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Analysis of the Impacts of Transit Signal Priority on Bus Bunching and Performance

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ABSTRACT (150-250 words)

Efficient and reliable public transit systems provide opportunities to reduce congestion, emissions in urban areas and provide access and mobility to residents. Headway, or the time difference between departing or arriving vehicles, is a useful measure to gauge bus transit performance; because short headways can lead to bus bunching incidents that quickly degrade transit level of service. While Transit Signal Priority (TSP) has been shown to decrease travel time and delay experienced by buses, little work has shown how TSP may affect bus bunching. This research attempts to understand the characteristics of bus trips, especially TSP, that prevent or promote short headways, or bus bunching. A study of two transit routes in SE Portland is presented. High values of negative serial correlation were observed among consecutive headway observations. A regression model is used to analyze factors (boardings, alightings, stops, lift usage, Transit Signal Priority and direction of travel) that may influence bus headways. Priority requests are shown to have a significant effect on headways.

1. INTRODUCTION

The Transit Capacity and Quality of Service Manual (TCQSM 2003) lists two categories of performance measures for determining transit level of service: *availability* and *convenience*. Transit *availability* is defined by the spatial and temporal location of transit vehicles, namely, how close transit facilities are to passenger origins and destinations and when transit service can be expected. The TCQSM defines *convenience* as how comfortable transit is for passengers and how reliable the service, or, how regular and timely the service is. Therefore, the challenge for transit operators is to provide service that is both on schedule and frequent.

In the case of high frequency routes, even spacing of transit vehicles or headway regularity may be more important to passengers than precise schedule adherence. This headway between transit vehicles effectively determines availability and convenience, and is a key component of transit service quality. The stochastic nature of the transportation system environment exposes transit vehicles to incidents such as congestion, and varying passenger demand, that can have significant effects on headway regularity (Feng and Figliozzi 2011). Often, these events slow a leading bus down so that the following bus catches up creating a bus bunching event. Bus bunching creates a negative experience for transit passengers, as a leading, late bus will incur more passenger boardings, quickly reaching capacity. The following bus is then utilized by fewer passengers, which speeds up travel times, compounding bus bunching. This research aims to (1) determine the effects of TSP and other bus measures, i.e. boardings, alightings and lift usage, on bus headways, (2) analyze headway predicting factors on a bus route with TSP and one without TSP using linear regression models that do not include significant levels of serial correlation.

1.1 Background

Bus bunching, or short headways, has been defined in the literature as early as Abkowitz and Englestein (1983 and 1984), where the need for control strategies to mitigate headway variations is discussed. Bus bunching represents a specific form of headway irregularity, and an extensive body of literature addressing headway regularity exists. Reviews of such strategies can be found in (Strathman et al. and Desaulniers and Hickman 2007).

Kimpel et al. (2008) and Strathman et al. (2002) analyzed the relationship between headway deviation and number of on board passengers, as well as the relationship between running time variation and operator years of experience using linear regression models. Hammerle et al. (2005) found two causes of bus bunching: on street effects and irregular terminal starting time; according to Hammerle most instances of bus bunching were caused by events at the terminals. Feng and Figliozzi (2011) developed a method to identify the temporal and spatial location of bus bunching events and analyze the causes of those events.

Transit Signal Priority, TSP, is the process by which the movement of transit vehicles is given preference or advantage over other vehicle movements. Specific examples of TSP include scheduling signal coordination for transit speeds or real time adjustment of traffic signal cycles to reduce the delay experienced by a transit vehicle. Furth and Muller present three categories of TSP (2000)and defines conditional priority as granting priority to transit vehicles that meet certain conditions (i.e. greater than 30 seconds late). This type of priority represents the system in place in Portland, Oregon, where only buses that meet certain conditions (defined below) are granted priority.

TSP has been shown in many cases to have a significant effect on reducing travel time and delay. For instance, Furth and Muller evaluated TSP for a single intersection, finding that conditional TSP provided benefits to late buses while not significantly increasing delay to other vehicles in the system. A study simulating an arterial by Dion et al. found that TSP provided benefits to buses without significant impact to general traffic. Skabardonis evaluated the improvement of several TSP strategies, both passive and active, along a coordinated corridor (2000). TSP has been evaluated in Portland, at the aggregated route level (Kloos et al. 1995). Kimpel et al. evaluated SE Powell Boulevard; however, the focus was on performance measures related to bus run time variability at the route level; these authors did not find a significant system wide improvement in routes with TSP (2005).

Headways and bus bunching have been shown in the literature to identify poor performance. TSP has been shown to affect travel time but a connection to vehicle headways has not been clearly made. We attempt to understand the impact of Transit Signal Priority and other factors on headways and bus bunching. Further, we build on the work of Feng and Figliozzi (2010) and Albright and Figliozzi (2011) to model the effects of bus trip characteristics and TSP on headways and potential bus bunching.

2. STUDY OVERVIEW

2.1 Route Description

This study focuses on two TriMet bus routes in southeast Portland. Route segments that follow similar east-west arterials were chosen. TriMet's Route 9 connects the City of Gresham with Southeast, downtown and North Portland. Route 15 connects Gateway in Northeast Portland, with Southeast, downtown and Northwest Portland. While Routes 9 and 15 can be characterized as a medium frequency routes during off-peak hours, high frequency service is available during the peak demand hours.

Weekdays between 6:00 to 10:00 AM in the westbound direction and 4:00 to 7:00 PM in the eastbound direction scheduled headways can be as low as five minutes. The studied Route 9 segment extends from SE Powell Blvd and Milwaukie to SE Powell and 84th. The Route 15 segment follows SE Belmont, SE Morrison, SE Stark and SE Washington from 7th Ave to 86th. Detailed bus performance data was collected for weekdays during the month of November, 2011 for both routes from TriMet's Bus Dispatch System (BDS) for a total of 20 days.

2.2 Data Description

2.3 TriMet Stop Event Data

Stop event data are recorded after a bus leaves a stop and details stop level information such as location, arrival time, leave time, scheduled time, as well as passenger information such as the number of passengers boarding and alighting and lift usage. It is important to note that scheduled times in the data are scheduled departure times from the bus stop; there are no scheduled arrival times. Further, scheduled departure times are not enforced at all stops, but only at *time point stops.*

2.3 TriMet Priority Request Data

TriMet also logs transit priority request data made by late buses. When a bus meets the priority request criteria (see next section), priority is requested by an Opticom light emitter. The time interval from the time the Opticom light is activated to the time the priority request is cancelled is logged by each vehicle with a bus trip identifier.

2.3 Portland TSP

TSP is enabled at all signals in the Route 9/ SE Powell corridor except SE Powell and SE 82nd where signal progression is timed for SE 82ndover SE Powell. TSP is not available along the Route 15/SE Belmont corridor. At the TSP enabled intersections, priority actions available are green extension and red truncation. TSP is available 24 hours a day; however, it is conditional and available only to those buses meeting the three conditions listed below (Urbanik 2002):

1. The bus is on route. This ensures that priority is only given to buses actively serving passengers.
2. The doors are closed. Priority should not be given to a bus that cannot move. For instance, a bus stopped at a near-side bus stop should not affect the timing plan for that intersection. In that situation, when the doors close and the bus is able to move through the intersection, priority can be then be requested.
3. The bus is late by at least 30 seconds (departure time from last stop is 30 seconds greater than scheduled). TriMet and the City of Portland have chosen 30 seconds as the lateness threshold that activates TSP.

TriMet buses' Opticom light emitter activation is linked to the AVL and APC system on each bus and each condition is checked on real-time. The priority light emitter is deactivated when late buses are less than 30 seconds late. The signal controllers currently in use at these intersections are unable to log TSP events and therefore this research relies on TSP request data provided by TriMet (it is assumed that TSP requests are provided whenever possible).

3. DATA PREPARATION AND ANALYSIS

The following analysis attempts to characterize headway performance and determine factors that contribute to short headways or bus bunching. First, the set of stop events is adjusted to emphasize influencing factors, and aggregated into trip records. Consecutive trips are paired to form headway records. Regression analysis is used to build models that predict final headways for each bus corridor.

3.1 Estimating Time at Stops

Preliminary regression models presented some issues with using both boardings and alightings at the stop level. The nature of boardings and alightings is that they occur simultaneously at a bus stop. Boardings generally require more time than alightings as a passenger must show a bus pass or valid transfer ticket to an operator, or pay for a new bus ticket. Alightings only require the passenger to exit the vehicle.

For instance if a bus stops and 5 passengers board and 8 passengers alight the bus, it is most likely that the 5 boarding passengers will consume the largest portion of the total dwell time at the stop. Linear regression is used to model dwell times predicted by boardings, alightings, lifts and stops for each route. The coefficients found, in seconds, predict how much time each of predictors add to dwell time at a stop. These coefficients and regression results are presented in table 1.

The stop event data was then adjusted to only include the factor (boardings or alightings) with the most influence at each stop event. For each stop event the time required for boardings is compared to the time required for alightings. The larger value is kept at that value in the data, while the value representing the lower time is set to 0 seconds for that stop event. Considering the previous example, on route 15, the 5 boardings would predict approximately 5×4.9, or 24.5 seconds. The 8 alightings predict 8×2.9, or 23.2 seconds. In this case the 5 effective boardings remain for that stop event and 8 alightings are replaced by 0 effective alightings.

Table 1. Dwell Time Regression Model

Route 15/ SE Belmont Corridor

Factor	Coefficient Value	Std. Error	P-Value	Variable Mean	Mean Contribution (Sec)	Percentage Contribution (%)
Intercept	-0.267	0.056	0.000	1.0	-0.3	-4.1
Boardings	4.911	0.042	0.000	0.5	2.6	39.6
Alightings	2.893	0.044	0.000	0.5	1.5	22.5
Doors Opened	3.156	0.060	0.000	0.8	2.6	39.2
Lifts Used	39.044	0.626	0.000	0.0	0.2	2.7
Mean Dwell (Seconds)	6.578					
Number of Observations	117,097					
R-Square	0.330					
Adjusted R-Square	0.330					

Route 9/ SE Powell Corridor

Factor	Coefficient Value	Std. Error	P-Value	Variable Mean	Mean Contribution (Sec)	Percentage Contribution (%)
Intercept	-0.360	0.075	0.000	1.0	-0.4	-4.0
Boardings	3.148	0.032	0.000	0.9	2.7	30.1
Alightings	1.598	0.034	0.000	0.8	1.3	14.8
Doors Opened	4.800	0.062	0.000	1.1	5.1	57.1
Lifts Used	37.078	0.744	0.000	0.0	0.2	2.0
Mean Dwell (Seconds)	8.901					
Number of Observations	83,189					
R-Square	0.364					
Adjusted R-Square	0.364					

3.2 Creating Trip and Headway Records

To develop headway records the following step are taken to determine stop event records that define a single bus trip and aggregate the bus performance data at each stop in the trip:

1) Aggregate multiple stop events at the same stop.
2) Eliminate express service buses.
3) Limit the stop event data to corridor specific records.
4) Join the priority request data to matching bus stop events.
5) Aggregate stop events along the bus route into trip records.

After trip records are prepared, headway records are then defined as two consecutive bus trips along the corridor. These records consist of the aggregated characteristics of the front bus (bus 1) and the rear bus (bus 2), as well as start and final headways between the buses calculated at the start and end points. Note that the start headway is calculated between the departures of the buses at the first stop and final headway is calculated between the arrivals of the buses at the final stop in the corridor.

3.3 Regression Analysis

Headways at the first stop and other aggregate trip values are then used to predict the final headway value in a regression model. The following factors are used as predictor variables in the final headway for trips models:

- Initial headway – the difference in seconds between the departure of the front and rear bus
- Total Effective Boardings (front and rear bus separately) – the total number of passengers that board the bus, summed over the entire duration of the trip
- Total Effective Alightings (front and rear bus separately) – total number of passengers that alight the bus over the entire duration of the trip
- Total Lifts (front and rear separately) – the total number of times the passenger assistance lift is used during the trip
- Total Stops (front and rear separately) – the total number of stops where the bus opens the doors at a stop along the trip
- Priority Requested – two Boolean dummy variables (1 if priority is requested along the route and 0 if not) are constructed for each combination of priority requests between the two buses(front only, rear only, both and none)
- Direction – one Boolean dummy variables for each direction (1 if direction is Eastbound and 0 if the direction is Westbound)

Note that priority dummy variables are true for a bus if it requests priority at any point along the corridor. This study does not distinguish between requesting for the entire corridor or only the last stop. Also the priority dummy variables are only used a predictor in the Route 9 headway regression model, and not in the Route 15 model, as TSP is not available on the SE Belmont corridor.

3.4 Serial Correlation

The initial models for the corridor are shown in table 2. The signs of the variables are intuitive and expected, however, the temporal nature of the closely related trips created possibility that the data may exhibit serial correlation. In order to determine if serial correlation was a factor in these data sets, the Durbin-Watson test was performed on the base models. The Durbin-Watson two-sided test statistic and its P-value are shown in the last two lines of table 2. In both routes the Durbin-Watson statistic is near 2.9 with a P-value of 0.0. The hypothesis for the two-sided Durbin-Watson test follows:

$$H_0: DW\ Stat = 2\ (no\ serial\ correlation)$$
$$H_1: DW\ Stat\ \neq 2$$

This P-value suggests the statistic is significant and not equal to 2. Therefore the null hypothesis is rejected and serial correlation is determined to be present in both route models. Significant test statistics greater than 2 indicate negative serial correlation is present. While serial correlation does not bias the estimated coefficients, it tends to reduce the standard errors of the estimated coefficients. To remove the serial correlation from the data, the data sample is adjusted by removing the odd numbered rows from the dataset. This ensures the number of observations remains high and the serial correlation is removed as seen in further models. The adjusted models are shown in table 2 as well. Note that the P-values indicate the statistic is no longer significant. Therefore the null hypothesis is accepted and serial correlation is determined to no longer be present in the model.

For example in Model 4, two interaction terms were significant, the interaction between the eastbound direction and priority in only bus 1 and priority in only bus 2. Additionally the priority in bus 1 only variable and the priority in bus 2 only variable are significant while the eastbound variable is not. Therefore model 4 shows there is significant interaction between direction and TSP. The first case (P1) reduces the final headway, a potential cause of bus bunching, while the second case (P2) increases the final headway, thus, inhibiting bus bunching potential. The eastbound direction on route 9 carries passengers away from downtown. Slavin et al. (2012) have studied the boardings and passenger load along this corridor and found less boardings occur in the eastbound direction but passenger load is the same between directions. The interaction between eastbound direction and priority suggests more variability (i.e. more stops) causes the bus 1 priority to decrease headways and the bus 2 priority to increase final headways. The interaction

In Model 11only one interaction term was significant, the interaction between rear bus lift usage and rear bus only priority. Additionally, the rear bus priority only variable was significant, but the rear bus lifts variable was not. In this case Model 11predicts that when only the rear bus uses priority, headway is reduced by 23 seconds, but each lift adds an additional 59.6 seconds to the headway. This interaction term likely suggests that when bus 2 uses the passenger assistance lift, the time required to operate the lift impacts the lateness of the bus, requiring it to then request priority going forward.

Table 2. Preliminary Models

	Initial Models with Serial Correlation						Adjusted Models Without Serial Correlation					
	Route 15/ SE Belmont			Route 9/ SE Powell			Route 15/ SE Belmont			Route 9/ SE Powell		
Predictor Variables	Coefficient Value	Std. Error	P-Value	Coefficient Value	Std. Error	P-Value	Coefficient Value	Std. Error	P-Value	Coefficient Value	Std. Error	P-Value
Intercept	96.960	15.287	0.000	97.060	16.764	0.000	103.638	22.004	0.000	104.359	23.591	0.000
Start Headway	0.936	0.006	0.000	0.937	0.007	0.000	0.931	0.009	0.000	0.934	0.009	0.000
Eastbound Direction	19.371	9.452	0.041	15.101	7.281	0.038	13.714	13.508	0.310	15.282	10.331	0.139
Bus 1 Boardings	-2.754	0.352	0.000	-2.262	0.262	0.000	-2.596	0.510	0.000	-2.547	0.370	0.000
Bus 1 Alightings	0.822	0.436	0.060	0.165	0.343	0.630	0.687	0.623	0.270	-0.246	0.474	0.604
Bus 1 Lifts	-28.591	5.534	0.000	-24.932	5.987	0.000	-30.308	8.449	0.000	-19.615	8.657	0.024
Bus 1 Stops	-7.733	1.033	0.000	-7.671	1.007	0.000	-7.614	1.471	0.000	-6.258	1.425	0.000
Bus 2 Boardings	2.658	0.356	0.000	3.112	0.259	0.000	2.427	0.506	0.000	2.992	0.362	0.000
Bus 2 Alightings	-1.372	0.445	0.002	-1.235	0.341	0.000	-0.810	0.639	0.205	-1.151	0.490	0.019
Bus 2 Lifts	37.170	5.415	0.000	19.793	6.024	0.001	40.692	7.536	0.000	21.938	8.345	0.009
Bus 2 Stops	4.828	1.030	0.000	4.117	0.991	0.000	4.524	1.477	0.002	3.995	1.377	0.004
Priority Bus 1 Only	N/A			9.145	9.143	0.317	N/A			-1.390	12.845	0.914
Priority Bus 2 Only	N/A			-15.512	9.161	0.090	N/A			-16.688	12.763	0.191
Priority Both 1 and 2	N/A			8.804	8.138	0.279	N/A			-6.050	11.307	0.593
Number of Observations			2,914			3,008			1,457			1,504
R-Square			0.911			0.895			0.903			0.902
Adjusted R-Square			0.911			0.895			0.902			0.901
Durbin-Watson Stat			2.881			2.890			1.969			1.991
Durbin-Watson P-Value			0.000			0.000			0.504			0.792

Table 3. Models with Priority Interaction – Route 9/SE Powell Blvd.

	Model 4 (Eastbound Direction * Priority)			Model 5 (Bus 1 Boardings * Priority)			Model 8 (Bus 1 Stops * Priority)			Model 11 (Bus 2 Lifts * Priority)		
Predictor Variables	Coefficient Value	Std. Error	P-Value	Coefficient Value	Std. Error	P-Value	Coefficient Value	Std. Error	P-Value	Coefficient Value	Std. Error	P-Value
(Intercept)	110.564	21.513	0.000	110.952	21.048	0.000	50.121	11.900	0.000	116.646	21.133	0.000
Start Headway	0.934	0.009	0.000	0.934	0.009	0.000	0.940	0.009	0.000	0.933	0.009	0.000
Eastbound Direction												
Bus 1 Boardings	-2.717	0.347	0.000	-2.582	0.345	0.000	-3.061	0.310	0.000	-2.710	0.344	0.000
Bus 1 Alightings												
Bus 1 Lifts	-17.340	8.548	0.043	-18.850	8.633	0.029	-21.846	8.610	0.011	-17.236	8.602	0.045
Bus 1 Stops	-6.212	1.246	0.000	-6.425	1.253	0.000				-6.480	1.254	0.000
Bus 2 Boardings	3.010	0.343	0.000	3.010	0.343	0.000	3.354	0.285	0.000	2.994	0.341	0.000
Bus 2 Alightings												
Bus 2 Lifts	21.306	8.223	0.010	22.536	8.315	0.007	23.208	8.343	0.005			
Bus 2 Stops	2.534	1.226	0.039	2.629	1.218	0.031				2.738	1.219	0.025
Priority Bus 1 (P1)	44.299	12.731	0.001									
Priority Bus 2 (P2)	-46.220	12.701	0.000							-23.424	9.717	0.016
Priority Both (PB)							100.687	24.544	0.000			
Priority No Buses												
P1 Interaction Term	-81.536	16.602	0.000									
P2 Interaction Term	64.530	16.578	0.000	-0.813	0.428	0.058				59.623	15.611	0.000
PB Interaction Term							-6.768	1.567	0.000			
P-None (Base Case)	Base			Base			Base			Base		
Number of Observations			1,504			1,504			1,504			1,504
R-Square			0.904			0.902			0.901			0.902
Adjusted R-Square			0.904			0.901			0.901			0.902
DW Stat			1.971			1.978			1.965			1.982
DW P-Value			0.533			0.639			0.475			0.699

Table 4. Final Headway Regression Models

	Final Model Route 9					Final Model Route 15				
Predictor Variables	Coefficient Value	Std. Error	P-Value	Mean Contribution	Percent Contribution	Coefficient Value	Std. Error	P-Value	Mean Contribution	Percent Contribution
(Intercept)	114.733	21.465	0.000	114.0	12.9	108.853	19.737	0.000	108.9	13.3
Start Headway	0.933	0.009	0.000	830.2	93.7	0.930	0.009	0.000	762.1	92.9
Eastbound Direction										
Bus 1 Boardings	-2.732	0.346	0.000	-52.6	-5.9	-2.939	0.403	0.000	-53.6	-6.5
Bus 1 Alightings										
Bus 1 Lifts						-29.930	8.421	0.000	-4.5	-0.6
Bus 1 Stops	-6.451	1.236	0.000	-103.6	-11.7	-6.545	1.107	0.000	-104.8	-12.8
Bus 2 Boardings	3.006	0.342	0.000	65.1	7.3	2.390	0.408	0.000	43.5	5.3
Bus 2 Alightings										
Bus 2 Lifts						40.580	7.473	0.000	6.9	0.8
Bus 2 Stops	2.631	1.223	0.032	37.2	4.2	3.872	1.100	0.000	62.0	7.6
Priority Bus 1 (P1) *	44.488	12.699	0.000	44.5	5.0			N/A		
Priority Bus 2 (P2) *	-54.371	12.906	0.000	-54.4	-6.1			N/A		
Interaction Eastbound*P1 *	-84.500	16.545	0.000	-84.5	-9.5			N/A		
Interaction Eastbound*P2 *	62.437	16.548	0.000	62.4	7.0			N/A		
Interaction Bus 2 Lift*P2 *	58.583	15.437	0.000	58.6	6.6			N/A		
Mean Final Headway					886.742					820.507
Number of Observations:					1,504					1,457
R-Square					0.905					0.903
Adjusted R-Square					0.904					0.902
Durbin-Watson Stat					1.979					1.970
Durbin-Watson P-Value					0.646					0.530

*Note that Priority contributions are shown at the whole contribution rate and not the mean contribution rate to illustrate the relative impact of priority requests.

3.5 Final Headway Model

After the significant interaction terms have been found the final models can be prepared by building a new model with all original variables and each of the significant interaction variables added into the model. After removing the insignificant variables, proceeding in a stepwise fashion, the final headway models for route 15 and route 9 can be seen in table 4. In this table, note that only significant (at the P-value <0.05 level) factors are shown. The coefficient value column denotes the seconds each additional unit of that factor adds to the final headway between trips, or in the case of dummy variables the seconds that variable adds to the model when 1 or true. The P-value column shows the significance. For both models the number of observations, R-Square and Adjusted R-Square values are shown below the significant factors. Additionally the Durbin-Watson statistic and significance are provided as well.

In both models R-Square values are high and the variable signs are intuitive. Note how similar and not significantly different the start headway, bus 1 boardings, bus 2 boardings, bus 1 stops, and bus 2 stops coefficients are even though the routes are different.

Route 15 final headways are increased by initial headway, rear bus boardings, rear bus lifts and rear bus stops. The final headways are decreased by front bus boardings, front bus lifts, and front bus stops. The greatest mean contributors to bus bunching are front bus stops and front bus boardings with -104.8 and -53.6 seconds respectively. More than 90% of the final headway variation is explained by the model (adjusted $R^2 = 0.903$). The Durbin-Watson statistic is not significant in this model, and therefore serial correlation is not present in the model. As expected each of the front bus factors, which slow the bus down increase the likelihood of bunching.

For Route 9 final headway is increased by initial headway, rear bus boardings and stops, priority in only bus 1, and the interactions of eastbound direction and priority in only bus 2 and bus 2 lifts and priority in only bus 2. As expected greater values for these variables tend to decrease the likelihood of bus bunching as they increase initial headway or slow the rear bus down. Route 9 final headways are decreased by front bus boardings, front bus stops and rear bus priority requests. The highest mean contributors to bus bunching are front bus stops and front bus boardings with -103.6 and -52.6 seconds respectively. An adjusted R^2 of 0.895 demonstrates almost 90% of the variability in final headways is explained by the model. The Durbin-Watson statistic fails to be significant in this model as well signifying that serial correlation issues have been effectively addressed. As expected boardings, and stops for both the front and rear bus have the same effects as the model for route 15, where front bus factors slow the front bus, decreasing headway, and rear bus factors slow the rear bus, increasing headways.

In the case of Route 9 priority can add or reduce 5% or more of the final headway in a short segment (less than 5 miles). These coefficients and percentage contributions for priority are conservative as well because in high frequency periods, scheduled headways can be as low as 5 minutes. Front bus priority tends to increase headways while, the rear bus priority request has the opposite effect of increasing bus bunching due to the possibility of speeding up the rear bus. This relates to the effectiveness of skipping stops or giving selective priority to maintain headways especially in high frequency periods.

4. CONCLUSIONS

This study analyzed archived AVL/APC data from November 2009 for TriMet bus routes 9 (SE Powell) and 15 (SE Belmont). Segments of the routes were established in SE Portland from Milwaukie Ave to 86th Ave. The bus dispatching data, in stop event form, was converted to entire corridor trips and trips defined by time stops along the routes. For each set of trips, headway records were created between pairs of consecutive bus trips with initial headway equal to the change in departure times from the first stop and final headways equal to the change in arrival times at the last stop. Other factors (boardings, alightings, lift usage, stops, and TSP requests) were aggregated for each bus between the first and last stop. Final headway prediction models were created using regression analysis.

With high statistical significance, front bus factors (boardings, alightings, lifts) tend to decrease headway and encourage bus bunching, while rear bus factors tend to increase headways across all models. Priority requests have the opposite tendency, however. Where priority requests are significant, front buses tend to increase headways when requesting priority and rear buses decrease headways, which can lead to bus bunching. There is potential to use selective granting of TSP in order to maintain scheduled headways. In the Route 9/ SE Powell model where priority is available, TSP is a significant predictor of final headway in both the front bus only and rear bus only cases. Though, the greatest average contributors to decreased headways and bus bunching are the number of rear bus stops.

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