Bit by bit: a method for using bus data to develop plan bus priority interventions in Portland, Oregon, USA.

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Abstract

Bus Priority Interventions are small-scale changes that improve bus speed and reliability. These include changes to street geometry, bus stops, and traffic signals. Automated Vehicle Location-Automated Passenger Counting (AVL-APC) data can help transit agencies by providing insight into bus location, speed, and passenger volumes. This project demonstrated an end-to-end methodology for using AVL-APC data to create a concept design for bus priority interventions on a bus route in Portland, Oregon. This mixed-methods approach paired quantitative data analysis with site visits to identify what was causing delay on the route and suggest targeted interventions. Scenario analysis of historical trip data was employed to predict the impact of different interventions. Historical trips that fell into two different scenarios were compared: a delay scenario (where a specific delay-inducing event occurred, like a red light) and a non-delay scenario (where that event did not occur). This end-to-end methodology could be used by transit agencies and transportation planners to quickly assess different corridors and interventions, diagnose problems, and determine which projects would create the greatest customer and financial benefits. Employing this approach could help planners prioritize time and resources to ensure that the highest impact projects are pursued.

Keywords: Public transit operations, Bus priority, AVL-APC data

1. Introduction

As urban populations grow, 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, or 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.

This study sought to use bus data to support the design and prioritization of BPIs. The research question was: how can Automated Vehicle Location-Automated Passenger Counting (AVL-APC) data help identify opportunities for bus priority and predict the benefits of specific interventions? Detailed quantitative and qualitative analysis of a bus route in Portland, Oregon was conducted to identify specific BPIs that would be most appropriate for the corridor and predict their impact. The result of this study was a data-driven plan to improve bus speed and reliability on one transit corridor. By doing so, an end-to-end methodology was demonstrated that transit agencies could use to efficiently and thoughtfully implement bus priority programs across their networks.

2. Literature review

2.1 Types of delay

Bus delays can be grouped based on where they occur: near bus stops, intersections, or while travelling in between two stops (Massachusetts Bay Transporation, 2023; Ryus, 2013). 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 is stopped at a red light (signal delay) or because it is stuck behind a vehicle that is 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 in between stops, when congestion or curbside activity (e.g., parking) reduces vehicle travel speed. Different BPIs are best suited for different types of delay, so bus routes must be carefully observed to ascertain which type of BPI is most needed.

2.2 Broader transportation context

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 (Portland Bureau of Transportation, 2018). 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.

2.3 Types of BPIs

BPIs can be divided into three major categories: bus stop management, street design, and signal priority (Ryus, 2013; TransLink, 2023). Bus stop management includes interventions that reduce the number of bus stops or adjust their placement to allow buses to clear intersections more rapidly. It can refer to upgrading stops so that 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 avoids the bus having to wait for a gap in traffic when it must merge back into the drive lane after servicing the bus stop (National Association of City Transportation Officials, 2016). Street design can give buses dedicated right-of-way to ensure they are not inhibited by other vehicles. This includes dedicated bus lanes, peak-only bus lanes, and queue jumps, which allow buses to travel in their own lane for part or all of the street.

Active Transit Signal Priority (TSP) involves actively modifying signal lengths as transit vehicles arrive at 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 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 arrived late.

2.4 Assessing the impact of BPIs

There is significant literature assessing the impact of different types of bus priority interventions. Many of these studies employed regression analyses to predict how transit speed and reliability compared before and after a bus priority intervention was implemented. This approach was used to study the impact of bus stop consolidation, TSP, and dedicated bus lanes on passenger activity and transit operations (El-Geneidy et al., 2006; Kimpel et al., 2005; Surprenant-Legault & El-Geneidy, 2011). Alternatively, other research sought to compare the performance of multiple routes in the same city, where only certain routes or stops received bus priority treatments (Diab & El-Geneidy, 2013, 2015).

Many of these studies leveraged Automated Vehicle Location (AVL) and Automated Passenger Counter (APC) data. AVL data are GPS data produced by buses which track the actual time that a bus leaves and arrives at each stop (Furth et al., 2006). A variant of AVL data is often referred to as "Breadcrumb AVL" data. Where standard AVL datasets only include the location of the bus when it passes specific stops or time points, Breadcrumb AVL data have a record of the bus's speed and location every five seconds. This allows planners to pinpoint specific sections of a road segment with high levels of delay or congestion. APC data track how many passengers board and alight from the bus at each stop, as well as the estimated passenger load.

3. Study context

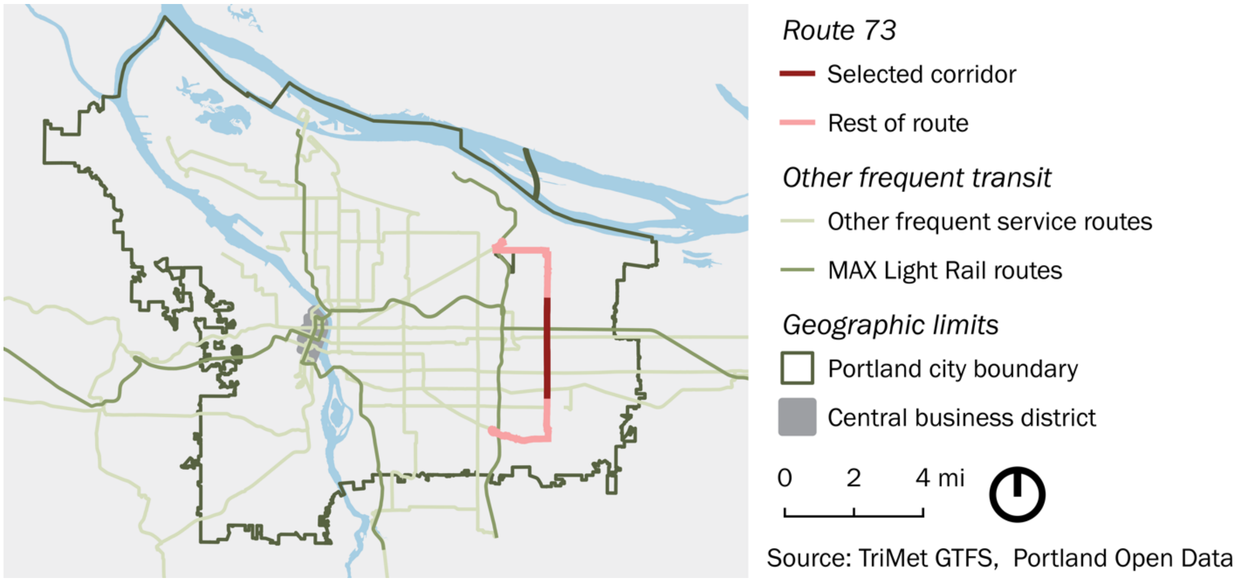
3.1 Transit in Portland

Portland is the largest city in Oregon, with 2.5 million people living in the Portland metropolitan area – the 25th largest metropolitan area in the United States (United States Census Bureau, 2024). The main public transit agency in the region is the Tri-County Metropolitan Transportation District of Oregon (TriMet), which operates buses, a light rail system (named the MAX), and a commuter rail line (TriMet, 2024). TriMet's ridership has decreased since the COVID-19 pandemic – ridership in 2023 was 58 million unlinked trips, compared to 97 million in 2019 (TriMet, 2023). 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).

In response, 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 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 2023, more than 40 projects have been funded (City of Portland, 2023b). Portland recently launched the FX2 line, a high-capacity bus route that benefits from many bus priority interventions. The route has been a major success: travel times are down by 17% and ridership has grown by 40% (Keeling et al., 2023a).

3.2 Selected route

This study investigated opportunities for bus priority interventions that would improve Route 73's speed and reliability. Specifically, the middle section of Route 73 was analyzed: NE/SE 122nd Avenue between NE Halsey Street to the north and SE Powell Boulevard to the south.



Source: TriMet GTFS, Portland Open Data

Figure 1: Map of Portland and frequent public transportation routes

After meeting with TriMet, this corridor was jointly chosen by TriMet and the investigators due to high levels of delay, feasibility of bus priority interventions, and equity reasons. Many parts of the corridor had high levels of travel delay and above-average passenger demand. Making changes to this street would likely be feasible, as the street is 76 feet wide and entirely owned by the city. This means that there would be ample space that could be dedicated to transit vehicles, and fewer jurisdictional issues that could complicate the project. The planning context would be particularly amenable to bus priority. The City of Portland designated this portion of NE/SE 122nd Avenue as a "Civic Corridor" as part of the City's 2035 Comprehensive Plan (City of Portland, 2023a). 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." A new transportation plan for the street was finalized in January 2024, which recommended specific safety and active transportation changes, and made general recommendations about the need for bus priority on the corridor (Portland Bureau of Transportation, 2024). Last, equity played a role in corridor selection. The route serves a high proportion of low-income and racialized neighborhoods, including Hazelwood, Mill Park, and Powellhurst-Gilbert (City of Portland, 2024).

Route 73 is an 8.8-mile route that travels North-South through East Portland, connecting the Parkrose/Sumner Transit Center in North Portland to the Lents Town Center in the south. 61% of the route runs along NE/SE 122nd Avenue, from NE Skidmore Street to SE Foster Road. As of May 2024, Route 73 is one of the 18 bus lines that make up Portland's Frequent Service Network – routes with headways of 15 minutes or less.

Table 1: Summary statistics for Route 73

Statistic	Value	Rank among frequent routes
Headway	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

The selected corridor is 2.7 miles long, bounded by NE 122nd Avenue and NE Halsey Street to the north and SE 122nd Avenue and SE Powell Boulevard to the south. The corridor connects to several frequent transit lines, including the MAX Blue Line, and the FX2, 9, and 20 bus routes. Along this corridor, NE/SE 122nd Avenue is typically 76 feet wide, with 2 parking lanes, 2 unprotected bike lanes, 4 driving lanes, and a center turn lane. Bus stops are exclusively pull-out stops, and the bus must cut across the bike lane to access them.

4. Data

Two datasets were used for this analysis: stop-level AVL-APC data, and Breadcrumb AVL data. The stop-level dataset included the actual time that a bus left and arrived at each stop, as well as the number of passengers who boarded and alighted. 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. The Breadcrumb AVL dataset showed the location and speed a bus was traveling, in five-second increments across its entire service period. TriMet shared the stop-level data for its entire bus network, from January 2022 to December 2022. To speed up calculations, only data from the month of October were used. Additionally, TriMet shared stop-level AVL-APC and Breadcrumb AVL data for Route 73 for the week of March 4-10, 2024. Except for the operational analysis – which compared Route 73 to other frequent service routes – and the run-time and stop-time models, the 2024 data were always used.

5. Methodology

This study sought to define an end-to-end methodology for using bus data to recommend bus priority interventions. This methodology entailed four key steps:

1. High-level quantitative analysis of AVL-APC data to identify where and when delay occurred and develop hypotheses for what changes would be most appropriate.
2. Site visits to investigate hypotheses and recommend specific bus priority interventions.
3. Scenario analysis of AVL-APC data to predict the impact of these interventions.
4. Operational analysis of AVL data to understand whether these travel time savings could reduce the number of buses needed to service the route.

5.1 High-level quantitative analysis

Bus data were first examined to understand what times of day delays and passenger demand were highest and where on the corridor delays occurred. Line plots of average bus speed (including dwell time) and the average passenger load by hour were produced. The Breadcrumb AVL data were then used to map bus speeds across the entire corridor. The corridor was split into 250 points, each 20 meters apart. The observations in the Breadcrumb AVL dataset were then assigned to their closest point. The average speed for each point was then calculated and mapped, for northbound and southbound trips. Two simple regression models were then developed to predict run-time (i.e., travel-time between stops including dwell, in seconds) and stop-time (i.e., dwell time, in seconds). These models used several independent variables, including time of day, segment length, stop position, and passenger activity at the stop (i.e., number of Ons, Offs, and whether a ramp was deployed). The models included dummy variables for the six intersections with the largest cross-streets (SE Powell Boulevard, SE Division Street, SE Stark Street, E Burnside Street, NE Glisan Street, and NE Halsey Street), to help identify which intersections disproportionately increased delay.

Bus data were analyzed to identify stops that should be removed, using a methodology developed by Stewart and El-Geneidy (2016). This approach suggests stops for removal if they meet several conditions. 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 the stop. These stops are relatively unimportant to the route's passengers, but their high variability means that they can cause significant reliability challenges. Passenger quality was 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 ramp deployments. Bus ramps are deployed when passengers (e.g., those with mobility impairments) request help with boarding or alighting from a bus. 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 light rail or frequent service bus networks, 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.

These analyses served three purposes. First, they guided the site visits by influencing when the corridor should be visited, which intersections should be observed in detail, and what things should be looked for. The coefficients generated by the models were later used to predict the impact of specific types of bus priority interventions. The stop analysis was used to create a shortlist of stops that were recommended for removal.

5.2 Site visits

Two site visits were completed in March 2024. 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 vehicle behavior at key intersections.

These site visits were conducted with three objectives. First, the investigators sought to build an understanding of what it "felt" 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.

Following this site visit, recommendations for specific bus priority interventions were made:

1. Right-turn except bus lanes at the six largest intersections.
2. Next-generation transit signal priority at the six largest intersections.
3. In-lane bus stops, particularly at E Burnside Street, SE Division Street, and SE Powell Boulevard.
4. Bus stop consolidation at seven bus stops.

These interventions are described in detail the next section.

5.3 Scenario analysis

Scenario analysis was used to predict the likely impact of these interventions. While the steps differed based on the intervention, the general approach was to compare historical trips that fell into two different scenarios: a delay scenario (where a specific delay-inducing event occurred, like a red light) and a non-delay scenario (where that event did not occur). These scenario analyses were only conducted using data from trips that took place during the PM peak (3-6PM), the time when delays and passenger demand were highest. Accordingly, the travel-time savings predictions are only valid for trips during the PM peak.

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 (SE Powell Boulevard, SE Division Street, SE Stark Street, E Burnside Street, NE Glisan Street, and NE Halsey Street). This intervention has the effect of always ensuring that transit vehicles end up at the front of the queue, rather than having to wait at a 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. These time savings were then multiplied by the percentage of time that a bus waited at the back of the queue at a given intersection, which represented how often this intervention would be useful.

Next-generation Transit Signal Priority

TriMet implemented "next-generation TSP" on the FX2 bus route in 2022 and is rolling the technology out across the system. The new TSP system has led to major reductions in signal delay on the FX2 bus route, with an overall reduction in average red light waiting time of 82% (Menard, 2024). TSP has been most impactful in East Portland, where the FX2 route travels along SE Division Street on a road configuration that is very similar to NE/SE 122nd Avenue (i.e., five car lanes, and an additional right turn-lane at intersections) (Keeling et al., 2023b).

This project sought to quantify the travel time savings of implementing this new TSP system on NE/SE 122nd Avenue. First, the Breadcrumb AVL data were used to calculate the amount of time spent at red lights at each signalized intersection on the corridor, in both directions. Then, the 82% reduction in intersection delay achieved by the FX2 project was assumed to be possible for five of the seven signalized intersections on the corridor. At the other two signalized intersections – NE/SE 122nd Avenue and E Burnside Street and SE 122nd Avenue and SE Division Street – a 41% reduction was assumed. This lower reduction – half of what was achieved by the FX2 project – accounts for the fact that E Burnside Street and SE Division Street both have major transit lines running on them, the MAX Blue Line and the FX2 bus route. In the case where Route 73 arrives 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, in part by facilitating bus-only phases (Koonce & Haines, 2024).

Curb extension in-lane bus stop

In-lane bus stops extend the curb into the street to allow buses to service a stop in the drive lane, rather than pulling into the parking lane. This saves time after the stop is complete, because the bus no longer needs to wait for a gap in traffic before merging into the drive lane. To calculate the impact of this intervention, the Breadcrumb AVL data were used to calculate the difference between the amount of time that a bus was physically present at a bus stop and the amount of time that the bus door was open. This difference is assumed to be "pull-out delay" – time that the bus needed to wait before re-entering regular traffic. Extreme values, where this pull-out-delay was below the 5th percentile of pull-out-delay or above the 95th percentile, were excluded. To calculate expected savings, pull-out delay was multiplied by the percentage of time that a bus serviced a given bus stop. Since this intervention would be relatively expensive, the investigators assumed a maximum of 10 in-lane bus stops could be added.

Stop consolidation

The bus data analysis identified seven bus stops that could be justifiably removed while minimizing negative impacts. A four-step process was used to assess the benefit of eliminating these stops:

1. For each $Stop_N$, the average travel time between $Stop_{N-1}$ and $Stop_{N+1}$ was found for trips where the bus stopped at $Stop_N$ and trips where the bus did not stop at $Stop_N$.
2. This difference was then adjusted to account for the fact that passengers boarding and alighting at $Stop_N$ would likely use either $Stop_{N-1}$ or $Stop_{N+1}$ if stop $Stop_N$ was removed. This passenger activity time must be incorporated into the predictions. To calculate passenger activity time (in seconds), the mean number of boarding passengers at $Stop_N$ was multiplied by 5.6, the mean number of alighting passengers was multiplied by 2.7, and the mean number of ramp deployments was multiplied by 32. These coefficients are sourced from the stop-time regression 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 stop at Stop_N occurred, to get the *expected* savings.

The travel-time savings from each of these four interventions were summed to calculate the predicted savings of implementing all changes.

5.4 Operational analysis

These savings were then considered within the context of the PM peak round-trip cycle time. The round-trip cycle time is the round-trip travel time plus the time dedicated to the two layovers at the bus stations at either end of the route. Analyzing this would reveal whether the bus priority interventions would allow TriMet to reduce the number of buses needed to service the route. To calculate the number of buses needed to service the route, the following formula was used:

Number of buses servicing the route = (round-trip cycle time) / (desired headway).

Since the travel time savings alone were insufficient to reduce the number of buses servicing the route, the amount of time dedicated to layovers was investigated to identify whether these could be reduced as well. Layover time lets drivers rest and provides padding to reduce the risk that delays on one trip cause delays on future trips. Specifically, the proportion of time dedicated to layovers was calculated. For example, if a route's round-trip cycle time was 100 minutes, and 25 of those minutes were dedicated to layovers, the route's layover percentage would be 25%. The layover percentage for Route 73 was compared to other frequent service routes to reveal how much Route 73's layovers could be reduced by. This would indicate whether enough time could be saved to let TriMet reduce the number of buses servicing the route during the PM peak.

6. Results

6.1 High-level quantitative analysis

The high-level analysis of bus data showed that speed challenges and passenger volumes were highest during the PM peak (from 3-6 PM), particularly southbound. Delays were overwhelmingly concentrated before major intersections – where traffic backed up while waiting for the light to turn green – rather than between intersections. The regression models highlighted that delays were highest where NE/SE 122nd Avenue crossed SE Powell Boulevard, E Burnside Street, and SE Stark Street. Last, the stop consolidation analysis identified seven stops with low levels of passenger quality, infrequent ramp deployments, and tighter-than-average stop spacing.

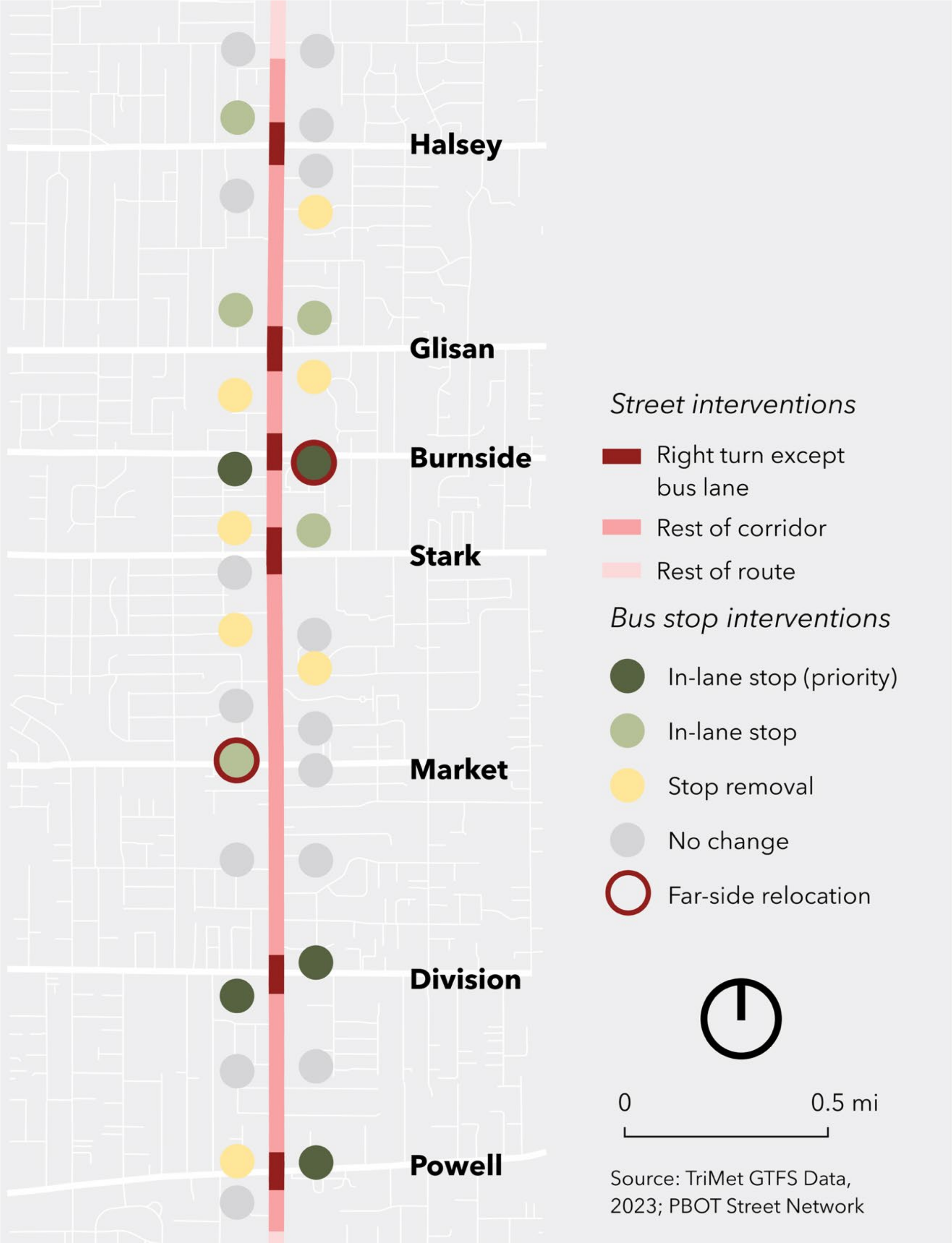
Table 2: Results from Run-time and Stop-time regression models

		1.Run-time model			**2. Stop-time model**		
	Term	**Coef.**	**SE**	**P-value**	**Coef.**	**SE**	**P-value**
Segment information	(Intercept)	-1.2	0.6	0.0	3.1	0.2	<0.001
	Trip is northbound	-1.8	0.3	<0.001	0.0	0.2	0.9
	Trip occurs during PM Peak	3.9	0.3	<0.001	-0.9	0.2	<0.001
	Nearside stop	0.5	0.3	0.2	0.8	0.2	<0.001
	Signal on segment	4.9	0.4	<0.001	-	-	-
	Distance (miles)	161.4	2.6	<0.001	-	-	-
Dwell information	Stop occurred	7.1	0.3	<0.001	-	-	-
	# of Ons	7.2	0.1	<0.001	5.6	0.1	<0.001
	# of Offs	1.7	0.1	<0.001	2.7	0.1	<0.001
	Ramp deployment	32.3	0.8	<0.001	32.1	0.5	<0.001
Intersection dummies	Powell	30.2	0.7	<0.001	15.0	0.4	<0.001
	Burnside	33.1	0.6	<0.001	8.6	0.4	<0.001
	Division	24.3	0.7	<0.001	-0.6	0.4	0.1
	Stark	33.9	0.7	<0.001	1.2	0.3	<0.001
	Glisan	28.3	0.6	<0.001	1.1	0.3	<0.001
	Halsey	23.9	0.7	<0.001	0.5	0.3	0.2
R^2		**0.57**				**0.51**	

6.2 Site visits

The site visit confirmed 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 E Burnside Street (northbound) and SE Powell Boulevard (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 SE 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 the corridor, 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 NE/SE 122nd Avenue. For example, the southbound stop located on SE 122nd Avenue and SE Division Street appeared to have significant pull-out delays, because the bus had to wait for the high number of vehicles turning from SE Division Street onto SE 122nd Avenue to clear out before it could merge into traffic.

The four recommended bus priority interventions that came out of this site visit were distributed across the entire corridor.



Source: TriMet GTFS Data, 2023; PBOT Street Network

Figure 2: Distribution of bus priority interventions across corridor

6.3 Scenario analysis

The different scenario analyses enabled the prediction of travel time savings related to each transit priority intervention. If these savings were added up, time savings of up to 3.1 minutes northbound and 4.4 minutes southbound 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).

Table 3: Predicted travel time savings from bus priority interventions

Direction	Intervention	Exp. savings (seconds)	Exp. savings (minutes)
Northbound	Right-turn except bus lanes	14	0.2
	TSP	112	1.9
	In-lane bus stops	33	0.6
	Stop consolidation	28	0.5
Southbound	Right-turn except bus lanes	18	0.3
	TSP	140	2.3
	In-lane bus stops	30	0.5
	Stop consolidation	76	1.3
Northbound	All	187	3.1
Southbound	All	264	4.4
Grand total	All	451	7.5

6.4 Operational analysis

These travel time savings could enable a reduction in TriMet's operating costs if they let TriMet reduce the number of buses needed to service Route 73. A round-trip cycle during the PM peak lasted 121 minutes for Route 73. On average, 93 of those minutes were used for travel, while 28 minutes were "layover time", when the bus waited at the bus depot. The number of buses required to service a route equals the round-trip cycle-time (including layover) divided by the headway. Since Route 73 had 15-minute headways, it required 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. Since the scenario analysis found that bus priority interventions could reduce travel times by 7.5 minutes, layover times would need to be reduced by 8.5 minutes to achieve a 105-minute round-trip cycle time.

To determine whether this reduction was justifiable, the proportion of cycle time used for layovers was calculated for Route 73, as well as the other frequent service routes. Route 73's layover proportion was 28 minutes / 121 minutes = 24%. This was higher than the average frequent service route, which had a layover proportion of 18%. This implied that layovers were disproportionately high on Route 73. Reducing overall layover time from 28 minutes to 20 minutes (4 minutes reduction each way) would achieve a round-trip cycle time of 105 minutes, while still maintaining a layover proportion of 19%. Shorter layovers are in some ways more justifiable on routes with bus priority interventions, because these interventions reduce travel time variability (on top of creating travel time savings). The impact on operators would be lessened by the fact that these layover reductions could be restricted to peak times.

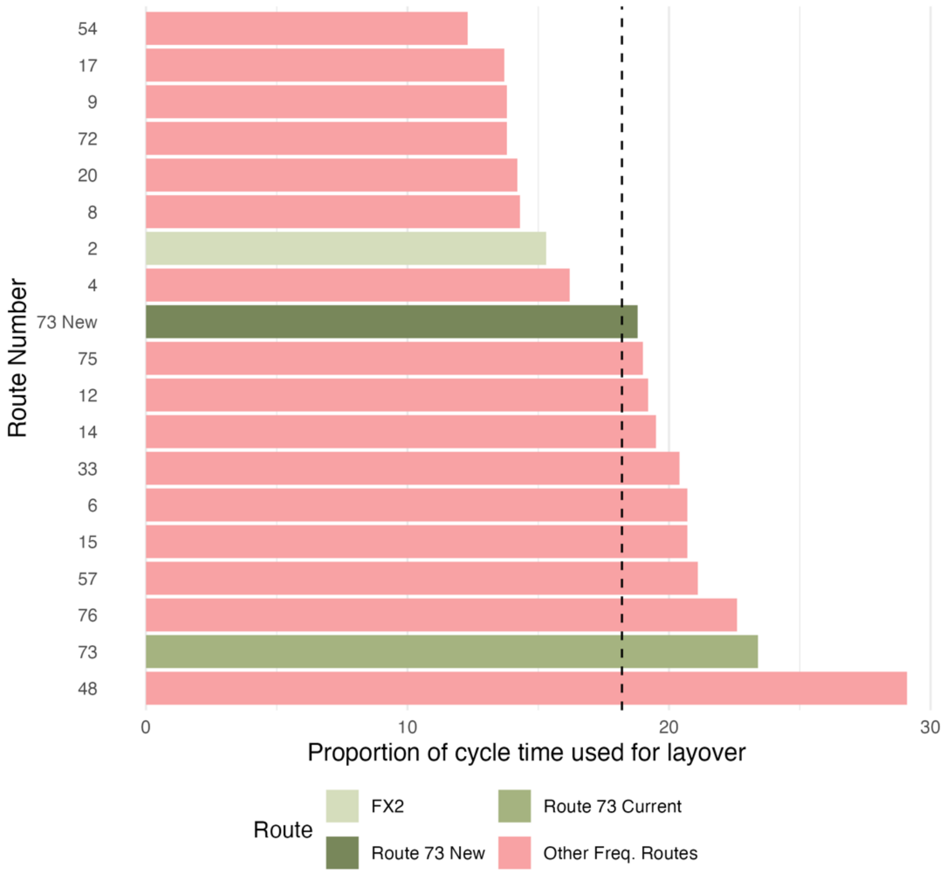


Figure 3: Proportion of cycle time dedicated to layovers for frequent routes

Going from 8 to 7 buses on this route during the PM peak 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 as well, but the impact of these interventions on off-peak travel was not investigated.

7. Discussion and conclusion

This project demonstrated a methodology for using bus data to develop recommendations for bus priority interventions across an entire corridor. Travel speed and passenger demand were studied to understand how they varied spatially and temporally across the study area. This informed which areas should be observed in-person, and which bus priority interventions would be most appropriate. Scenario analysis was used to shed light on what kinds of savings could be expected if these bus priority interventions were implemented. These travel time savings were then considered within the context of the entire bus route to determine whether financial savings would be possible.

This data-driven approach could allow transit agencies and transportation planners to quickly assess different corridors and interventions, diagnose problems, and determine which projects would create the greatest customer and financial benefits. Employing this methodology could help planners better prioritize time and resources to ensure that the highest impact projects are pursued. The results of these analyses could feed business cases, and this methodology could be deployed after projects are complete to help learn what does and does not work.

This project suggests that focusing efforts on a single corridor – rather than implementing spot improvements across the entire network – may be more useful. A focus on one corridor will concentrate the travel-time improvements on a single route. Achieving benefits above a certain threshold are required to unlock financial benefits, because sufficient time must be saved before the agency can serve a route with fewer buses. Concentrating benefits on a single route may make them more salient to customers, and thus could make them more likely to be recognized and appreciated.

There were several limitations related to the study. If all the different bus priority interventions were implemented, they would affect each other, making it unclear whether all the savings would be achieved. Since the Breadcrumb AVL dataset was only available for a single week, and the scenario analysis focuses on the PM peak, there are only 120 historical trips (60 each way) to analyze. Increasing the dataset to an entire month or an entire quarter could increase confidence in the estimates. The estimated savings from TSP were in part based on the savings achieved by the FX2 bus route. While that bus route's context is similar to Route 73's, it is unclear whether the savings would translate, given that there are some differences between the two (e.g., FX2 has articulated buses and all-door boarding).

Future research could test the efficacy of this methodology by examining a bus route before and after bus priority interventions were implemented. First, this methodology could be applied using pre-intervention bus data to predict the savings of specific interventions. Next, these predictions could be compared to the actual savings generated by the bus priority interventions.

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AUTHOR CONTRIBUTION

The authors confirm contribution to the paper as follows: Study conception and design: Redelmeier & El-Geneidy; Data collection: Redelmeier & El-Geneidy; Analysis and interpretation of results: Redelmeier & El-Geneidy; Draft manuscript preparation: Redelmeier & El-Geneidy. All authors reviewed the results and approved the final version of the manuscript.

DECLARATION OF CONFLICTING INTERESTs

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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