be appropriate where delays are only bad during peak times, or where bus volumes are insufficient to merit a full-time bus lane. Peak-only bus lanes are typically situated in the parking lane, with parking prohibited during those hours. Peak-only bus lanes are especially appropriate where there is high parking turnover, and the parking activities can be relocated to other times of day. Where delays are not 'peaky', bus bulbs may be more appropriate than a peak-only bus lane, as bulbs provide benefits throughout the day. Dedicated bus lanes have been deployed across North America, with some cities finding travel time savings ranging from 50 – 150 seconds per kilometer (Danaher, 2010). Bus lanes' implementation costs depend on whether street reconstruction is required. If not, the main expenses include signage and/or painting the lanes red. Their visibility means that they may require significant political capital to implement, with peak-only lanes generally facing less public opposition than 24-hour lanes.

Turn pockets

A significant portion of transit delay is created when buses must wait behind cars and trucks that are waiting to turn right. This is especially the case at intersections that prohibit right-turn on red.

Turn pockets give turning vehicles their own lane to wait in, separating them from the rest of traffic.

This saves transit vehicles from needing to change lanes to get around turning vehicles. Right-turn pockets are located in the parking lane. Turn pockets can be implemented at all times or purely at peak-hours (by prohibiting on-street parking during those times). Beyond speeding up transit, they have safety benefits by reducing pressure on drivers to make risky turns (TransLink, 2023b). Turn pockets are not feasible where a curbside transit lane already exists, because to implement them one would need to cut into the sidewalk. To be effective during peak times, turn pockets must be long enough to accommodate the longest routinely occurring queue. Cost to implement is low, given that only minimal restriping and signage is required.

Source: City of Portland

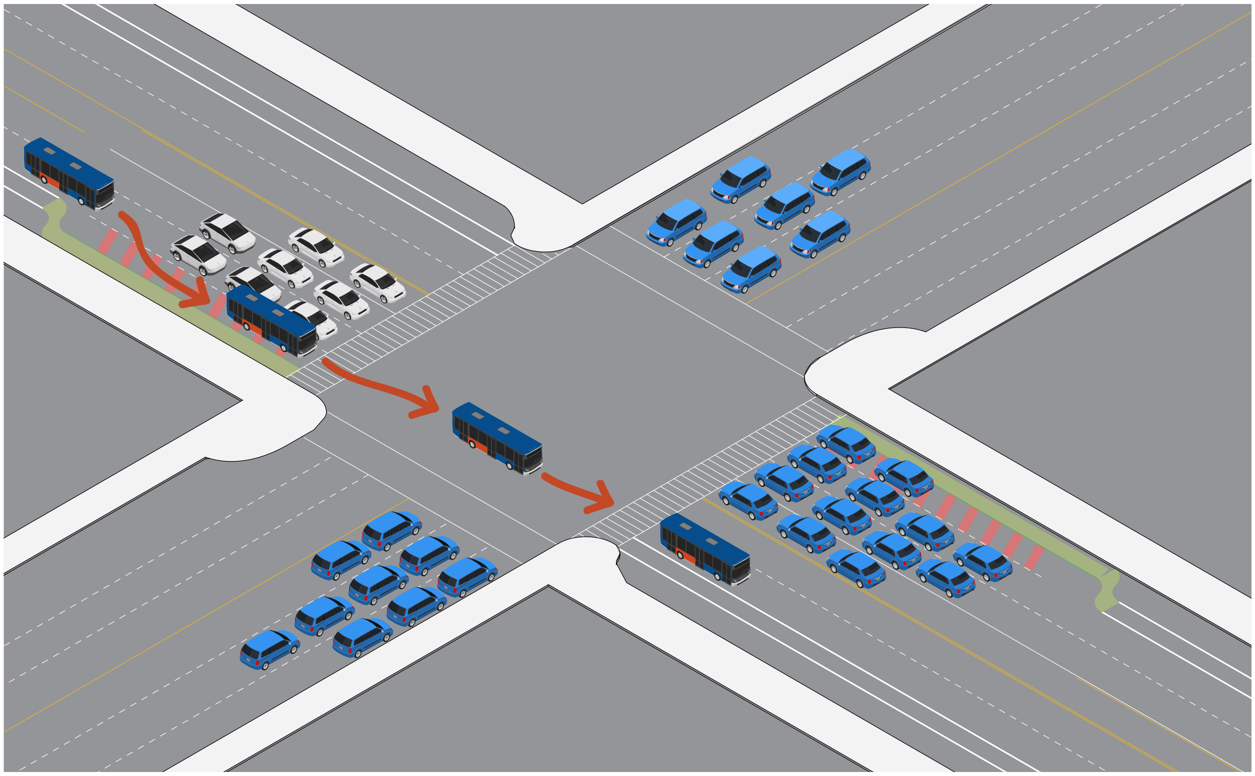
Queue jumps

Queue jumps, also called transit approach lanes, are short bus-only lanes located immediately before an intersection.

Without a queue jump, a buses may have to wait at the back of the traffic queue if they arrive at an intersection last. Queue jumps allow buses to bypass the vehicles that are queuing at an intersection, giving them a head start on traffic. To maximize benefits, they can be paired with transit signal priority, which provides transit vehicles with an early green signal, allowing them to get a head start on the queuing traffic. In some instances, only buses are allowed in the queue jump lane. In others, right-turning vehicles are also able to use the lane, but only buses can use it to go straight. In the latter scenario, queue jumps are only effective where the intersection has low right-turn queues. This reduces the risk that the bus will have to wait behind other vehicles while in the queue jump. To guarantee that the bus can always access the queue jump lane, it must be deep enough to allow buses to bypass peak traffic queues.

Queue jumps on New York City's M86 bus line reduced time stopped in traffic by 7% westbound, and 30% eastbound (Transportation, 2017). Other studies have estimated that queue jumps reduce travel times of 5-15%, with impact higher when intersections are more congested (Kittleson et al., 2007). In the Portland context, queue jumps were first trialed on Powell Boulevard, with bus travel time reduced by 5-8% (Hunter-Zaworski et al., 1995). Queue jumps are a low-cost intervention, as they require minimal signage, lane re-striping, and potentially paint to indicate how the lanes may be used. They are somewhat more expensive when paired with transit signal priority that gives the bus an advance green.

Queue jumps allow buses to bypass cars waiting at red lights



Transit signal priority

Passive signal priority

Transit travel times can be improved by making changes to traffic signals.

Passive signal changes involve re-timing traffic signals to allow buses to benefit from a "green wave", a steady stream of green signals (National Association of City Transportation Officials, 2016). These are most effective on streets with a high volume of transit vehicles (i.e., 10 or more per hour). Timing is most effective on one-way streets, since the signal must be optimized in only one direction. Selecting a transit-friendly signal progress may be complicated by the presence of major cross-streets, given that it may not be possible to optimize for both streets. Transit friendly progressions must take into account dwell times, as well as running times. In San Francisco, the transit agency implemented a passive transit signal priority on Geary Street, a one-way corridor with frequent headways. These were found to reduce peak travel times by 4%, or 20 seconds (Pangilinan & Carnarius, 2011).

Active signal priority

Active transit signal priority (TSP) involves actively modifying signal lengths as transit vehicles approach intersections.

The most common form of TSP is a "green-extension", where the green phase is made longer to allow the bus to travel through the intersection without having to stop at a red light. Alternatively, a "red truncation" shortens the length of the red phase, to reduce the time a transit vehicle must wait at an intersection. Active TSP can also entail a bus-only phase, wherein only buses can travel through intersections. These can be inserted just before the green phase, to give buses a head-start on other vehicles, or just after the end of the green phase, to give them an additional opportunity to cross the intersection if they arrive late. Active TSP is most appropriate on corridors with relatively long signal cycles or long distances between signals, so that the bus can "contact" the traffic signal sufficiently early to request a change in phase length. Moderate or longer headways ensure that the TSP does not have too much of an impact on waiting times at cross streets.

Dedicated signal provides transit priority to buses

Source: TriMet

Historically, the efficacy of active TSP in Portland has been mixed, but this has changed recently.

In Fall 2022, TriMet launched the FX2 bus route, which received several Bus Priority Interventions, including a “next-generation” LYT TSP system (LYT Blog, 2022). With LYT, the bus continuously shares updates regarding its location and speed to a traffic management center. This is used to predict the estimated time when the bus will arrive at upcoming signalized intersections. Based on business rules defined by the Portland Bureau of Transportation (PBOT), these traffic signals lengthen or shorten to increase the likelihood that the signal will be green when the bus arrives at the intersection. If the bus must stop at an intersection, the signal is able to provide it with an advance green phase at three opportunities throughout the traffic light cycle.

This system improves upon traditional TSP systems in three ways. First, in traditional TSP systems the bus ‘calls’ the traffic signal via a line-of-sight connection (Feng et al., 2015; Koonce & Haines, 2023). In the LYT system, the bus communicates its GPS information to a central control room. This means that the bus can share information about its location further in advance and reduces the risk that the call is disrupted by bad weather. The LYT system also provides more insight into bus performance (e.g., travel speeds at different points of time, green-light success rate), which allows the city to recalibrate signals to reduce intersection delay. Last, the LYT system is more effective at providing the bus with bus-only phases – giving the bus more opportunities to clear the intersection per cycle. These improvements have enabled an 82% reductions in signal delay along the FX2 route and a 30% increase in green light success rate (Menard, 2024).

Source: TriMet

Transit speed and reliability metrics

Agencies and academics use many metrics to track the performance of transit on different corridors including speed, travel time, on-time performance, travel time coefficient of variation, and delay.

Speed (i.e., miles per hour) and travel time are the most familiar metrics. These can be further contextualized by comparing the transit vehicle speeds and travel times to car speeds and travel times. These comparisons speak to how competitive the transit system is relative to cars, with research indicating that choice riders are more likely to take transit when transit travel times are within 1.5 times the length of car travel times (El-Geneidy et al., 2009). The most common measure of reliability is On-Time Performance (OTP) (Ryus, 2013). This is calculated by finding the percentage of time that a transit vehicle arrives at a stop within a certain time threshold of the stop schedule. The thresholds vary by agency, with many agencies, including TriMet, counting all stops that arrive between 1 minute before the scheduled stop time and 5 minutes after as "on time" (TriMet, 2024b) .

More complex ways of capturing reliability include travel time coefficient of variation (CV) and peak delay (PD).

Travel time coefficient of variation is frequently found in academic literature. It is calculated by dividing the average travel time by the standard deviation of travel times. A higher CV indicates that there is significant variation between how long a trip normally takes and the fastest and slowest trips (Diab & El-Geneidy, 2013). CV has been criticized for being difficult to understand by non-technical users and challenging to relate to everyday traveling experiences (Federal Highway Administration, 2005).

Source: TriMet

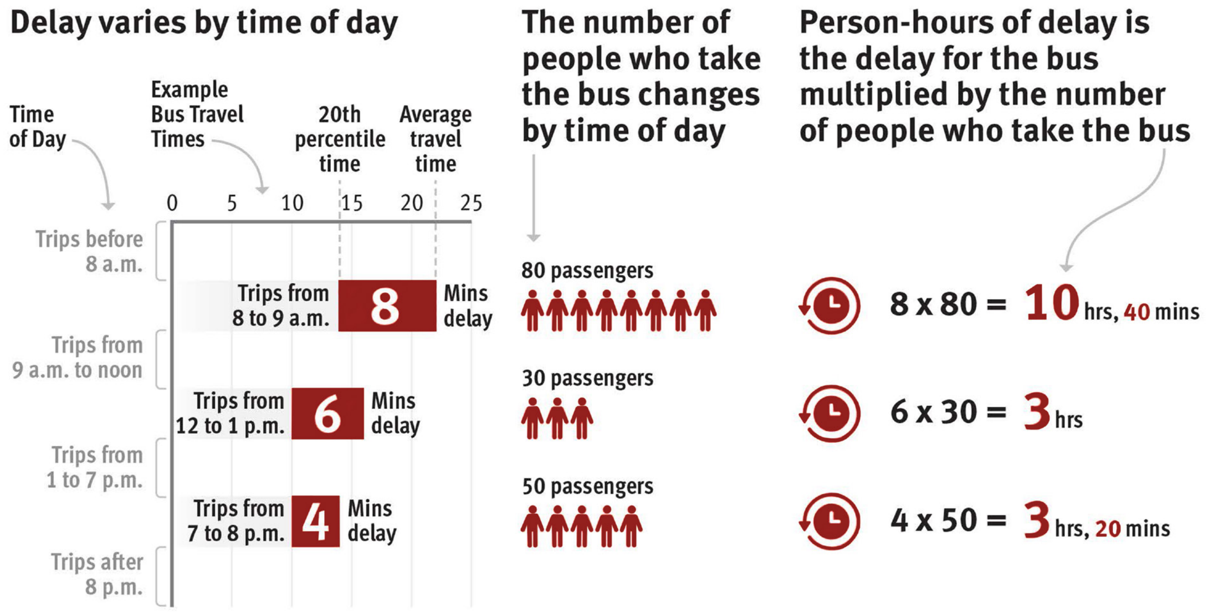
Delay is measured by getting the difference between the fastest travel times and the slowest.

The exact percentiles used vary by transit agency. In Vancouver, TransLink focused on the difference between an optimal trip (20th percentile) and the median trip (50th percentile) (TransLink, 2023a). In Portland and other parts of the United States, the difference between 10th percentile and 90th percentile trips are used (Nelson Nygaard, 2021; Portland Bureau of Transportation, 2018). Since the slowest trips tend to take place during peak travel times while the fastest trips take place during off-peak, this metric is often referred to as peak delay. Delay may be normalized for distance, by dividing the delay time by the street segment's distance. This accounts for the fact that longer segments would otherwise be more likely to have more delay than shorter segments. These measures of bus performance are particularly helpful in identifying areas where congestion is making operations slower, and thus more expensive.

To account for the number of people who are being affected by delays, these reliability metrics can be adjusted for passenger volumes.

This is done by multiplying a road segment's travel time coefficient of variation or delay by the number of passengers using the segment. Adjusting for passenger volumes helps highlight segments where delays are common and where passenger demand is high. **When delay is multiplied by passenger loads, the resulting metric is referred to as person-hours of delay** (Portland Bureau of Transportation, 2018).

These metrics can be calculated based on performance across the entire day, or can be calculated on an hourly or even trip basis. Evaluating the range of travel times at the trip or hourly level identifies whether specific times of day have more variability in travel time, or whether speed and reliability challenges occur throughout the day (Nelson Nygaard, 2021). Different types of bus priority measures are more suitable depending on the delay type.



Source: TransLink

PART 3:
STUDY CONTEXT

Part 3: Study context

This project focuses on transit in Portland, Oregon, where transit operating costs have risen due to increasing congestion.

Portland is the largest city in Oregon, with 2.5 million people in the Portland metropolitan area, the 25th largest metro area in the United States (United States Census Bureau, 2024). The region's main transit agency is the Tri-County Metropolitan Transportation District of Oregon (TriMet), which operates buses, light rail (named the MAX), a commuter rail line, and a streetcar network (TriMet, 2024a). TriMet's ridership has not fully recovered since the COVID-19 pandemic – ridership in 2023 was 58 million unlinked trips, compared to 97 million in 2019 (TriMet, 2023b). Increasing congestion in Portland has worsened bus speeds and made TriMet's service more expensive to operate. A 2018 report by TriMet and the Portland Bureau of Transportation (PBOT) found that speeds on the five highest ridership lines decreased by 8% between 2009 and 2017 (Portland Bureau of Transportation, 2018).

TriMet and PBOT have launched several programs dedicated to improving bus performance and creating more dedicated spaces on the road for transit vehicles.

In 2018, the city published the Enhanced Transit Corridors (ETC) plan, which presented a methodology for identifying streets that deserved bus priority interventions (Portland Bureau of Transportation, 2018). The ETC plan also proposed a toolbox of specific types of bus priority interventions that could increase speed and reliability (Portland Bureau of Transportation, 2017). Two years later, Portland adopted the Rose Lane Project, where 13 bus lines and two streetcars were identified as meriting enhanced transit treatment (City of Portland, 2022). As of April 2023, 29 projects had been built, 17 had been funded, and a further 18 were being explored (City of Portland, 2023d).

Source: Portland Bureau of Transportation

PART 4:
OVERVIEW OF METHODOLOGY

Part 4: Overview of methodology

This project was divided into two phases: Corridor selection and Concept design. Each of these incorporates quantitative and qualitative methods.

Phase 1: Corridor selection

Used Automated Vehicle Location-Automated Passenger Counter (AVL-APC) data to identify corridors with high levels of delay and passenger demand, and then pick the most appropriate one for detailed study.

Phase 2: Concept design

Examined chosen corridor in detail, conduct site analysis to identify specific bus priority interventions, and predict their expected impact.

This project was split into two phases — Corridor selection and Concept development — each oriented around a different sub-question. The first phase was dedicated to analyzing the entire TriMet bus network to identify specific corridors that merited bus priority. This involved a quantitative analysis of TriMet's AVL-APC data to understand areas with frequent transit delay and high levels of passenger demand. Six corridors stood out after this analysis was completed, and these were then researched to understand the appropriateness of studying each corridor in greater detail. Factors determining appropriateness included the feasibility of changing the corridor, whether TriMet or the PBOT was already studying the corridor, and the equity implications of improving the corridor. The investigators met with TriMet to discuss corridor selection and jointly agreed to study 122nd Avenue between Powell Street and Halsey Street in greater detail, where Bus Route 73 runs.

The next phase entailed developing a concept for bus priority for Route 73 on 122nd Avenue. Bus data in this area was examined in greater detail, to understand where on the corridor delays occurred, and what times of day those delays were highest. This enabled the investigators to develop hypotheses about what challenges the corridor was facing, and what interventions might remedy those. Next, the investigators conducted a site visit of the corridor to examine these hypotheses and deepen their understanding of the area. Following this site visit, recommendations for specific bus priority interventions were made, and further data analysis was conducted to predict the impact of these interventions. The final step was to understand whether these interventions could produce financial savings for TriMet by allowing the agency to reduce the number of buses serving Route 73.

PART 5: CORRIDOR SELECTION

Part 5: Corridor analysis

Analyzing TriMet's bus network enabled the identification of a corridor that was most suited for bus priority interventions.

Scope

This phase entailed an analysis of TriMet's bus network to identify corridors that were good candidates for bus priority. TriMet serves several municipalities, including the cities of Portland, Gresham, Hillsboro, and Beaverton. Given that the Rose Lanes project is run by the City of Portland, this project focused on bus routes that travel at least partially within the Portland city limits. The Portland city limits are the area with the highest transit ridership in the metro region. Although TriMet operates light rail, streetcars, and commuter rail, this project focused exclusively on road segments used by buses. This is because improvements to these road segments cost significantly less than changes to road segments carrying light or heavy rail.

Quantitative analysis methodology

This project first identified corridors that were good candidates for bus priority based on quantitative and qualitative criteria.

Candidate corridors should have many street segments that meet two conditions. First, there must be significant variability in travel times across these segments. Second, a high number of passengers must ride the bus on these segments. This implies that there is a problem to solve and that many people would benefit from the project.

To identify priority road segments, the investigators first identified the segments that each bus travelled on. This would highlight instances of interlining — instances where buses from multiple routes converged onto the same street for part of their trip. Interlining often occurs on streets that connect to a transit hub, such as the Portland Transit Mall. Since multiple bus routes use interlined segments, they are likely to be candidates for bus priority, because they carry many passengers from multiple routes and improvements to interlined segments benefit several bus routes.

To identify interlining, the investigators used the R 'sf' package's st_intersection function to identify where routes intersected. A shapefile of TriMet's bus routes was sourced from an archived General Transit Feed Specification (GTFS) dataset available online. This shapefile had subtle imperfections — instances where real overlaps were not correctly identified due to small deviations in the shapefile. An R script was written to correct these 'false negatives', using the following logic. A Road Segment X_n on Route X was said to intersect with Route Y if:

1. Road Segments X_{n-1} and X_{n+1} intersected with Route Y
2. Road Segment X_n was <200 meters long
3. 80% of Road Segment X_n was within 15 meters of Route Y
4. Route X and Route Y were going in the same direction in this section (e.g., both were travelling east)

This method was tested to ensure that false negatives were correctly identified. After completing this process, the Portland transit network was divided into a series of unique segments, which each carried 1-12 bus routes. These segments generally covered the entire distance between two bus stops.

The next step was to identify which road segments had the most travel time variance.

TriMet's Automated Vehicle Location (AVL) dataset included the actual time that a bus left and arrived at each stop. If a trip had 10 stops (including the first and last stops), it appeared in the AVL dataset 10 times, with one entry for each stop. By subtracting the time a bus left $Stop_N$ from the time it arrived at $Stop_{N+1}$, we calculated the actual travel time in seconds between two bus stops.

These times generated two variation metrics for each segment: Travel Time Coefficient of Variation (CV) and Peak Delay (PD).

When calculating Peak Delay, the difference between the travel time of the 10th percentile (fastest) trip and the 90th percentile (slowest) trip was used, in keeping with TriMet's methodology (Portland Bureau of Transportation, 2018). Where interlining occurred, these metrics were calculated for each route travelling on the segment, and then the average of these figures was taken. If a segment had a high travel time CV or PD, it meant that the bus was frequently delayed between these stops and that there was a large difference between the fastest and slowest travel times. This meant that the road segment connecting these two stops met the first condition for bus priority: high variability in travel times. These metrics were calculated for all trips, as well as three subsets: trips that began during the AM Peak (between 8 and 9AM), Lunch (12 to 1PM) and the PM Peak (4-5PM).

Data was cleaned to ensure accuracy and efficiency. The TriMet dataset ranged from January 2022 to December 2022. To speed up calculation times, only data from October 2022 was used. The dataset was restricted to weekdays, since traffic patterns are materially different on weekends and holidays. Rows that did not have a location were filtered out, as these could not be connected to the road segments. The AVL dataset had a "Pattern Distance" column, which tracked how far the bus travelled between two stops. Where the distance between a given stop pair was ±10% different than the most common distance between that stop pair, entries were discarded. Finally, stops were omitted where the time between stops was less than 6 seconds, or more than 750 seconds. Given that TriMet's stops tend to be 400 meters apart, the lower bound was assumed to reflect faulty data. Extremely long travel times were discarded as these were assumed to be caused by issues other than regular vehicle delay (e.g., mechanical problems, car accidents).

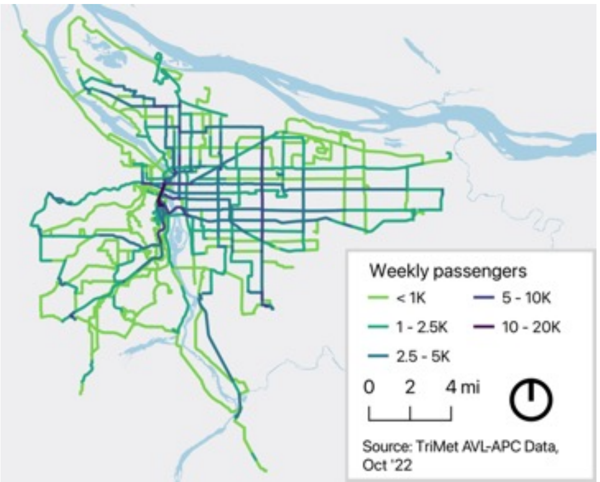
Road segments were classified based on how many passengers they carried. The TriMet dataset contained Automated Passenger Counter (APC) data, which recorded the number of passengers that got on and off at each stop. The APC data allowed the calculation of the number of passengers travelling on each road segment.

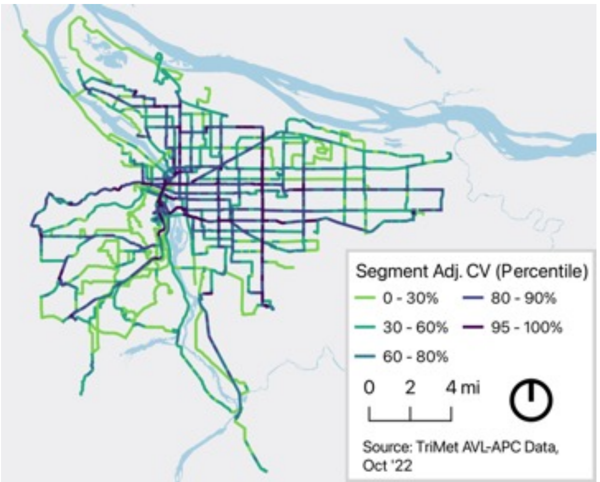
The delay and demand metrics were combined to identify segments that should be prioritized. The delay metrics (CV and PD) were multiplied by the number of passengers on a segment to get passenger adjusted CV and adjusted PD (also known as Person-Hours of Delay). If several routes used a segment, the adjusted CV and adjusted PD were calculated for each route, and these were summed up to get the total adjusted CV and adjusted PD for that segment.

Maps were created to review the distribution of priority segments across Portland.

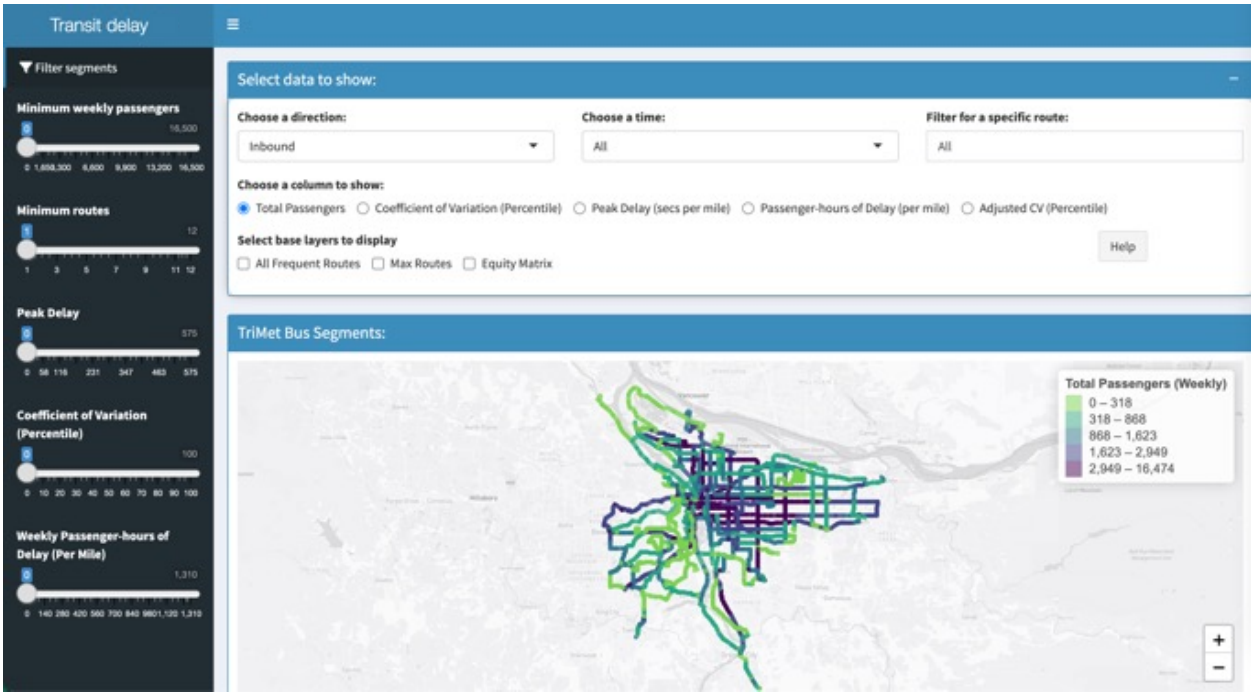
These maps helped identify corridors where several priority segments were located near each other. Maps were produced to show corridors that carried the highest passenger volumes, and had the highest levels of CV, adjusted CV, PD, and adjusted PD. These maps were then assessed to locate groups of priority segments.

Examples of maps created to support corridor selection





A dashboard was built to support this analysis, enabling the creation of interactive maps. The dashboard permitted the investigators to easily filter segments based on different criteria, such as minimum passengers carried or minimum levels of PD. It let the investigators filter between different times of day, inbound versus outbound trips, or specific routes.

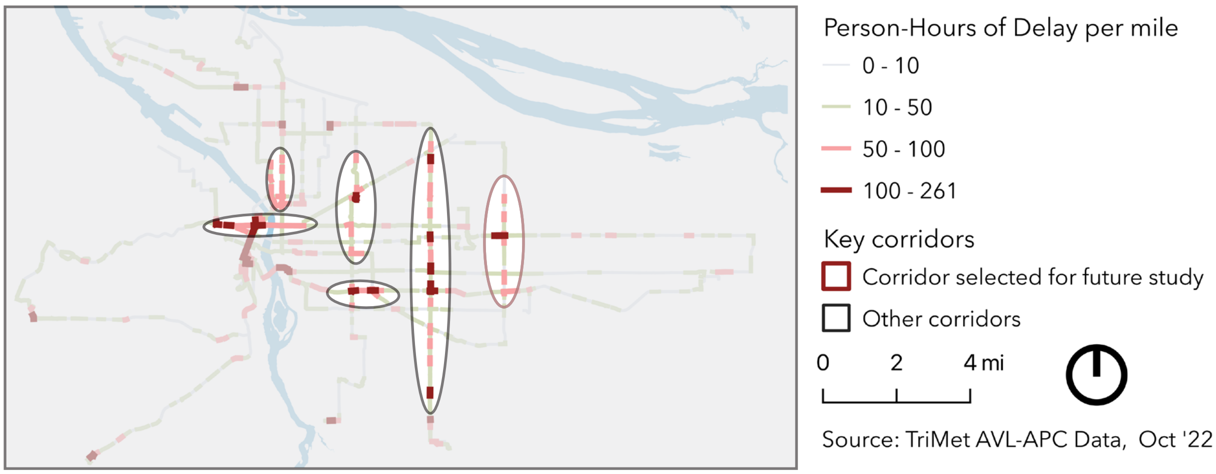


Results of quantitative analysis

This mapping process identified six road corridors with several segments that had high levels of adjusted PD (i.e., Person-Hours of Delay) and adjusted Travel Time CV.

Two were east-west routes – Route 20 on Burnside and Route 9 on Powell – and four north-south – Route 6 on King, Route 75 on 42nd, Route 72 on 82nd, and Route 73 on 122nd.

Corridors identified by quantitative analysis



Corridors (from left to right)	Rte 20: W Burnside & 23rd to E Burnside & 12	Rte 6: King from Killingsworth to Holladay	Rte 9: Powell from Milwaukee to 52nd	Rte 75: 42nd from Freemont to Cesar Chavez & Hawthorne	Rte 72: 82nd from Sandy to Duke	Rte 73: 122nd from Halsey to Powell

Feasibility, usefulness, and equity

These corridors were researched to understand the feasibility, usefulness, and equity impact of implementing bus priority.

This research would help determine which corridor should be selected for future study.

The feasibility analysis focused on jurisdictional or physical challenges to implementing bus priority. Route 9, on Powell, was excluded for these reasons. Powell is owned by the Oregon Department of Transportation (ODOT), which has prioritized travel speed over multi-modal transportation (Oregon Metro, 2019). Powell is narrow at points, which means there is limited space on the street to allocate to buses. Delays are worsened by a rail crossing that can shut down the street for minutes; this could not be mitigated by bus priority (Griggs, 2023). The analysis also excluded Route 6; since a streetcar runs on King, it was deemed to be too challenging to implement bus priority.

The planning context made improving Route 73 more feasible. A transportation plan for 122nd Avenue – the street that carries Route 73 for most of its run – was finalized in January 2024 (Portland Bureau of Transportation, 2024). It recommended safety and active transportation changes, but details on bus priority were limited. The PBOT had received a $20 million grant from the US Department of Transportation's Safe Streets and Roads for All program to make safety improvements on 122nd Avenue (City of Portland, 2023a).

The usefulness analysis investigated whether TriMet or the PBOT had already studied the corridor.

This excluded routes 20 and 82. Route 20 had received a bus lane in Summer 2023 – after the AVL data was recorded but before this study began (City of Portland, 2023c). Route 82nd, which has the highest Person-Hours of Delay in the bus network, is the subject of detailed planning for a BRT-style bus service (City of Portland, 2024a). Due to a desire for this analysis to not be duplicative of existing efforts, Route 82nd was excluded.

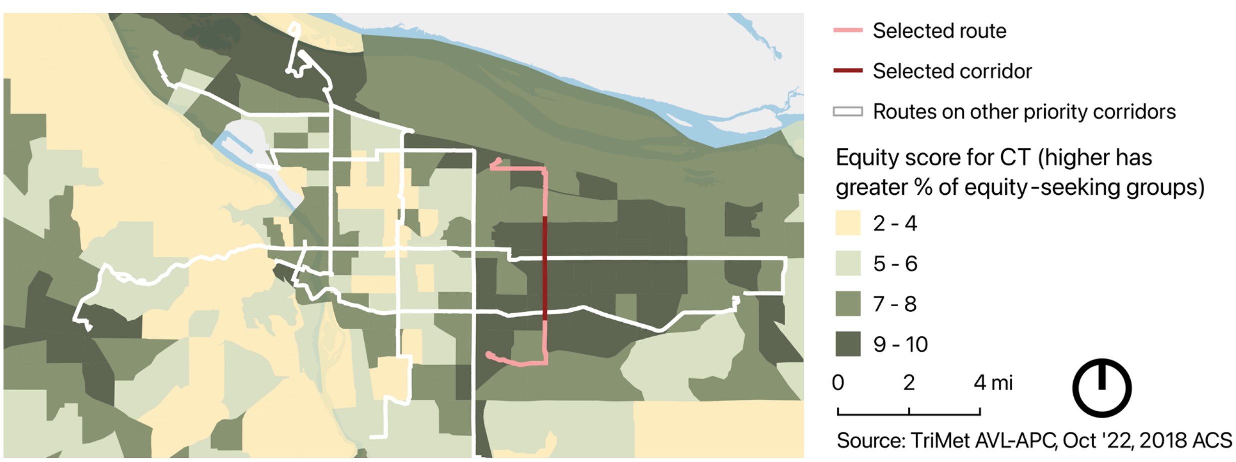
The equity analysis focused on whether the route served areas with high concentrations of equity-seeking groups.

An equity score was calculated for each Census Tract (CT) in TriMet's service area, using a methodology developed by the PBOT (City of Portland, 2024b). The equity index scored CTs from 1-10. It was based on a "race and ethnicity" rating and an "income" rating, which each ranged from 1-5. The race and ethnicity rating was based on the percentage of residents in a CT who self-identified as a person of color or Latinx. Based on this percentage, the Jenks "natural breaks" classification method was used to divide CTs into five clusters. CTs with the highest percentage received a score of 5, while those with the lowest percentage receive a score of 1. The income rating used the same method to group CTs based on their household income. Lower income CTs received higher scores. These two ratings were combined calculate that CT's overall equity score. Following the PBOT's methodology, data from the 2014-2018 American Community Survey was used to calculate these scores. The equity index was overlaid alongside the map of priority routes.

Of the six routes that had been considered, Route 73 served the highest proportion of low-income and racialized neighborhoods.

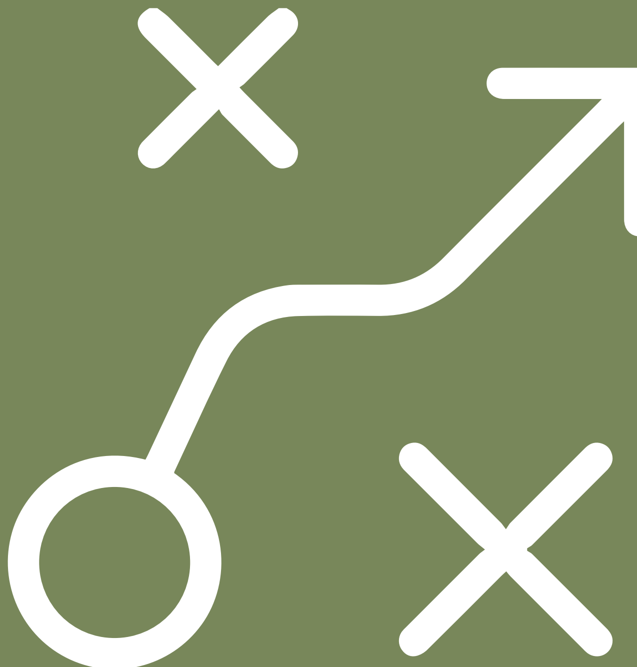
The parts of Route 73 that had the highest levels of Person-Hours of Delay had especially high concentrations of equity-seeking groups.

Priority routes overlaid on top of CT equity scores



This phase's findings were presented to TriMet and it was jointly agreed to spend the next phase developing a concept design for enhanced transit for Route 73rd along 122nd Avenue between SE Powell Street and NE Halsey Street.

PART 6:
CONCEPT DESIGN



Part 6: Concept design

Detailed quantitative and qualitative analysis of the corridor enabled the recommendation of specific bus priority interventions.

Scope

The next phase entailed a detailed analysis of the selected corridor, culminating in a concept design for bus priority on 122nd Avenue. The corridor was researched to understand the planning context. Quantitative analysis was conducted to identify places and times of day with particularly high levels of delay. These areas were then observed in-person, which enabled the recommendation of specific bus priority interventions. The impact of these changes was then quantified to predict the travel time and financial implications of these changes.

Source: Portland Bureau of Transportation

Route description

Route 73 is a north-south that travels through East Portland, connecting the Parkrose/ Sumner Transit Center in North Portland to the Lents Town Center in the south.

Statistic	Value	Rank among frequent routes
Headway[3]	15 minutes from 7AM - 8PM	–
Daily ridership[1]	3,500	13
Rides per revenue hour[1]	16.2	3
Average trip length[2]	41 minutes	16
Trip length – PM Peak[2]	46 minutes	16
Distance[3]	9.3 miles	17

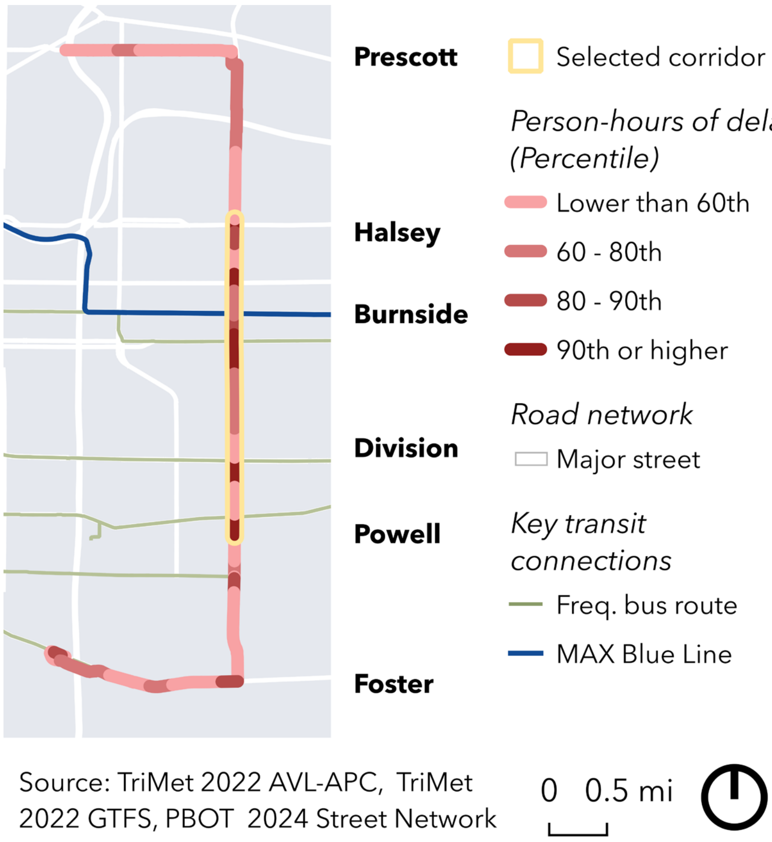
1. As of March 2023; 2. As of October 2022; 3. As of February 2024

Selected corridor

The selected corridor is ~3 miles long, bounded by 122nd and NE Halsey to the north and 122nd and SE Powell to the south.

Due to high passenger volumes and above average delay, most of this corridor ranked in the top 80th percentile by adjusted CV and Person-Hours of Delay. This was especially true where 122nd intersected with major cross streets, including Powell, Stark and Burnside. The corridor connects with several frequent transit lines, including the MAX Blue Line, and the FX2, 9, and 20 bus routes.

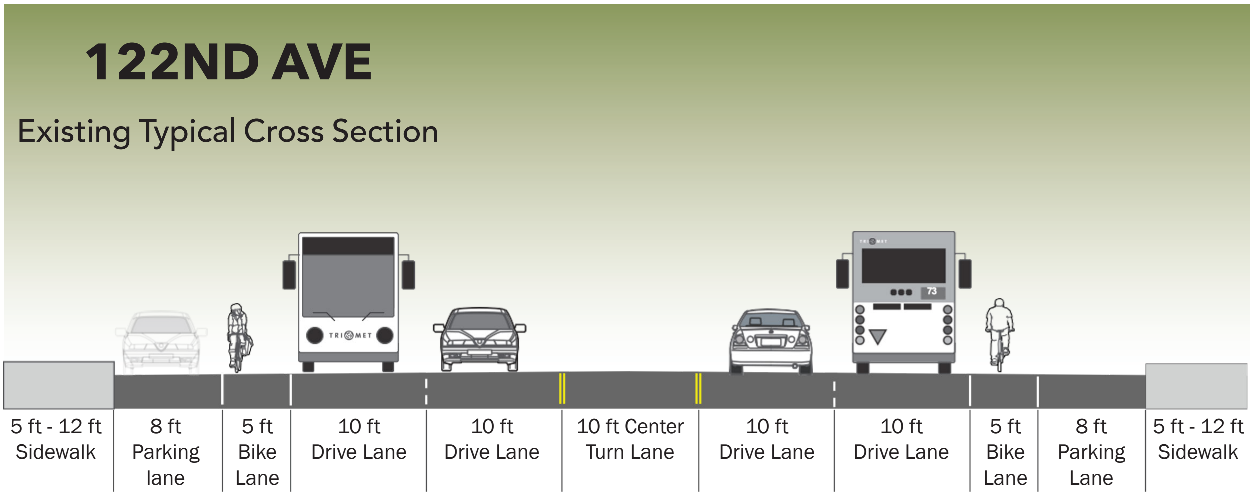
Major points of delay on Route 73



Source: TriMet 2022 AVL-APC, TriMet 2022 GTFS, PBOT 2024 Street Network

Along this corridor, 122nd Avenue is typically 76 feet wide, with 2 parking lanes, 2 unprotected bike lanes, 4 driving lanes, and a center turn lane.

Typical cross section



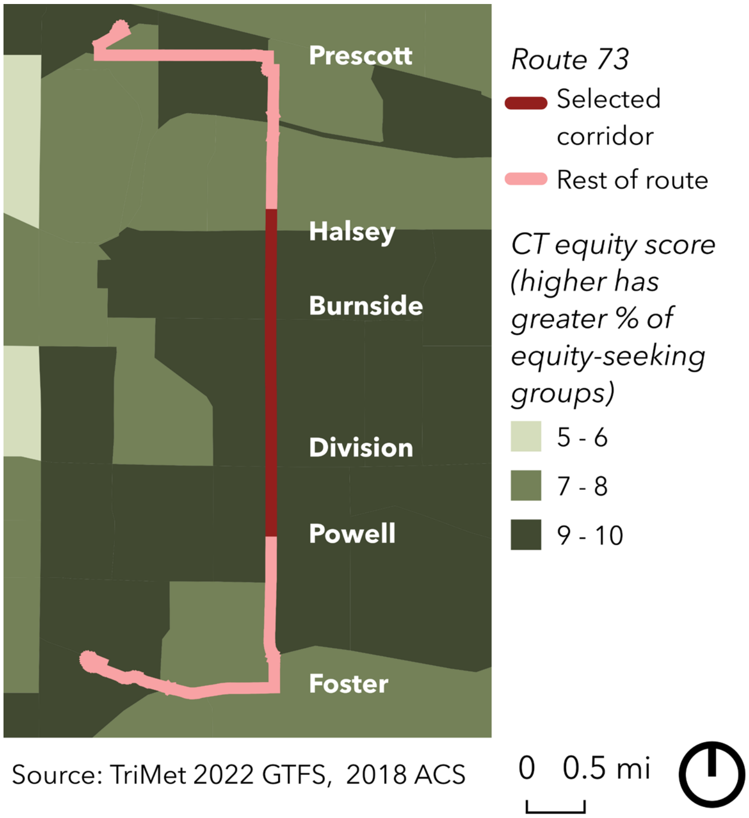
Source: City of Portland

Equity

Route 73 travels through a concentration of lower income and racialized neighborhoods.

This includes Hazelwood, Mill Park, and Powellhurst-Gilbert. 11 out of the 18 Census Tracts that Route 73 travels through had an equity score of 9 (out of 10) or more, based on the PBOT's equity index. The selected corridor is particularly equity serving: all of the census tracts along the corridor had an equity score of 9 or higher. This includes the area around 122nd and Burnside, where the East Portland Safe Rest Village is. The village is one of six low barrier housing developments which provides temporary housing for people experiencing homelessness. (City of Portland, 2024b).

Selected corridor overlaid onto East Portland CTs, colored by equity score



Source: TriMet 2022 GTFS, 2018 ACS

Safe Rest Village on 122nd and Burnside provides low-barrier housing

Source: City of Portland

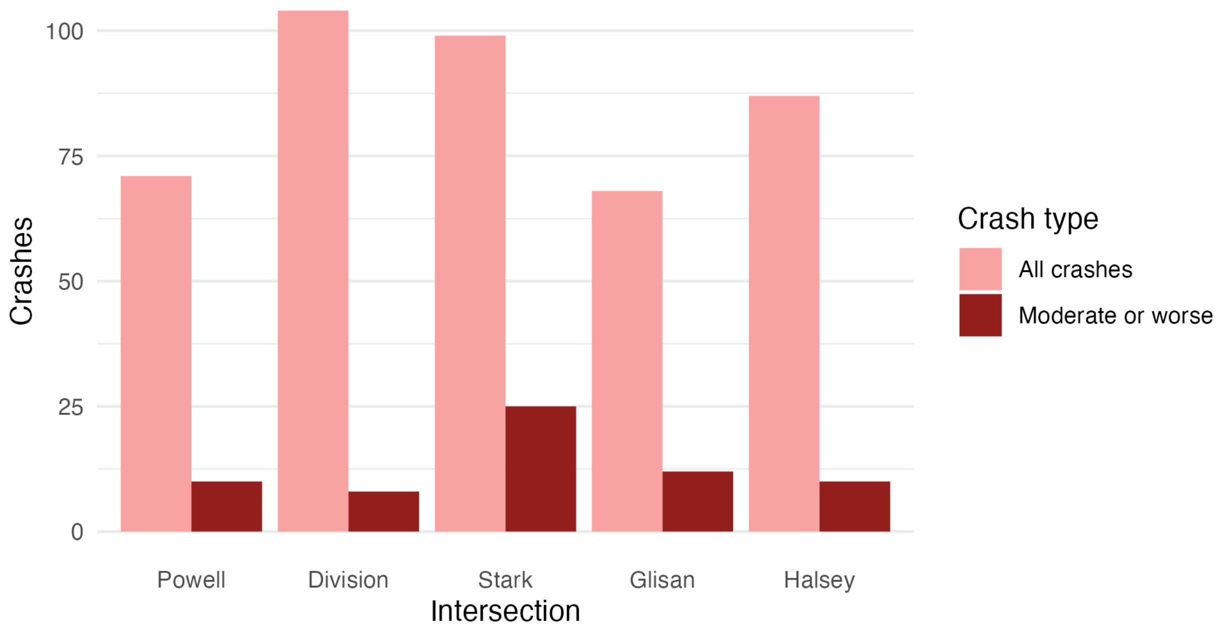
Traffic safety

The corridor is one of the most dangerous streets in Portland.

11 people died in deadly crashes on 122nd Avenue from 2017 to 2021 – the third most out of any street in Portland. SE 122nd Avenue and Stark Street and SE 122nd Avenue and Division Street were identified as the two least safe intersections in Portland by the PBOT, based on the high number of collisions (City of Portland, 2024c). The speed limit on the corridor is 30 miles per hour, but many drivers go more than 10 miles per hour over the speed limit (Portland Bureau of Transportation, 2024). Key culprits include poor lighting, auto-oriented business, and a lack of separation between cars and active travelers.

Source: City of Portland

Number of crashes from 2017-2021 at high crash intersections located on corridor



Source: City of Portland, Vision Zero

Current land-use

The areas bordering this corridor range from single-family homes to sprawling commercial businesses.

The south, between Powell Street and Division Street, consists of light commercial activities and small-scale dwellings. North of Division Street are several blocks of dense low-rise apartment complexes. Beyond this, the corridor has a number of large businesses with significant off-street parking, This includes many auto-oriented businesses, including five car dealerships.

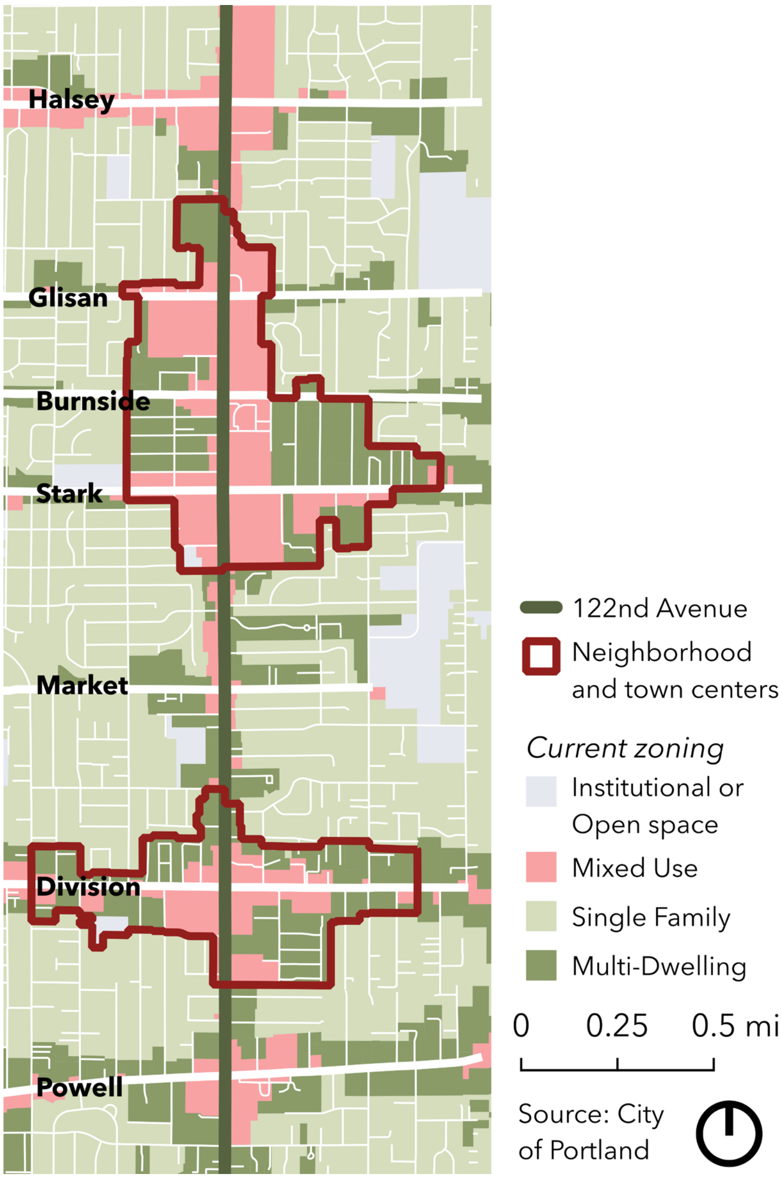
Future plans

Recent planning changes aim to densify 122nd Avenue and make it less car-oriented.

The City of Portland listed 122nd Avenue as a Civic Corridor as part of the City's 2035 Comprehensive Plan (City of Portland, 2023b). These corridors are intended to be "distinctive places that are models of ecological urban design, with transit-supportive densities of housing and employment, prominent street trees and other green features, and high-quality transit service and pedestrian and bicycle facilities."

In addition, the sections where 122nd Avenue crosses Burnside Street and Division Street have been designated as town and neighborhood centers, respectively, in Portland's 2035 Comprehensive Plan (City of Portland, 2023b). These areas were designated as pedestrian districts. These two distinctions indicate that the city intends these areas to grow into dense, mixed-use neighbourhoods with high levels of active mode share.

Zoning map of the corridor



Source: City of Portland

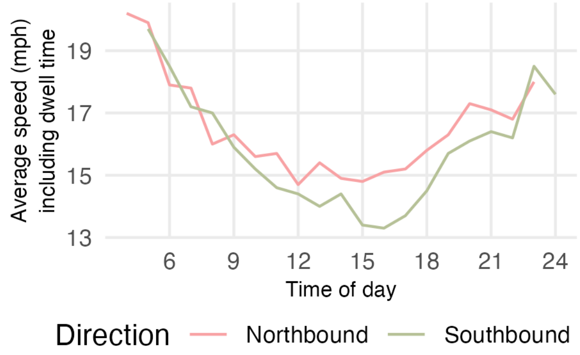
Quantitative analysis of corridor

Summary statistics

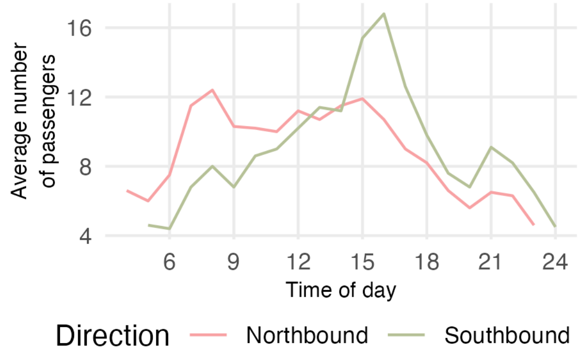
AVL-APC data for the corridor was analyzed in detail to understand how speed, reliability, and passenger demand varied spatially and temporally.

These analyses were conducted to allow the investigators to identify which parts of the corridor merited the most in-depth observation, and when these places should be observed. The analyses helped the team develop hypotheses about what types of BPIs would be most appropriate. As the two charts to the right indicate, speed challenges and passenger volumes were highest during the PM peak (from 3-6 PM), particularly southbound. The table below supplements these charts with additional summary statistics related to on time performance and person-hours-of-delay. It shows what time of day the minimum/maximum figures (e.g., minimum speed) occur.

Average speed by time of day



Average passengers by time of day



Key summary statistics for corridor

Category	North-bound	Northbound time	South-bound	Southbound time
Mean passenger load	9.4		9.4	
Max passenger load	12.4	8AM	16.8	4PM
Mean speed (mph)	16.2		15.5	
Min speed (mph)	14.7	12PM	13.3	4PM
On time performance (%)	78%		75%	
Min on time performance (%)	68%	1PM	57%	4PM
Daily person-hours-of-delay	51		56	

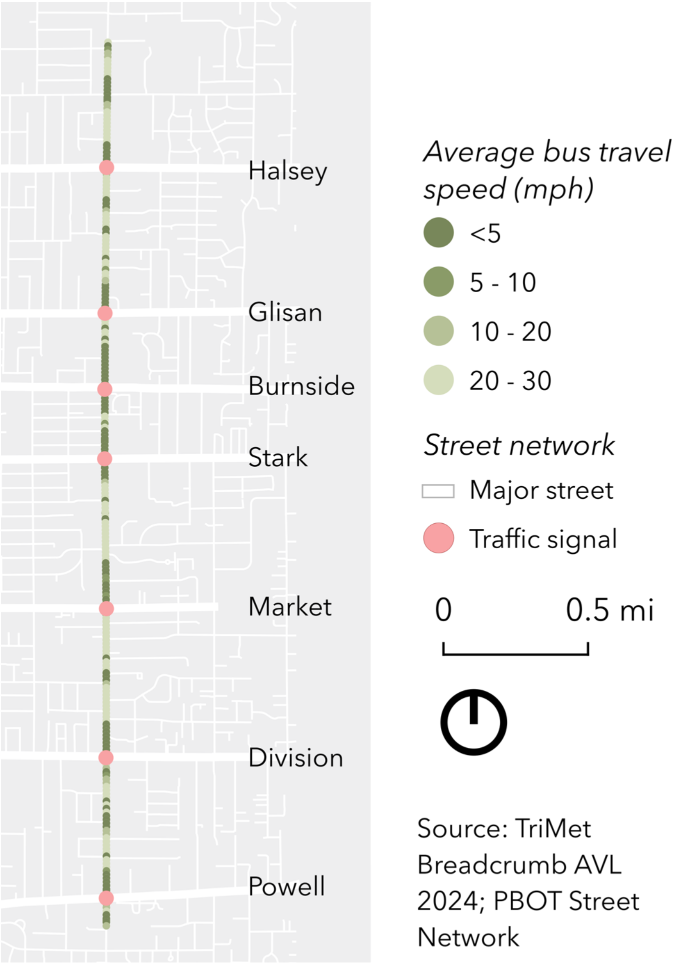
In-depth speed analysis

Breadcrumb AVL data was used to understand where exactly delays occurred along the corridor.

Breadcrumb data provides the location of a given bus every five seconds, the bus's speed, and the date and time of the observation. This allowed the investigators to triangulate the parts of the corridor where buses traveled especially slowly, and then visualize these areas. The map to the right shows the results of this analysis.

Delay was mostly concentrated before major intersections, where traffic backed up while waiting for the light to turn green. Delay between intersections was minimal, outside of the stretch between Stark Street and Glisan Street.

Bus travel speed southbound at PM peak



Source: TriMet Breadcrumb AVL 2024; PBOT Street Network

Source: Portland Bureau of Transportation

Regression models

Delays can occur both when a bus is travelling between stops and at stops themselves. To investigate this in greater detail, two simple regression models were developed to model run-time as well as dwell time. The run-model predicted travel-time between stops (in seconds, including dwell time). A similar exercise was conducted to predict dwell time at stops: the dependent variable was time spent at a given stop (Arrive time - Leave time). To isolate problematic intersections, dummy variables for the six most prominent intersections were included. The run-time model showed that travel was slowest on segments that crossed Burnside, Stark, and Powell. The stop-time model highlighted that two intersections, Powell and Burnside, had disproportionately long dwell times. This may have been due to those intersections having near-side stops (in one direction).

Results from 2 regression models

		1.Run-time model		2. Stop-time model	
	Term	**Coef.**	**P-value**	**Coef.**	**P-value**
	(Intercept)	-1.2	0.04	3.1	<0.001
	Northbound	-1.8	<0.001	0.0	0.91
	PM Peak	3.9	<0.001	-0.9	<0.001
	Nearside stop	0.5	0.16	0.8	<0.001
	Signal on segment	4.9	<0.001	-	-
	Segment length (miles)	161.4	<0.001	-	-
Dwell information	Stop occurred	7.1	<0.001	-	-
	# of Ons	7.2	<0.001	5.6	<0.001
	# of Offs	1.7	<0.001	2.7	<0.001
	Ramp deployment	32.3	<0.001	32.1	<0.001
Intersection dummies	Powell	30.2	<0.001	15.0	<0.001
	Burnside	33.1	<0.001	8.6	<0.001
	Division	24.3	<0.001	-0.6	0.07
	Stark	33.9	<0.001	1.2	<0.001
	Glisan	28.3	<0.001	1.1	<0.001
	Halsey	23.9	<0.001	0.5	0.18
R^2		0.568		0.514	

Implications of Quantitative Analysis

These quantitative analyses helped focus the on-site observations by influencing their timing, location, and the questions to answer.

Based on their results, visits would need to be conducted between 3-6 PM and focus on the six major intersections. Second, they implied that certain types of interventions could be more appropriate. Since delay was concentrated at intersections, queue jumps that targeted the area directly before an intersection might be more helpful than a dedicated bus lane across the entire corridor. The particularly poor performance of Powell and Burnside in the Stop-time model implied that a far-side relocation could be helpful. Last, some of the stop-time model's coefficients would be useful for later efforts to quantify changes.

Source: Portland Bureau of Transportation

Site analysis

Description

During the first week of March 2024, two site visits were conducted.

These site visits were conducted with three objectives. First, the investigators sought to build an understanding of what it “feels” like to move along the corridor as a pedestrian or transit user. Second, the investigators sought to clarify how the corridor was currently used, including by developing a general understanding of mode share and movement patterns (e.g., speeds, turning behavior). Last the investigators sought to get insight into the factors that created intersection delay, including traffic queue lengths, turn volumes, and traffic signals. Each of these factors could help clarify which sorts of bus priority interventions would be most appropriate. Both site visits were conducted during the PM peak, and lasted three to four hours each. The site visits consisted of walking the entire corridor, riding Route 73 northbound and southbound, and observing key intersections. Photos and videos were taken of the corridor, but no interviews were conducted.

Delay findings

The site visits served to confirm many of the hypotheses that came out of the previous phase of quantitative analysis. Delays were concentrated at intersections, with traffic moving at relatively free flow speeds between intersections. Delay was most significant at near-side stops located directly before signalized intersections, such as Burnside Street (northbound) and Powell Street (southbound). At both of these intersections, triple stopping behavior — where the bus stopped to wait in traffic, then stopped to pick up passengers, then stopped at the red light — was observed multiple times. Besides Division Street and SE 122nd Avenue (where vehicles can only turn right during green phases), few right-turn queues were observed, with right-turning vehicles able to travel through intersections by turning right at red lights or during designated right-turn phases. Across 122nd Avenue, buses that had pulled over to pick up passengers faced challenges merging back into the drive lane. This was particularly the case on far-side bus stops located after intersections with significant turn volumes onto 122nd. For example, the southbound stop located on 122nd and Division appeared to have significant pull-out delays, because the bus had to wait for the high number of vehicles turning from Division onto 122nd to clear out before it could merge into traffic. Last, it was notable that protected left-turn phases tended to occur before the regular green phase on 122nd. This meant that a bus waiting at a red light often needed to wait an extra 30 seconds for left-turning vehicles before it could enter the intersection.

Source: Portland Bureau of Transportation

Pedestrian and cyclist experience

Site visits revealed intangible parts of the pedestrian and cyclist experience on 122nd.

While these challenges were less relevant to the performance of the transit system, they did inform the broader context in which Route 73 operates. Resolving them would be critical to making 122nd Avenue more amenable to multi-modal users. Despite the visit occurring in early March, the corridor felt remarkably warm. 122nd is a textbook urban heat island, with limited green space, an abundance of asphalt, swaths of off-street parking, and high car volumes. The street felt noticeably hotter than other parts of the city, and one would expect that it would be quite unpleasant to walk or bike on in the summer. The pedestrian experience is limited by some narrow sidewalks, which can be as narrow as seven feet (the old County standard) (Portland Bureau of Transportation, 2024). Cycling activity was very minimal along the corridor – fewer than 10 cyclists were observed across the two site visits. Though a bike lane exists on both sides of 122nd, it is quite narrow (five feet, versus the recommended standard of six feet (National Association of City Transportation Officials, 2016), and offers no physical protection. The bike lane “dissolves” into the right turn lane at all intersections, further worsening the cycling experience.

Vehicle behavior further undermines active transportation users.

Speeding is common on 122nd. The speed limit was recently changed from 35 mph to 30 mph, but many drivers travel at speeds that exceed the speed limit by more than 10 mph (Portland Bureau of Transportation, 2024). Though the drive lanes are relatively narrow (10 feet wide), the presence of the unused bike lanes and a continuous center turn lane mean that the drive lanes feel far wider, facilitating speeding. It was common for vehicles in the rightmost drive lane to edge into the bike lane to give themselves a greater margin away from the cars in the other drive lane, and thus be able to drive even faster (see below). There are many driveways and business access lanes fronting onto 122nd. Cars can turn left into these passages at most points on 122nd, and do not always pay attention to pedestrian or cyclist traffic when doing so. Amidst all this competition for space, almost all of the corridor has an eight-foot parking lane in each direction. Due to the high amount of alternative parking options — most businesses have off-street parking and there is ample parking on side streets — this on-street parking is rarely used. While resolving active transportation challenges is not specifically in scope for this project, doing so would likely improve transit ridership, by making it easier for individuals to travel along 122nd without a car.

Cars hug the cycle lane, using extra space to drive at faster speeds

Source: Google Streetview

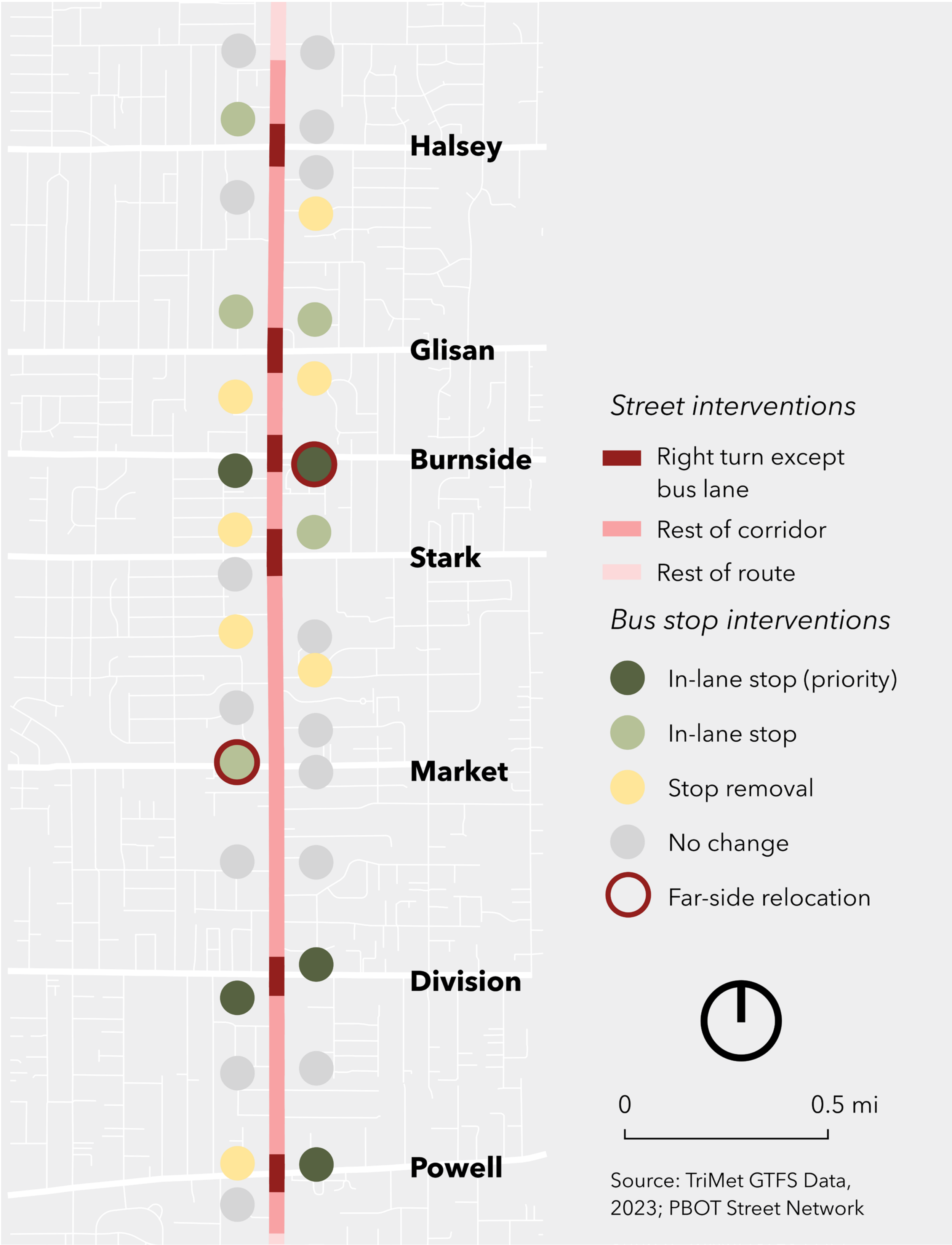
Ensuing recommendations

Based on the quantitative data analysis and the on-site observations, five bus priority interventions were identified: right-turn except bus lanes; signal priority; in-lane stops; relocation of near-side stops to far-side; and stop consolidation.

These interventions focus on reducing either intersection or stop delay, by allowing buses to clear intersections and stops more rapidly. With the exception of stop consolidation, interventions were focused on the six major intersections, and the stops serving them. As the map on the next page shows, the interventions are distributed across the corridor.

Delay type	Intervention	Rationale	Where to implement
Intersection delay	*Right-turn except bus lanes*	Allows bus to cut in front of waiting traffic	6 major intersections
	Transit signal priority	Increases likelihood will have green signal	All signalized intersections
Stop delay	*In-lane stops*	Eliminates "pull out delay"	Division, Burnside (both directions), Market southbound, Powell northbound
	Far-side relocation	Reduces risk of triple stopping	Burnside northbound, Market southbound
	Stop consolidation	Eliminates stops with highly variable stop times	3 northbound stops and 4 southbound stops

Recommended interventions



Prioritization and quantification

AVL-APC data and the coefficients generated by the regression models were used to predict the impact of different interventions.

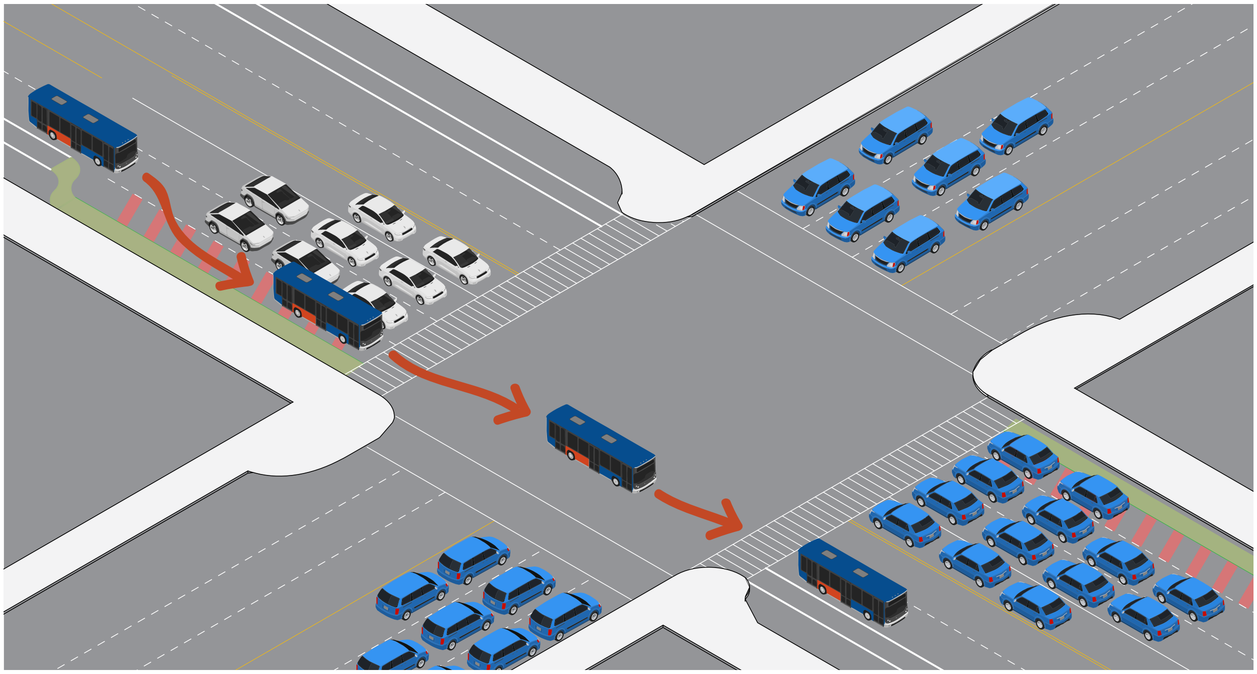
This could help planners prioritize specific interventions and determine where on the corridor they should be implemented first. The predictions could shed light into what savings can be expected from different BPIs.

Right-turn except bus lanes

Right-turn except bus lanes act as queue jumps that allow transit vehicles to use the right-turn lane to get to the front of the traffic queue.

These lanes are recommended to be installed on either side of the six intersections with the most intersection delay (Powell, Division, Burnside, Stark, Glisan, and Halsey). This intervention would have the effect of always ensuring that transit vehicles end up at the front of the queue, rather than having to wait at the red light behind other vehicles. To predict the impact of this intervention, Breadcrumb AVL data were used to calculate the travel time to the next stop under two different scenarios: when the bus stopped at a given intersection at the front of the queue, versus when the bus stopped at the back of the queue. This time savings was then multiplied by the percentage of time that a bus ended up stopped at the back of the queue at a given intersection, which represented how often this intervention would be useful. This intervention would be expected to save 14 seconds northbound and 18 seconds southbound. Savings are expected to be 0 seconds at Powell (southbound) and Burnside (northbound) currently, because those stops are located directly before their respective intersections, and so the bus typically arrives at the front of the queue after picking up passengers. If these stops were to be relocated to the far-side (as recommended later), implementing right-turn except bus lanes would be recommended at these two locations.

Possible right-turn except bus lane orientation



Next generation TSP

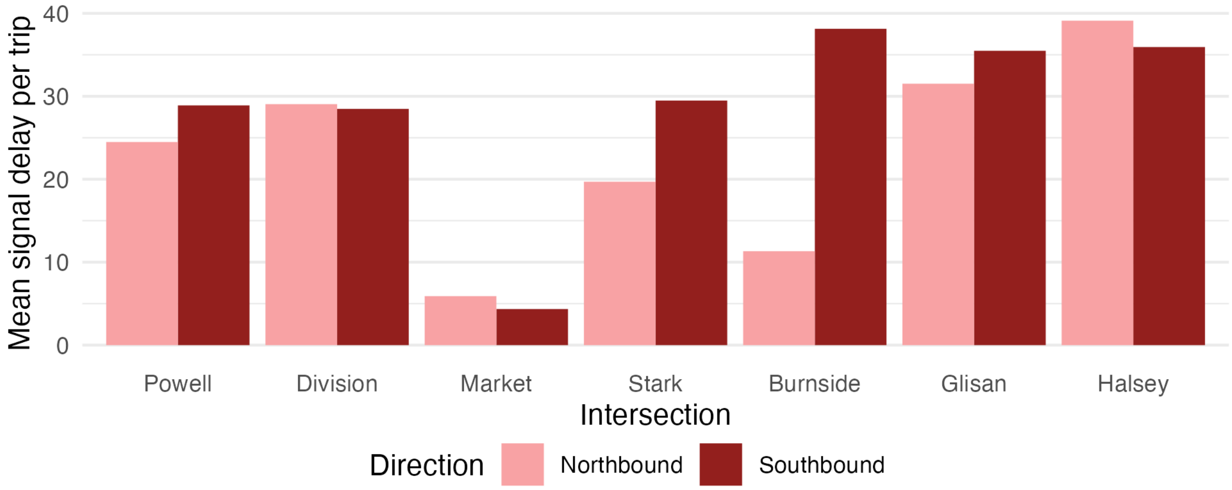
Next-gen TSP has paid dividends for the FX2 route, and could create impact on 122nd.

Signalized intersections on 122nd Avenue are already equipped with first generation TSP, whose impact has been mixed (Kimpel et al., 2005). In 2022, TriMet began using “next generation TSP” on the FX2 bus route. This adjusts signal timing to increase the likelihood that the signal will be green at the point that the bus arrives at the intersection. If the bus must stop at an intersection, the signal is able to provide it with an advance green phase at three opportunities throughout the traffic light cycle. This gives the bus a brief head start on the rest of traffic and allows it to clear the intersection after the shortest possible wait.

The new TSP system has reduced signal delay on the FX2 bus route, decreasing average red light waiting time by 82% (Menard, 2024). TSP has been most impactful in East Portland, where the FX route travels along Division Street on a road configuration that is very similar to 122nd Avenue (i.e., 5 car lanes, and an additional right-turn lane at intersections) (Keeling et al., 2023).

This project sought to quantify the travel time savings of implementing this new TSP system on 122nd Avenue. The 82% reduction in intersection delay achieved for the FX project was assumed for five of the seven signalized intersections on our corridor. At the other two signalized intersections – 122nd and Burnside and 122nd and Division — a 41% reduction was assumed. This lower reduction — half of what was achieved by the FX project – accounted for the fact that Burnside and Division both have major transit lines running on them, the MAX Blue Line and the FX2 bus route. In the case where Route 73 arrived at these intersections at the same time as a MAX or FX2 vehicle, Route 73 would likely not be prioritized (given that the average Route 73 bus carries fewer passengers than a MAX train or FX2 bus). As such, TSP would be less impactful at these intersections. It would likely still generate modest benefits, however, in part by facilitating bus-only phases (Koonce & Haines, 2024). As the table below shows, achieving these results would lead to expected savings of 122 seconds northbound and 140 seconds southbound during the PM peak.

Where was signal delay the highest on the corridor?



Far-side relocation:

Two stops at major intersections (Powell southbound and Burnside northbound) are located on the near-side, immediately before the intersection.

At both stops, triple stopping was observed multiple times. Powell southbound is recommended for removal (as there is a stop on the other side of the intersection), while Burnside is recommended for relocation to the far-side. The stop at Market Street southbound is recommended for relocation, as significant pull-out delays were observed there (see next section). Time savings from these changes are not calculated, as it is challenging to isolate their impact. Instead, implementing far-side stops is considered to be an enabling condition that is necessary for unlocking other benefits listed in this section.

Curb extension in-lane bus stop

In-lane stops allow buses to service a stop in the drive lane, rather than the parking lane.

This saves time because the bus no longer needs to wait for a gap in traffic before merging into the drive lane.

To predict the intervention's impact, Breadcrumb AVL data is used to calculate the difference between the amount of time that a bus was present at the bus stop and the amount of time that the bus door was open. This difference is inferred to be "pull-out delay" — time that the bus waited to re-enter traffic. Extreme values, where the difference was below the 5th percentile or above the 95th percentile, were excluded. To get the expected savings, pull-out delay was multiplied by the percentage of time that a bus serviced a given bus stop. Of the top 10 stops with the highest expected savings, the four supporting Division and Burnside streets are prioritized. These are located in the areas with the most pedestrian and cycling volumes, and have potential for more activity, given planned densification. One of these, Burnside northbound, is located at the near-side of the intersection, and recommended to be relocated to the far-side (where an in-lane stop would be located).

Stops with highest pull-out delay

Location	Direction	Delay	Position	Comments
Powell	Northbound	6.1	Far-side	High priority
	Southbound	5.1	Nearside	Recommended for removal
Division	Northbound	6.4	Far-side	High priority
	Southbound	4.8	Nearside	High priority
Market	Southbound	6.7	Nearside	High priority
Stark	Northbound	4.6	Far-side	
Burnside	Northbound	8.2	Nearside	High priority after far-side relocation
	Southbound	5.1	Far-side	High priority
Glisan	Southbound	5.4	Nearside	
Halsey	Southbound	4.8	Nearside	

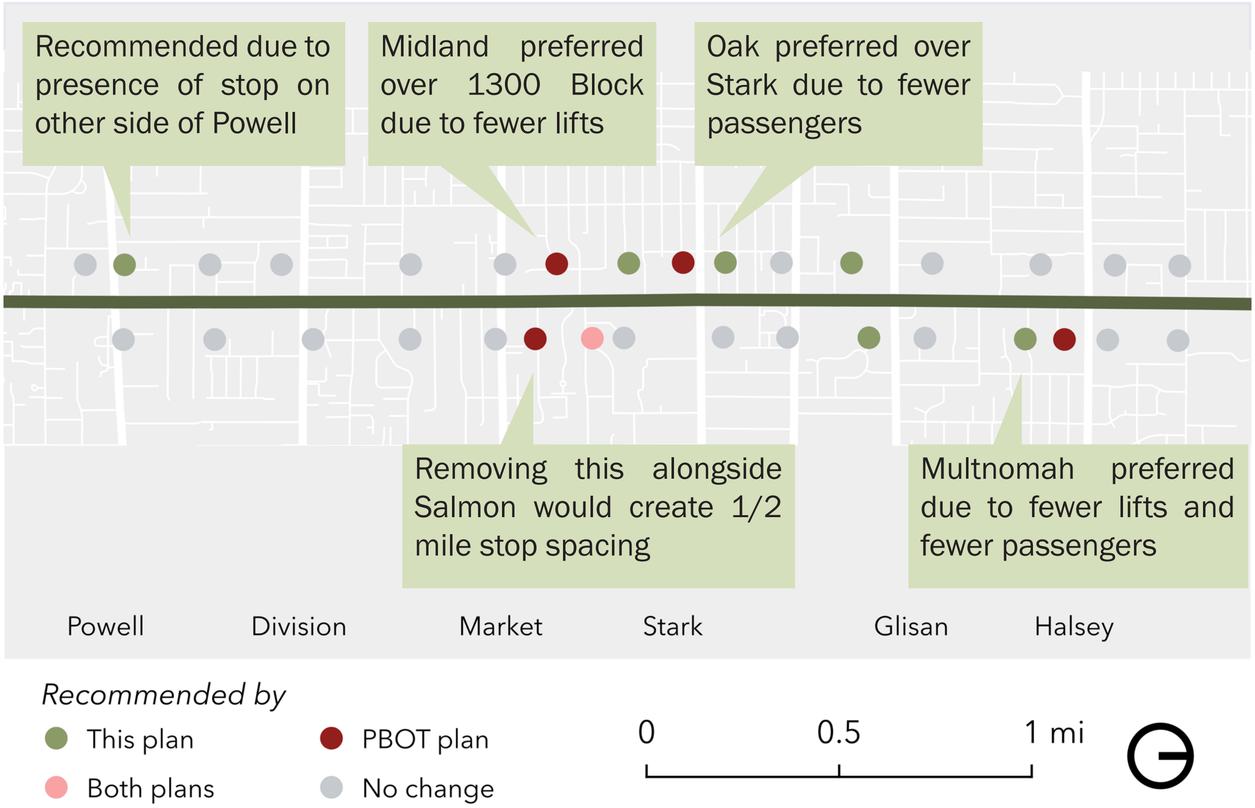
Stop consolidation

Seven stops are recommended for removal due to low passenger activity, tight stop spacing, and infrequent ramp deployments.

These stops were identified using El-Geneidy and Stewart's methodology, which suggests that stops should be removed if they meet several conditions (Stewart & El-Geneidy, 2016). First, they should have low "passenger quality", defined as having high variability in the number of passengers using the stop, and a low total number of passengers using them. These stops are relatively unimportant to the route's passengers, but their high variability means that they can cause significant reliability challenges. Passenger quality is calculated by dividing the mean number of passengers using a stop by the stop's dwell time coefficient of variation (CV). Second, the stop should have a low number of lift deployments. Bus lifts are deployed when passengers with mobility impairments (e.g., wheelchairs) are boarding or alighting from a bus. Thus, they are a good proxy for bus stops that serve high numbers of individuals who would struggle to walk to another bus stop if this one was removed. Third, removed stops should not offer nearby connections to the MAX or frequent service bus network, given that these stops facilitate transit connections. Last, stops should only be removed if they can be eliminated without creating stop spacing over 0.33 miles.

The below map shows the stops recommended for removal as well as the five stops recommended for removal by the PBOT's 122nd Avenue Plan (Portland Bureau of Transportation, 2024). The comments indicate why alternatives are suggested for four of the PBOT's recommendations. More detail is located in the appendix.

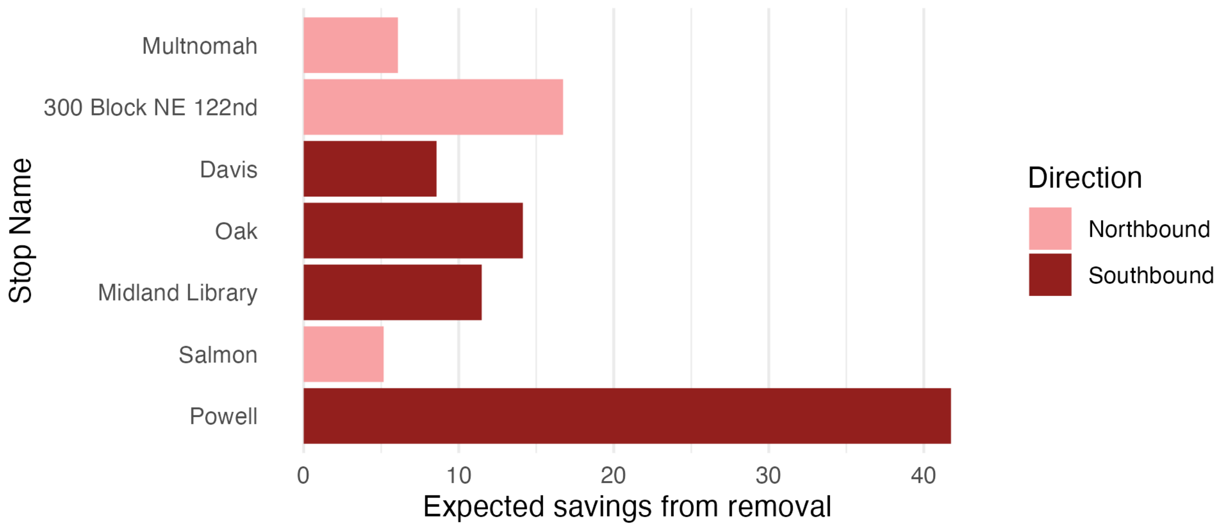
Stops recommended for removal



Quantifying the impact of removing these stops required a four-step process.

1. For each Stop N, the average travel time between Stop N-1 and Stop N+1 was found when the bus did stop at Stop N and when the bus did not stop at Stop N.
2. This difference was then adjusted for the fact that passengers boarding and alighting at Stop N would likely board at either Stop N-1 or Stop N+1. This passenger activity time needed to be accounted for. To calculate this time, the average number of boarding passengers at Stop N was multiplied by 5.6, the mean number of alighting passengers was multiplied by 2.6, and the mean number of lift deployments was multiplied by 32. These coefficients were sourced from the stop-time model.
3. The passenger activity time calculated in step 2 was subtracted from the time difference calculated in step 1 to get the time savings.
4. These time savings were then multiplied by the percentage of time that a bus stop occurs.

Stop savings



Summary of savings

If these savings were added up, time savings of up to 3.1 minutes southbound and 4.4 minutes northbound would be achieved during the PM peak. This would reduce travel times on the corridor by 20%. However, if all interventions were implemented, some of localized time savings might be lost, because the different interventions would affect each other's relative impact (Koonce et al., 2006).

Intervention	Exp. savings
Right-turn except bus lanes	0.5 minutes
Next-gen TSP	4.2 minutes
In-lane stops	1.1 minutes
Stop consolidation	1.8 minutes
Total	**7.5 minutes**

Potential for financial savings

Beyond improving the passenger experience, these interventions have the potential to reduce TriMet's operating costs.

This is true if the time savings let TriMet reduce the number of buses needed to service Route 73. Presently, a round-trip cycle during the PM peak lasts 121 minutes. On average, 93 of those minutes are used for travel, while 28 minutes are "recovery time", when the bus waits at the bus depot. Recovery time lets drivers rest and provides padding to reduce the risk that delays on one trip cause delays on future trips.

The number of buses required to service a route equals the round-trip cycle-time (including recovery) divided by the headway. Since Route 73 has 15-minute headways, it requires 8 buses to service the route during the PM peak. To service the route with 7 buses, the round-trip cycle-time would need to decrease by 16 minutes, to 105 minutes. This analysis found that bus priority interventions could reduce travel times by 7.5 minutes. **Thus, to achieve a 105-minute round-trip cycle time, recovery times would need to be reduced by 8.5 minutes.**

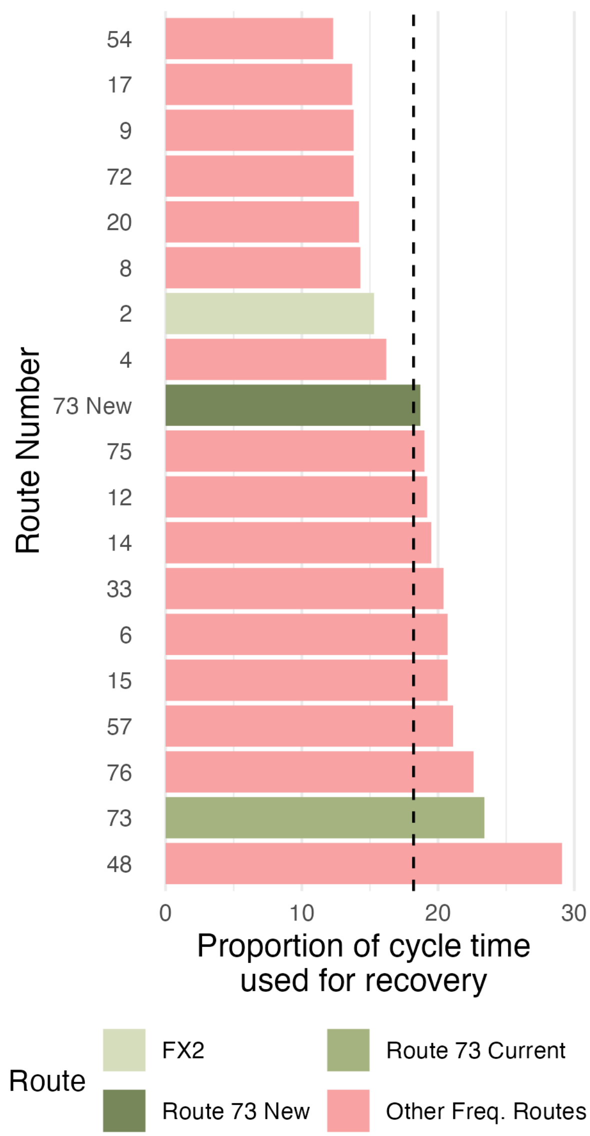
To determine whether this reduction was justifiable, the proportion of cycle time used for recovery was calculated for Route 73, as well as the other frequent service routes. For example, Route 73's recovery proportion was 28 minutes / 121 minutes = 24%. This was higher than the average frequent service route, which had a layover proportion of 18%. This implies that layovers were disproportionately high on Route 73.

Reducing recovery time from 28 minutes to 20 minutes would achieve a round-trip cycle time of 105 minutes, while still maintaining a recovery time proportion of 19%.

Shorter recovery periods would in some ways be more justifiable on routes with bus priority interventions, because these interventions should reduce travel time variability (on top of creating travel time savings). The impact on operators could be lessened by the fact that these reduced recovery periods could be restricted to peak times.

The below chart shows the proportion of cycle time dedicated to recovery currently, and under this reduced-recovery scenario.

Frequent service routes, organized by proportion of time used for recovery



There are some reasons why reducing recovery periods by this much might not be feasible.

This reduction would lead to a mean recovery period of 10 minutes, which would be the third lowest recovery time of all frequent service routes. In addition, Route 73 is not a particularly popular route to drive, and so in the context of TriMet's operator shortage, cutting layovers may not be tolerated by operators (Iler, 2021). Thus, while some reduction in layover time is likely justifiable, a reduction of 8.5 minutes might not be.

If recovery could not be sufficiently reduced, TriMet would need to find additional time savings to achieve a round-trip cycle time of 105 minutes.

This could include implementing TSP further along 122nd Avenue, such as at Holgate Street and Foster Street.

This might be financially justifiable, since going from eight to seven buses on this route during peak times would represent significant financial savings. Assuming an operating cost of $200 per hour, eliminating one bus three hours a day would save 150,000 a year. It is possible that these interventions could allow for the removal of buses during off-peak times, increasing savings even more. The impact of these interventions on off-peak travel was not investigated by this project.

Source: Don Iler

Assuming an operating cost of $200 per vehicle hour, saving one bus from 3-6PM during weekdays could generate $150,000 per year.

	Per hour	Per day	Per week	Per year
Expected savings ($)	$200	$600	$3,000	$150,000

PART 7: CONCLUSION

Conclusion

Detailed quantitative and qualitative analysis of the corridor enabled the recommendation of specific bus priority interventions.

This project used mixed methods to identify a corridor, recommend specific bus priority interventions, and predict their impact.

First, a high-level quantitative analysis was conducted of the TriMet bus network to identify segments with high delay and passenger demand. Six corridors had groupings of segments that fit this category, and after discussions with TriMet, Route 73 was selected because of feasibility, usefulness, and equity considerations. Route 73 was then analyzed in greater detail to identify where and when delays were most prominent. A site visit was conducted in March 2024 to help confirm which interventions were most appropriate and to gain more insight into how it felt to be a non-car user on 122nd Avenue. Finally, analysis of Breadcrumb AVL data was conducted to predict the impact of specific interventions.

Five types of changes were recommended, with these interventions potentially leading to 7.5 minutes of savings during the PM peak.

Most of the savings came from transit signal priority and stop consolidation. These interventions would be distributed across the corridor, and would reduce intersection and stop delay. If these savings were coupled with a reduction in recovery times to a level that was in-line with what was used elsewhere on the network, TriMet could potentially lower the number of buses servicing Route 73 during PM peak from eight to seven. This would save $150,000 a year.

This project demonstrated a methodology for how bus data can support bus priority projects.

AVL-APC data could be used both to identify corridors for improvement, diagnose problems within street segments, and predict the impact of specific interventions. This is important, because the outputs of these analyses could allow agencies to better prioritize their efforts on the corridors that most merit bus priority and then develop precise, data-supported business cases. AVL-APC data could be used on the back end to measure the impact that specific changes have created and learn lessons for future projects.

Next steps

Several steps are required to progress this project further.

These time savings could be paired with PBOT cost estimates to understand the costs linked to different interventions. These could be paired with the expected savings to determine the payback period for this project. Detailed design work would be required to implement particular interventions. These include the length of the right turn except bus lanes, the design of curb extensions, and the scenarios in which transit signal priority would be used.

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Photo references

TriMet photos were sourced from flickr (https://www.flickr.com/photos/trimet/albums/) and the TriMet website (https://trimet.org/photos/).

Photos from the City of Portland and the Portland Bureau of Transportation were sourced from various webpages maintained by the City of Portland and the 122nd Avenue Plan.

One infographic is adapted from the Portland Bureau of Transportatoin's Enhanced Transit Corridor's plan.

One infographic is adapted from TransLink's Bus Speed and Reliability Report.

One screenshot from Google Streetview is used, showing Route 73.

One picture is sourced from a Medium Blog Post by Don Iler.

APPENDIX: TRAVEL TIME SAVINGS PREDICTIONS

Appendix

Detailed calculation tables for travel time saving predictions associated with each bus priority intervention

Right-turn except for bus lane predicted time savings

Inter-section	Direc-tion	Back of queue travel time	Front of queue travel time	Time savings	% of time queuing	Exp. savings
Powell	North	20	16	5	42	2
Division	South	28	20	9	61	5
	North	25	18	7	58	4
Stark	South	22	17	5	32	2
	North	28	20	9	32	3
Burnside	South	25	15	10	62	6
Glisan	South	33	30	4	64	3
	North	27	22	5	42	2
Halsey	South	35	30	5	41	2
	North	25	18	7	32	2
Totals	South			33		18
	North			33		14
	All			66		31

Next-generation Transit Signal Priority predicted time savings

Intersection	Direction	Mean Delay per trip (secs)	Assumed reduction %	Savings per trip
Powell	South	31	82	25
	North	24	82	20
Division	South	29	41	12
	North	30	41	12
Market	South	4	82	4
	North	4	82	4
Stark	South	29	82	24
	North	18	82	15
Burnside	South	39	41	16
	North	12	41	5
Glisan	South	35	82	28
	North	30	82	25
Halsey	South	37	82	30
	North	39	82	32
Totals	South	156		112
	North	203		140
	All	360		251

In-lane curb extension stops predicted time savings

Inter-section	Direc-tion	Mean pull out delay	% of time stopping	Exp. savings	Stop position	Recommendation
Powell	South	6.1	100	6.1	Far-side	High priority
	North	5.1	96	4.9	Near-side	Recommended for removal
Division	South	6.4	98	6.3	Far-side	High priority
	North	4.8	100	4.8	Far-side	High priority
Market	South	4.2	91	3.8	Near-side	
	North	6.7	87	5.8	Near-side	High priority
Stark	North	4.6	96	4.4	Far-side	
Burnside	South	8.2	100	8.2	Near-side	Move to far-side and add in-lane stop. High priority
	North	5.1	100	5.1	Far-side	High priority
Glisan	South	5.4	96	5.2	Near-side	
Halsey	South	4.8	98	4.7	Near-side	
San Rafael	North	4.5	90	4.1	Near-side	
Totals	South	34		33		
	North	32		30		
	All	66		63		

Stop data for stops recommended for removal by this plan or 122nd Avenue Plan

Direction	Stop name	Weekly Ons + Offs	Gap created (miles)	Weekly lifts	Pax quality	Proposed by	Comments
North	Madison	1,150	0.25	48	0.46	122nd ave plan	Removing this along with Salmon would create 0.5 mile stop spacing
	Salmon	455	0.23	5	0.14	Both	
	300 Block NE 122nd	1203	0.36	9	0.56	This plan	
	Mult-nomah	613	0.36	1	0.22	This plan	
	Wasco	1738	0.21	38	0.89	122nd ave plan	Multnomah preferred due to fewer lifts, worse pax quality
South	Davis	1131	0.39	29	0.49	This plan	
	Oak	1669	0.26	15	0.92	This plan	Oak preferred due to worse pax quality
	Stark	2912	0.25	22	1.87	122nd ave plan	
	Midland Library	1586	0.33	26	0.81	This plan	
	1300 Block SE 122nd	1101	0.32	53	0.44	122nd ave plan	Midland library preferred due to high number of lifts at this stop
	Powell	4272	0.32	48	3.29	This plan	Stop on other side of intersection

Stop removal predicted time savings

Direction	Stop name	Avg. Ons + Offs	Time with stop	Time w/o stop	Time diff.	Avg. stop activity time	Time savings	% of time stopping	Exp. savings
North	Salmon	1.5	58	32	26	5.5	20.0	26	5.2
	300 Block NE 122nd	2.2	130	95	36	8.2	27.3	61	16.7
	Mult-nomah	1.5	81	59	22	5.4	16.6	37	6.1
South	Davis	2.1	216	187	29	15.0	14.5	49	8.6
	Stark	2.7	118	87	31	11.3	19.2	74	14.1
	Midland Library	2.4	74	46	28	11.5	16.5	70	11.5
	Powell	5.2	138	77	61	16.9	44.1	95	41.8
All	North subtotal						64		28
	South subtotal						94		76
	Grand total						159		104