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Utilizing High Resolution Bus GPS Data to Visualize and Identify Congestion Hot-spots in Urban Arterials

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ABSTRACT

Congestion and travel delay on urban roadways can influence operating costs and service attractiveness. This research uses high resolution bus data to examine sources of delay on urban arterials. A set of tools was created to help visualize trends in bus behavior and movement; this allowed larger traffic trends to be visualized along urban corridors and urban streets. By using buses as probes and examining aggregated bus behavior, contoured speed plots can be used to understand the behavior of roadways outside the zone of influence of bus stops. Speed plots can be utilized to discover trends and travel patterns with only a few days' worth of data. Congestion and speed variation can be viewed by time of day and plots can help indicate delays caused by intersections, crosswalks, or bus stops. This type of information is important to transit authorities looking to improve bus running times and reliability. Congested areas can be detected and ranked. Speed plots can be utilized to reevaluate bus stop locations, e.g. near-side vs. far-side, and to identify locations where improvement are needed, e.g. queue jump lanes. Transportation agencies can also benefit from this type of information because arterial performance measures are difficult to estimate.

INTRODUCTION

Arterial corridors are one of the most important elements of any transportation network. Despite their relative significance, however, arterial performance measures are relatively underdeveloped. While this is partially because arterials are difficult to monitor and analyze, it is also a result of nationwide focus being placed on the creation of performance measures, data collection efforts, and research developments for freeway operations. Arterials are difficult to study because of the number of intersections, both signalized and unsignalized, and their wide variability in composition. Given the number of interactions and factors affecting performance, intersections are often the weakest link in arterial performance and safety. Understanding where delays occur and where intersections are underperforming can improve transit service, increase overall ridership, and reduce delay experienced by passengers. Being able to recognize and understand where inefficiencies are occurring is the first step in solving arterial congestion problems, and having performance metrics which assess these conditions can be used by transit agencies and operators to identify these specific problem areas along urban arterials and implement solutions [1].

Using data collected from buses in Portland, Oregon, this study examines arterial traffic performance – building upon prior research – and uses high resolution bus data to examine portions of arterial roadways in between bus stops. Examining this inter-bus-stop area is useful for understanding general traffic conditions on arterials and for identifying potential issues. Furthermore, using this high resolution bus data provides the opportunity to explore the potential of using buses as probes to examine general traffic trends.

BACKGROUND

Traffic performance along arterials or corridors is a growing area of research in traffic operations, and has been examined through sampling travel times, applying traffic flow theory models, or looking directly at delays caused by signals [2] [3]. Because of the importance of arterials, a growing body of research is dedicated to improving these techniques to better understand performance. Some research predicts travel times by using aggregated data from signal loop detectors, green times, cycle lengths, and offsets for the signals in the corridor [4]. Additionally, researchers have analyzed archived bus data to examine travel-time delay, deviation, and coefficient of variation [7] [12] [13] [14] [15]. Others studies have examined readily available bus data to understand if it is a viable metric for arterial traffic performance.

Since 1997, the Tri-County Metropolitan Transportation District of Oregon (TriMet) has been archiving stop level automatic vehicle location (AVL) and automatic passenger count as part of the their Bus Dispatch System (BDS). Past research has included attempts to use this AVL bus data at the stop level alongside vehicle detector data to estimate trajectories and detect congestion [5]. Researchers have also used this data to help study factors which affect bus travel time and service reliability at the point-segment level [6] [7] [8], the stop-to-stop segment level [9], and the route level [10] [11].

It was not until recently that researchers began using high-resolution time and position bus data to estimate bus travel speeds between bus-stops, categorize speed breakdowns, and identify signal and/or queuing delays [16]. Until the recent introduction of high-resolution data, researchers were mostly able to examine bus-stop level behavior and bus stop to stop performance metrics on urban arterials. The introduction of higher resolution data has removed much of the guesswork involved in understanding bus performance in between bus stops, and allowed for improvements in the application of using buses as probes to assess arterial traffic performance.

The use of buses as probes to estimate travel times has been attempted in the past but with coarser data [17] [18]. In particular, TriMet buses have been used as probe vehicles to evaluate arterial performance and transit performance [19] [20] [21]. However, these studies were confined to first generation stop level AVL data which had only time records for bus arrivals and departures from a bus stop.

Recent research projects have focused on the proposed study area, SE Powell Boulevard, to study the performance of the adaptive traffic signal system (SCATS) [22], the impact of transit signal priority (TSP) on transit performance [9], air quality at bus stops [23], sidewalks at intersections [24], and sidewalks at mid-block locations [25]. In addition, recent papers have successfully integrated detailed signal timing and first generation AVL data to simultaneously estimate the impact of traffic volumes and intersections on bus travel times [1] and have examined arterial travel speeds using the newly available high resolution bus data [16]. This paper will add to the existing knowledge of arterial performance by illustrating tools that can be used to examine travel behavior and delay along urban streets and urban corridors and to show that high resolution bus data provide helpful insights into arterial road performance. To do this, we propose a simple method of visualizing high resolution bus data to quickly identify congestion and potential problem areas along arterial roadways. This methods combine both first generation AVL data and high resolution data. The sites of the different analyses are displayed in Figure 1 below.

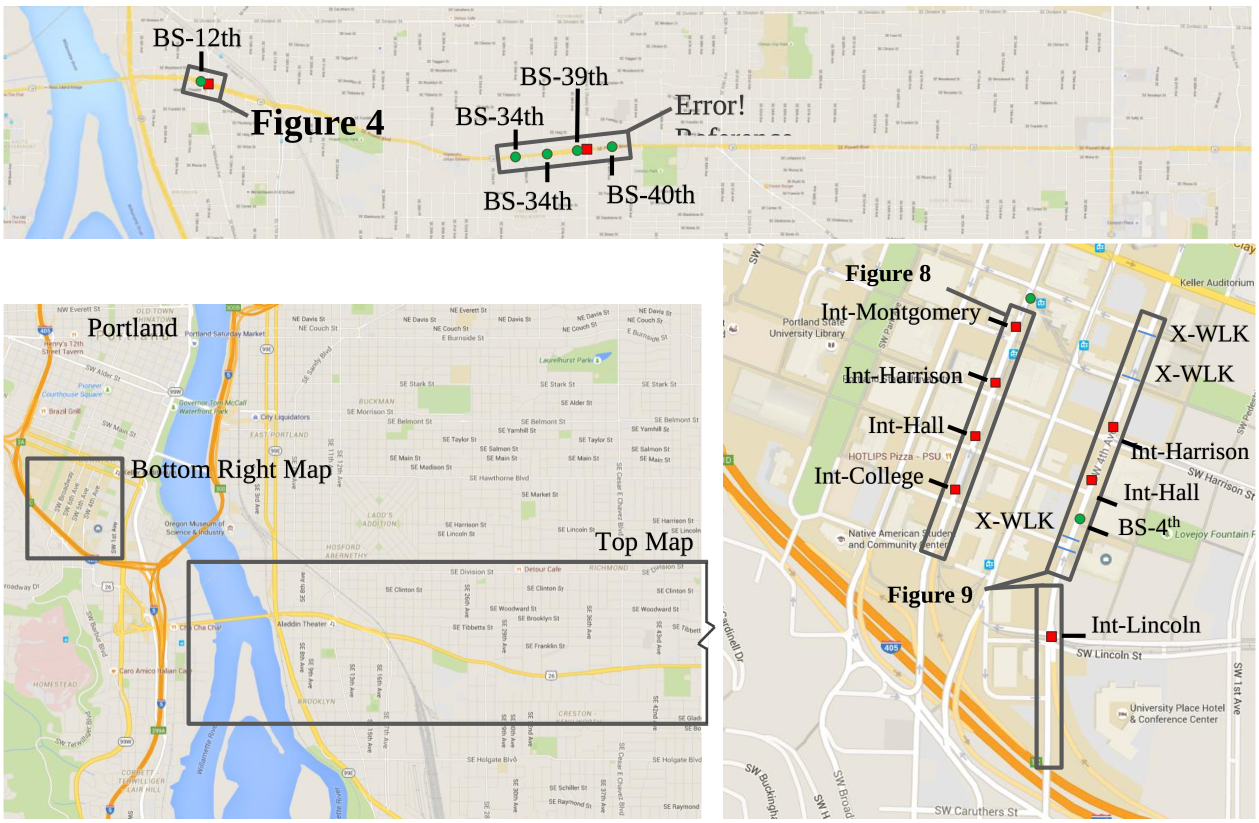

Figure 1: (Bottom-Left) Map of Portland showing the relationship between (Top) Map of Powell Blvd. in Portland, OR. Each of the bus stops used in the analysis are shown by green dots and labeled. Signalized intersections included in analysis are shown with red squares. (Bottom-Right) Map of downtown Portland. Includes the urban streets analyzed in the paper.

DATA

In late 2013, TriMet second generation AVL data became available. The second generation data have finer granularity at 5-second intervals (5-second resolution, 5-SR) time, position, bus identification, and other information are recorded (See Table 1).

This new AVL data has been integrated with first generation stop-level data to provide passenger boarding and alighting as well as arrival and departure data at bus stops. We merged the AVL and stop level data utilizing bus identification, location, train mileage, and trip ID fields. With the merged data it is possible to obtain information about traffic conditions in which buses operate, passenger movements, and dwell times at bus stops. While the 5-SR data generally records time and location information every five seconds, often referred to as "breadcrumbs," it fails to do so when (1) the bus is stopped, i.e. wheels are not moving, for more than five seconds or (2) when the bus enters an administrator defined area. For the latter case, the 5-SR dataset does not contain records around a bus stop; the bus stop area or bus zone is usually ten meters upstream and fifteen meters downstream from the bus stop pole. The bus identified bus zones utilizing train mileages before and after the bus stop. The bus stop level data includes vehicle arrival, dwell, and departure time, hence, the two datasets are complementary.

Table 1 Sample of 5-SR data set

Service Date	Vehicle ID	Meters	Actual Time	GPS Latitude	GPS Longitude
1-Nov-14	2004	55559	28773	45.50291	-122.42633
1-Nov-14	2004	55579	28778	45.50277	-122.42618
1-Nov-14	2004	55614	28783	45.50247	-122.42616
1-Nov-14	2004	55655	28788	45.50213	-122.42595
1-Nov-14	2004	55696	28793	45.50174	-122.42588
1-Nov-14	2004	55741	28798	45.50133	-122.42591
1-Nov-14	2004	55765	28803	45.50109	-122.42593
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DATA VISUALIZATION: HEAT MAP

A series of tools were developed to analyze the November 2014 high-resolution data. Using time and location coordinates of the entire 5-SR data set as inputs, an interactive heat map was created to display concentrations of GPS points. Because data is generally recorded every five seconds, locations where buses stop or move slowly, as indicated by speed, will leave higher levels of "breadcrumbs," and thus have denser collections of GPS points. The heat map tool assigns a color value to different densities, with high concentrations visible as red, and lower concentrations in blue. Due to the density of points, locations where buses stop, like bus stops and traffic intersections, and stretches of road where buses are moving slowly become easily visible. Several features have been built into the heat map to allow for customizability when examining these data, and by interacting with the heat map—either by zooming in to specific segments of road or by changing scale and blur attributes—the user can observe general trends in bus behavior.

Figure 2 illustrates the usefulness of this type of visualization. Within Box A are two bus stops—one for westbound traffic and one for eastbound traffic—and the intersection of Milwaukie & SE Powell. Even with the close proximity of the intersection to the westbound bus stop, clear trends about where buses are stopping can be seen, showing that many buses are stopping at the intersection before reaching the bus stop. Conversely, the bus stop for eastbound traffic is slightly upstream of the intersection, and the buses that stop at the bus stop and at the intersection cannot be easily distinguished from the visualization alone. For both bus stops, the gap in "breadcrumb" recordings as a result of the bus being within a bus zone, described above, is visible as a gap in the cloud. This gap can be seen slightly upstream of each bus stop, where the distance between zone edge and the bus stop pole is greatest.

Box B of Figure 2 illustrates another useful application of the heat map, finding locations of congestion. Because the maps show concentration of points, extended areas of high concentration indicate frequent points generated from slow-moving traffic. This stretch of road along Powell from 14th to 11th is notoriously congested in the morning peak. The congestion can also be triggered by right lane merger from SE 17th street and continue through the right edge of the figure. Differences in color and intensity between the different panels of Figure 2 are a result of different blur factors and zoom extents.

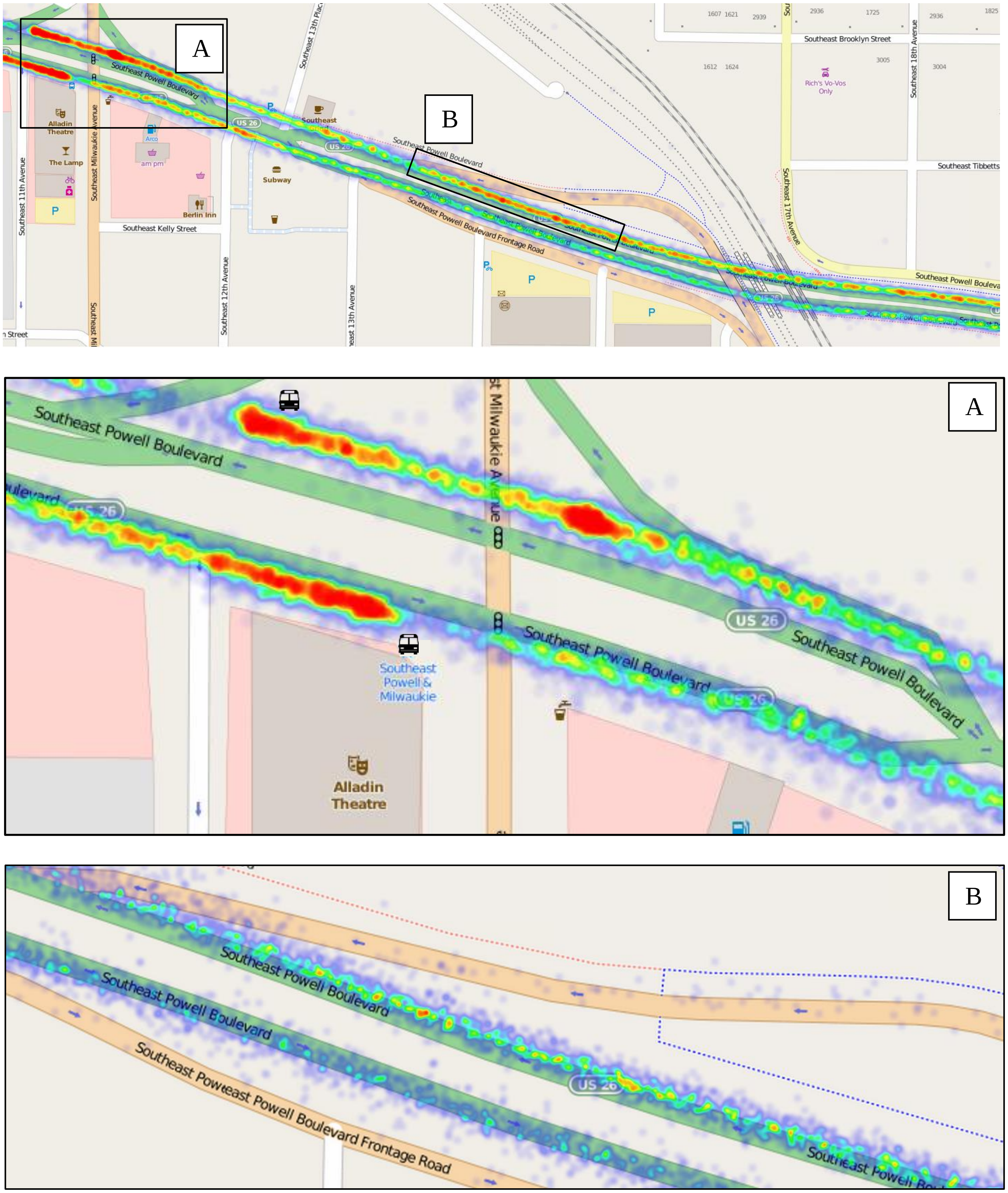

Figure 2: Example of heat map output: (top) analysis segment stretching along SE Powell from 14th to 11th, (middle) zoomed in portion of Box A – bus stop and (bottom) Box B – merger of 17th and Powell.

This tool was used to examine general behavior of buses and select areas that necessitated further exploration. From this initial data exploration, four distinct segments were chosen for further numerical analysis.

DATA VISUALIZATION: NUMERICAL METHOD

The heat map visualized a data set that included all buses for the month of November, 2014. The data set used in the numerical analysis, on the other hand, only included weekdays of the first three weeks. The fourth week was omitted from the analysis due to the Thanksgiving holiday and the altered holiday bus schedule that was in effect. This was done so that average workday travel trends could be analyzed. To examine bus behavior at the four selected segments in more detail, a method to filter, analyze, and visualize speeds from 5-SR was created. Filters were also made to select subsets of data based on day, time of day, and direction of travel.

First, the length of time (in seconds) and distance (in feet) is calculated between each pair of consecutive GPS points. By defining pairs of GPS points nearest to a Point of Interest (POI) for a selected direction of travel, speeds can then be determined for buses passing that POI. Any point along the route can be a POI. In this research bus stops and intersections were always POI, in addition POI were added so that segments between consecutive POIs have always a length less than 30 feet or 9.15 meters. Knowing the direction of travel also allows for the ability to determine points upstream and downstream of the POI. Once speed is determined, the process of examining a specific point, location, or segment can begin. All defined points are compared to the POI to find buses that are one GPS point upstream of the POI and one GPS point downstream of the POI. On the segments analyzed, for a typical weekday there are on average 70 point-pairs (one point upstream and one point downstream of the POI) surrounding any given POI. If 15 weekdays are included, this results in over 1,000 point-pairs to estimate travel times and speeds. Figure 3 shows the westbound bus stop at Milwaukie and SE Powell (same as seen in Figure 2). In the 5-SR dataset the location of the GPS points have more variability (longer tail) after the bus stop than before the bus stop.

Figure 3: Example of a POI, red dot at the westbound bus stop at Milwaukie and SE Powell.

Starting with a specific POI, average speed around that point can be calculated. The same process that is applied to individual POIs can also be applied to a range of POIs that occur over a specified segment. For this paper, four segment-level analyses were completed, with the average distance between consecutive POIs ranging from 25 to 30 feet.

APPLICATION (I): CONGESTED URBAN CORRIDOR

The first type of roadway to which this numerical approach was applied was SE Powell Boulevard. The boulevard runs from the nearby city of Gresham and enters into the downtown core of Portland, Oregon from the southeast. Powell Boulevard is a major arterial in the Portland metropolitan area and carries between 45,000 and 30,000 vehicles a day (more traffic closer to downtown Portland). It is a popular commuter route during the morning hours, bringing people from neighboring suburbs into downtown. Speed limits along Powell do not exceed 35 miles per hour. TriMet bus route 9 runs directly along the corridor. Bus stops are located in varying proximity to intersections, offering a variety of unique situations to investigate. Three segments along Powell were chosen to be examined in more detail.

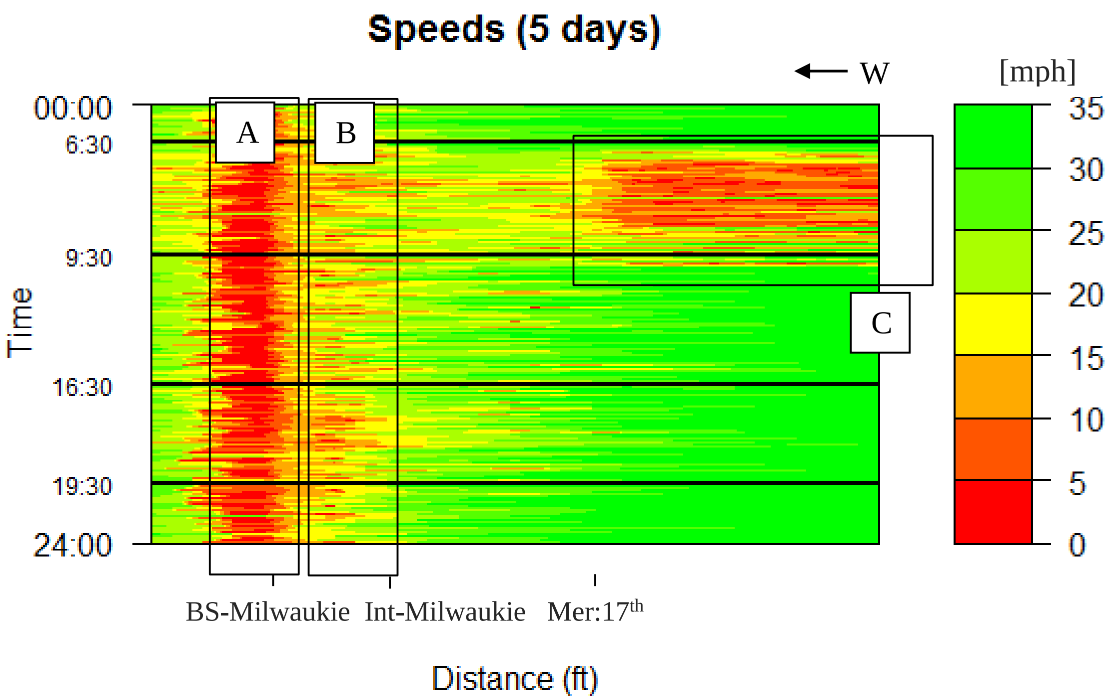

Figure 4: An application of numerical method applied to a 2,000 ft segment of SE Powell

Figure 5 – Powell Blvd and the merging of 17th Ave, congestion seen in box C of Figure 4.

Westbound SE Powell between SE 11th and SE 17th

Figure 4 shows the same segment viewed in Figure 2. For this illustration, color represents speed where green indicates faster speeds. Due to the 35 mph speed limit on Powell, all buses with speeds over 35 mph are represented by the highest level green. The y-axis is created by ordering all bus observations by time of day. In doing so, behavior during morning peak (indicated as 6:30 a.m. – 9:30 a.m.), midday off-peak (9:30 a.m. – 4:30 p.m.), and evening peak (4:30 p.m. – 7:30 p.m.) can be more easily examined. Horizontal lines are included in these plots to clearly distinguish the different time periods. The x-axis of these visualization represent distance, in feet, from the starting POI to the final POI, and is equivalent to the length of the segment. Direction of travel is given along the top border of each plot. Geometry of the segment, including intersection locations, bus stops, or other design features are ordered across the bottom of the plots. Keeping with previous examples, the stretch of SE Powell from 14th to 11th is included in Figure 4, with a satellite image of the segment in Figure 5.

The bus stop at SE Powell and Milwaukie is clearly visible as a vertical band of low speeds that stretches through the entire day (highlighted in Box A in Figure 4). Slower speeds caused by congestion and delay at the intersection of SE Powell (ADT ≈ 45,000) and Milwaukie (ADT ≈ 21,000) are also clearly visible (Box B). During the morning peak, we can see traffic is experiencing delays that extend backwards and towards Box C. Low speeds begin at the merger of 17th and SE Powell; 17th street (ADT ≈ 8,500) creates severe congestion during morning rush hours. This delay dissipates as the day progresses and typically disappear by 10:00 a.m.

Westbound SE Powell between 33rd and SE 42nd

This segment stretches nearly half a mile; within the segment are four bus stops and one signalized intersection, SE Powell and SE Cesar E Chavez Blvd. The bus stops are clearly visible as vertical red bands that last throughout most of the day (Figure 6). The percentage of buses that stop at Cesar E Chavez is compared to several other bus stop nearby in Figure 7.

During the morning peak there are also thin horizontal bands of slow speeds that stretch the width of the segment (Figure 6, Box A). In some days, delays and queuing that starts at Powell and 17th extend all the way to Powell and 39th and beyond. Between the morning peak and midday off-peak, intersection delay is also noticeable at Cesar E Chavez Blvd (Figure 6, Box B) and between the 40th St. bus stop and the Cesar Chavez bus stop.

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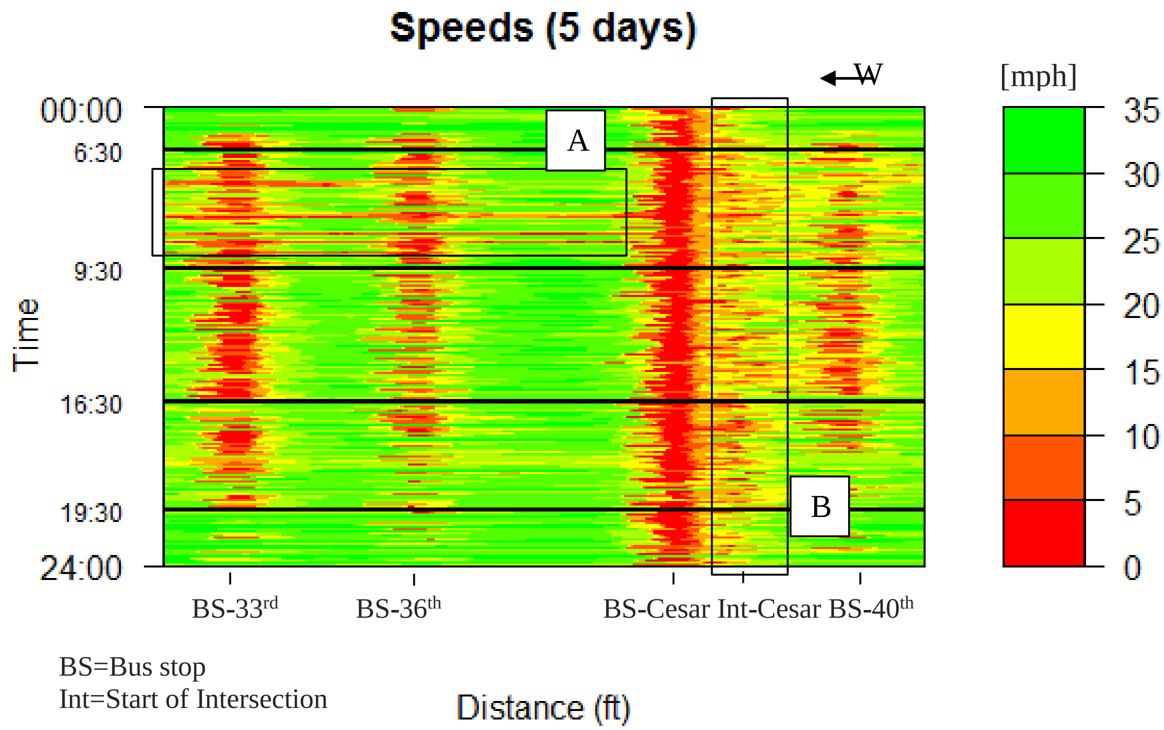
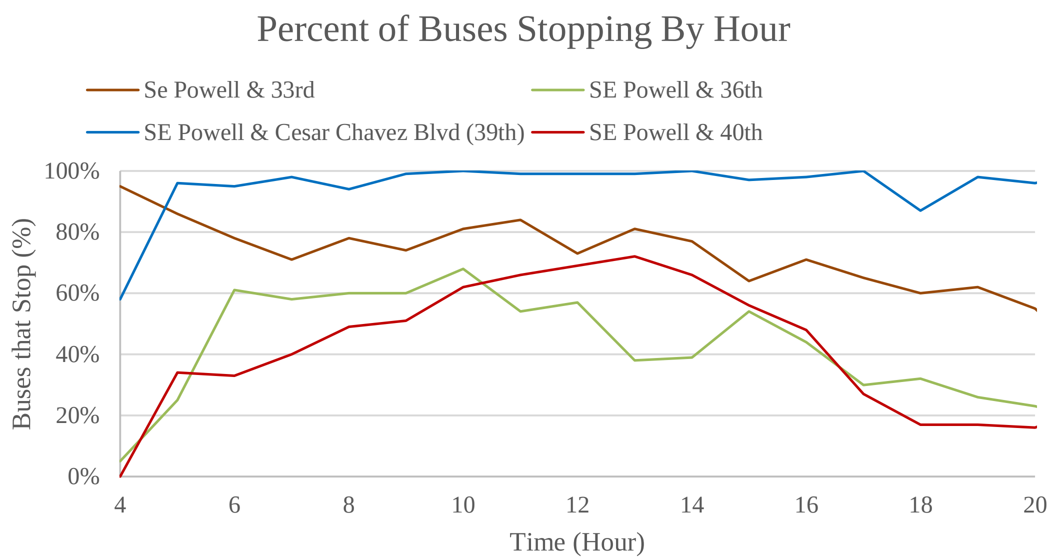


Figure 6: Speed plot between 42th and 33rd along SE Powell Boulevard.

It is possible to observe a correlation between the number of buses stopping by time of day and the intensity of the red color in Figure 6. While almost 100% of buses stop at 39th during the day, the same cannot be said for the 36th or 40th bus stops. The sporadic vertical red bands which appear at 36th and 40th, Figure 6, in the morning hours dissipate by the middle of the evening peak. The Cesar Chavez (39th) bus stop is the most utilized bus stop in this segment. This stop has the highest number of boardings and alightings and also some transit users use this stop to transfer to/from buses running along 39th.



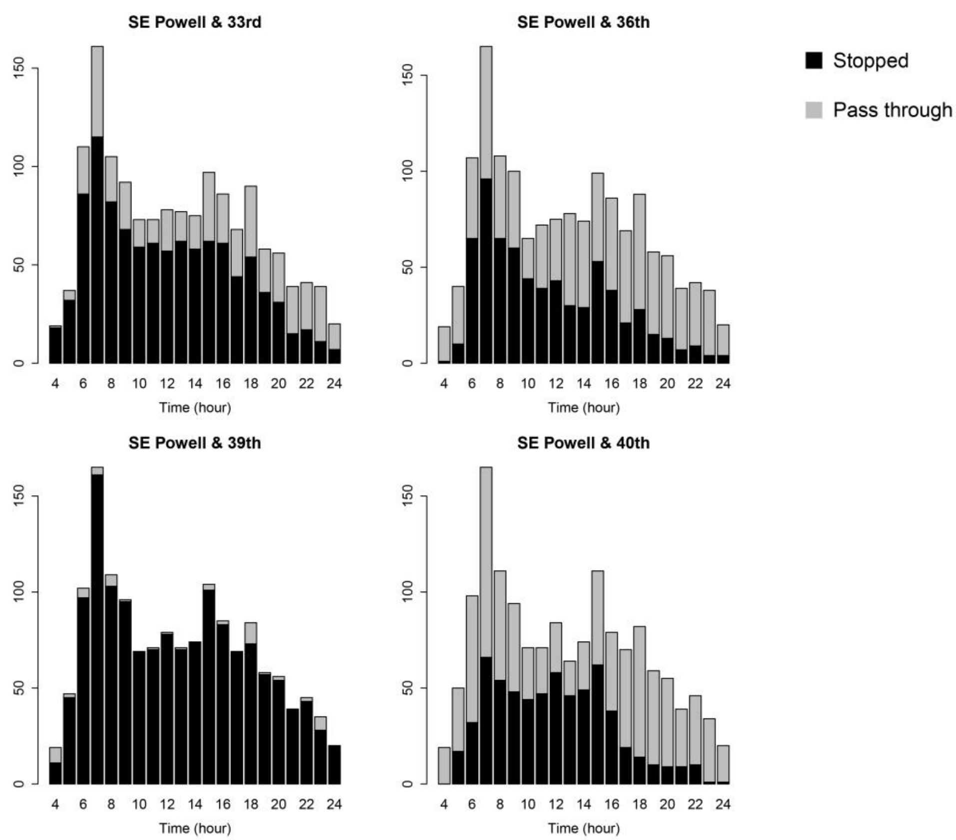


Figure 7: Percent of buses stopping by time of day for a cluster of bus stops near Cesar Chavez (39th)

APPLICATION (II): URBAN STREET

Urban streets behave differently than arterial corridors. They are characterized by lower speeds and sometimes increased stop-and-go traffic as a result of a more densely laid out grid, pedestrian crosswalks, and traffic signals. Both the heat map and numerical method were applied along two different urban streets. Bus route 9 enters Portland from the southeast and heads north along SW 6th St. (ADT ≈12,000). The 5-SR dataset from November 2014 was utilized to examine this urban street. A second street, SW 4th St. (ADT ≈ 11,000), was also chosen because it contains highly trafficked pedestrian crosswalks, bus stops, and intersections. A different set of 5-SR data was used for this street, from February 4th, 2015 and contained all buses that traveled along this segment (TriMet routes 12, 43, and 44). To supplement analysis along 4th St., footage of bus movements was also recorded and analyzed. Our video footage was able to more accurately portray when a bus is stopping, for how long a bus is stopped, and when a bus starts moving again. The video data showed that 5-SR data was accurate. In plots of downtown speeds, a 25 mph cap on speeds was used for the upper speed limit. Note that signal timing progression in the downtown core of Portland is set to a speed of 15 to 18 mph.

SW 6th between Jackson and SW Montgomery

This 1,100 ft segment of an urban street spans several intersections with no bus stops, allowing us to see how buses interact solely with closely spaced intersections. Figure 8 shows the four intersections covered by this segment. The intersections at College and Montgomery caused the most delay. Time of day is seen to be unimportant in determining traffic performance on this stretch of urban street. This segment along SW 6th street is part of a transit corridor and buses have a dedicated travel lane. Hence, traffic levels are not affecting bus travel time performance. Because intersections are more closely spaced and there are no bus stops, the benefits of a dedicated bus lane and signal timing progression can be seen in the various green horizontal bands that stretch the width of the segment.

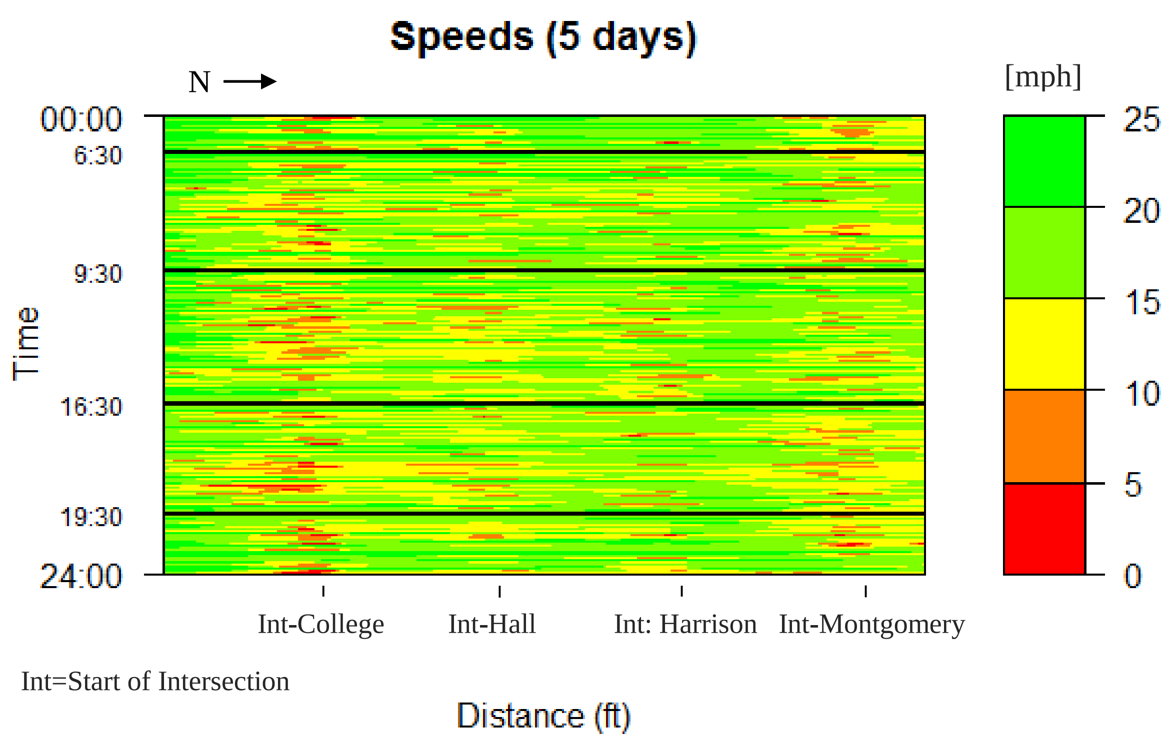


Figure 8: SW 6th from SW Jackson to SW Montgomery

SW 4th between SW Caruthers and SW Mill

The second urban street segment selected is a stretch of arterial road that feeds into the SW corner of downtown Portland. This segment, stretching along SW 4th St. from SW Caruthers to SW Mill St. includes one bus stop. Directly upstream from this stop there are two marked crosswalks with heavy pedestrian traffic (SW 4th and College). There are also two signalized intersections (Hall and Harrison) and a marked crosswalk (SW 4th and Montgomery) with significant pedestrian traffic. The 5-SR data for this segments is from February 4nd, 2015.

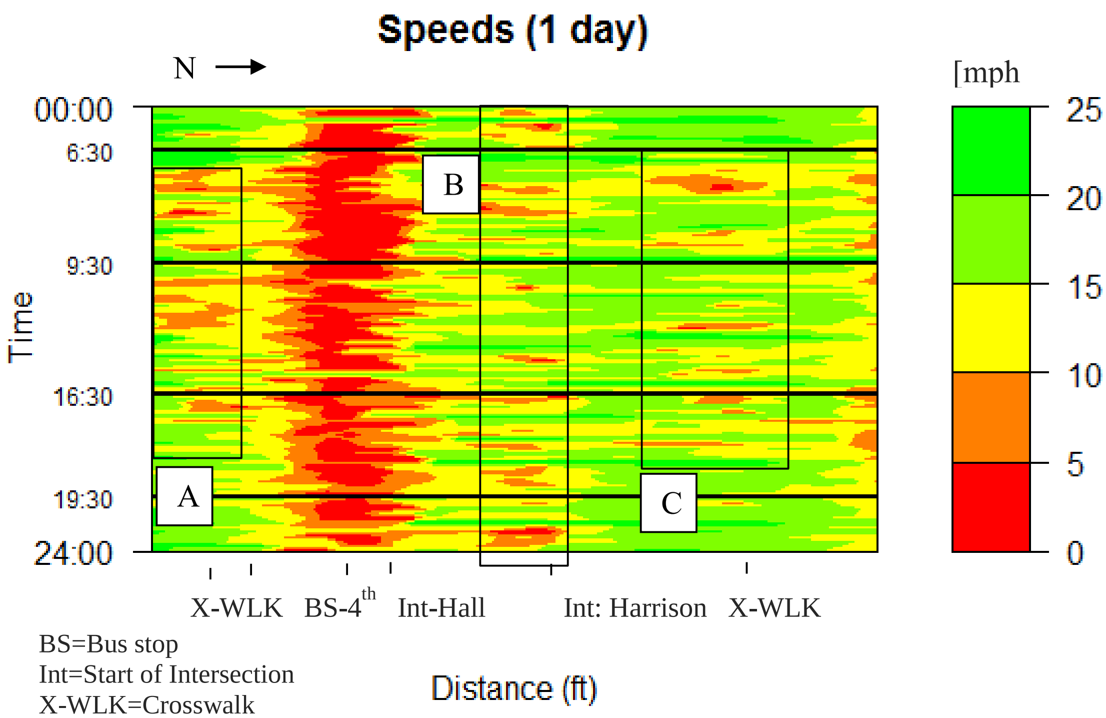


Figure 9: 4th Street Speed Plot.

Figure 10: (Left) Satellite view of crosswalk at college (A in Figure 9) and (Right) view of crosswalk at Montgomery (C in Figure 9)

The visualizations from this stretch of arterial roadway captures delay caused by crosswalk activity at SW 4th and College and SW 4th and Montgomery, Figure 9 boxes A and C respectively. There is heavy pedestrian traffic (students) going to/from Portland State University buildings along 4th street as well as office workers and students accessing food carts and restaurants along SW 4th street during the lunch break. Crosswalk activity can be seen during morning peak, midday, and early evening.

Thin bands of higher speeds can be seen upstream and downstream. These however, are interrupted occasionally by the signalized intersection at SW Harrison Street. The street car utilizes the SW 4th Street and Harrison intersection. Due to the street car's traffic signal preemption and relatively low speed signal timing coordination cannot be effectively achieved in this segment along SW 4th street. Figure 9 should be contrasted against Figure 8; on SW 4th there is no dedicated bus lane and signal progression cannot be implemented due to the street car and the heavily utilized marked pedestrian crosswalks.

DISCUSSION & CONCLUSION

Arterial corridors and urban streets are important components of any transportation network, and yet, there are few studies examining their performance. Using new high resolution bus location data, we have developed tools which can help to quickly locate and examine sources of delay along these streets. By using buses as probes and examining aggregated bus behavior, contoured speed plots can be used to understand the behavior of roadways outside the zone of influence of bus stops. Our analysis shows that speed plots can be successfully used to discover trends and travel patterns with only a few days' worth of data. Congestion and speed variation can be viewed by time of day, and with knowledge of a transportation network and/or Google Maps street or satellite views, these plots can help indicate congestion caused by intersections, crosswalks, or bus stops.

Transportation agencies can detect and rank congested segments or locations. Speed plots can also be utilized to reevaluate bus stop locations, e.g. near-side vs. far-side, and to identify locations where improvement are needed, e.g. queue jump lanes. This research focused on segments outside bus stops area of influence. Future research efforts can analyze speeds around bus stops.

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