Optimizing Bus Rapid Transit, Downtown to Oakland *

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Overview

We analyze Clever Devices bus data in search of ways to optimize bus traffic from Downtown to Oakland on Forbes and Fifth Avenues. A key finding is that eastbound buses on the dedicated lane on Fifth Avenue are less affected by rush hour traffic compared to eastbound buses on Forbes Avenue. This result is likely to hold for a possible dedicated lane on Forbes Avenue. On the other hand, bus trips on Fifth Avenue typically take about 4 minutes longer than on Forbes Avenue, despite Fifth Avenue having the dedicated bus lane. We caution that this difference should not be used to predict transit speed on a possible dedicated lane on Forbes Avenue. One complicating factor is that the bus lane stoplights on Fifth Avenue are synchronized for opposing traffic. Minor adjustments to the stoplight timing scheme could potentially allow for smoother eastbound bus traffic without disrupting westbound traffic. A related finding is that the "time cost" – the increase in overall trip time – resulting from servicing a bus stop on Fifth Avenue is substantially smaller than the time cost on Forbes Avenue. Our estimates of the time cost of servicing bus stops may be useful for optimizing the frequency of bus stops in a Bus Rapid Transit system.

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1 Executive summary

Bus transit from Downtown to Oakland on Forbes and Fifth Avenues is of particular interest to the PAAC because this corridor is the most heavily used section of the PAAC's planned BRT system. Our research was prompted by discussions with the PAAC in March 2011, when staff expressed interest in using data collected by Clever Devices to understand various facets of bus performance with the ultimate goal of identifying ways to optimize the BRT system. Here we present some of our results.

- Buses starting at Jumonville Street on Fifth Avenue's dedicated bus lane take an average of about 4 minutes longer to reach Bellefield Avenue compared to buses on Forbes Avenue. We refer to this as the "4-minute advantage" of Forbes Avenue over Fifth Avenue.
- The data suggests that the delay on Fifth Avenue is largely due to structural issues including traffic light asynchronization, additional stop signs, and lower speed limits.
- The structural differences between Forbes and Fifth Avenues prevent using the parallel sections of the two routes for a reliable prediction of the average transit time for a dedicated bus lane on Forbes.
- A clear upside to using a bus lane is that transit times for buses on dedicated bus lanes are less affected by rush hour traffic. This is confirmed by the data.
- Dwell time refers to the time a bus has its doors open while servicing a bus stop. Dwell time typically makes up around 15% of the total time of a trip. Note that dwell time does not include the time required for a bus to slow down and speed back up at a bus stop.
- The "time cost" for servicing a bus stop is the average increase in trip duration associated with servicing each stop. The data suggests that the time cost of servicing a stop on Fifth Avenue is currently less than 4 seconds. By contrast, the cost of servicing a stop on Forbes is about 13 seconds.
- The 4-minute advantage of Forbes Avenue over Fifth Avenue suggests that there may be ways to move passengers more quickly from Downtown to Oakland. Assigning more bus routes to Forbes Avenue instead of Fifth Avenue or exploring alternative stoplight synchronization schemes on Fifth Avenue are two examples.
- Exploratory graphics reveal the locations, times, and frequencies of the phenomenon of buses "bunching," and we suggest that further research on this topic could be fruitful.

2 Introduction

On March 18, 2011, PAAC representatives expressed interest in obtaining an analysis of PAAC bus data to address several questions. The key research goals outlined in that meeting were as follows:

1. Identify factors that influence dwell time and assess the relative importance of dwell time for overall bus trip time between Downtown and Murray Avenue on Forbes and the section of Fifth Avenue running parallel to Forbes. Dwell time refers to the amount of time that bus has an open door while servicing a bus stop.

2. Compare Oakland-bound bus traffic between Jumonville and Bellefield on Forbes and Fifth Avenues with the goal of predicting the effects of putting a dedicated bus lane on Forbes Avenue.

3. Study the phenomenon of buses "bunching" to understand the scale of the problem and its causes.

In this report we discuss our findings relating to each of the above research objectives.

3 Data

Data was provided from all 400+ buses with Clever Devices installed for October and April for the two school years 2009-2010 and 2010-2011. All results presented here are for October 2009. Accurately matching records to route-version-specific geographic locations in more recent months relies on the General Transit Feed Specification (GTFS) transit specification system which needs to be reconciled with the way that the Clever Devices encodes record locations.

4 Dwell time analysis

Figure 1 displays the corridor of interest, from Downtown to Forbes and Murray. We will discuss two aspects of dwell time. The first part is identifying things that contribute to dwell times at individual bus stops. The second part is to understand the relative contribution of dwell time to overall trip time. Figure 2 gives a first indication of sizes of typical dwell times.

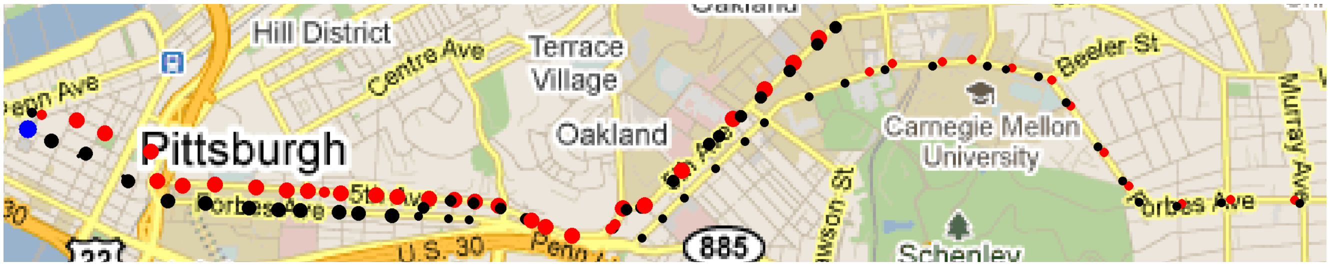


Fig. 1: *Including route 500, the 61s, and 71s, there are 98 serviced bus stops in the region of interest. The area of each circle is proportional to the number of route versions that contain the bus stop. The color indicates the direction of service. Black locations are serviced only by buses moving east. Red locations are serviced only by buses moving west. The blue location (far left) evidently serves traffic in both directions.*

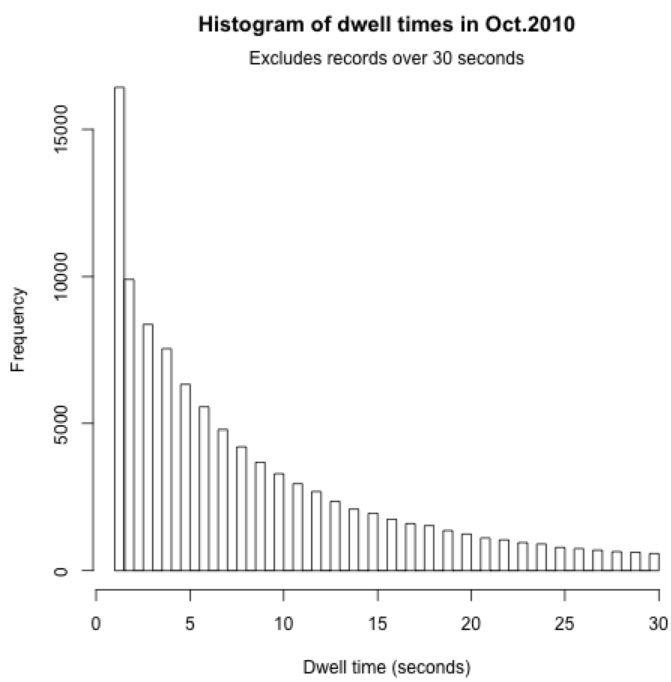


Fig. 2: *The distribution of dwell times for all records of serviced stops on the Murray-Downtown corridor in October 2010. Dwell times are highly variable and skewed right. The median dwell time is 6 seconds. Note that the horizontal axis is truncated on the right at 30 seconds.*

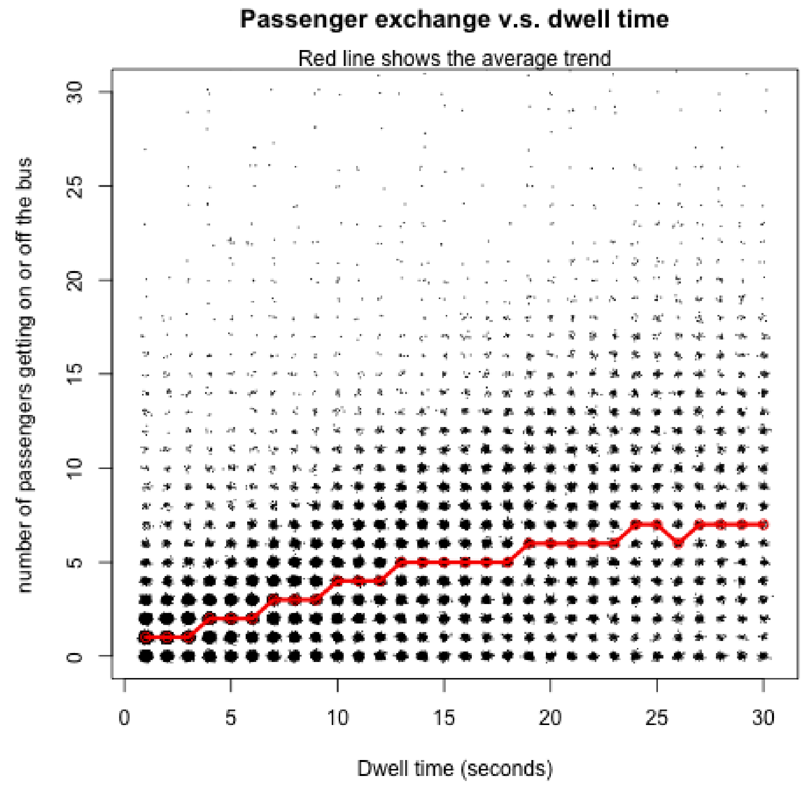


Fig. 3: *There is a weak relationship between the number of passengers entering and exiting the bus and the dwell time. We have reason to believe that there are substantial sources of error in the passenger counts data; without these sources of error the relationship might be more clear.*

4.1 Factors influencing dwell time

Figure 3 confirms that dwell time is associated with large numbers of passengers getting on and off the bus. Mysteriously, passengers seems to enter and exit the bus for dwells of as little as 1 second. This could be explained by people triggering the motion sensors as they stand near the the rear bus door when the bus doors open momentarily.

The data has little besides passenger exchange (Figure 3) that relates to dwell time. However, anecdotal evidence suggests that bus fare payment method, which is not available in the data, affects dwell time. People paying in cash tend to increase dwell time.

4.2 Effects of dwell time

Dwell time contributes to overall trip time. The total amount of dwell time in a trip depends partly on the fraction of bus stops that a bus services during a trip. Figure 13 illustrates the positive correlation between the fraction of bus stops that are serviced in each trip and the fraction of trip time that consisted of dwell time for each trip. Buses typically service somewhere between 10% and 50% of the bus stops illustrated in Figure 1. Adding up the dwell time over each trip, buses spend about 5% to 25% of each trip time idling at bus stops.

Note that there is not always a direct correspondence between dwell time and trip time, in the sense that a second of dwell time does not necessarily contribute a full second to the trip time. Dwell time is a measure of how long the doors of a bus are open, not how long the bus is motionless. A bus that is waiting at a red stoplight may open its doors and close them again as soon as the light turns green. Of course, in this case the dwell time that is recorded at the stoplight contributes nothing to the overall trip time, since the bus was stopped at the stoplight anyway.

Dwell time is conceptually similar to the "time cost" of servicing a bus stop. The time cost is the effect of servicing a bus stop on overall trip time. The time cost is not directly observable in the data. Instead, we estimate the time cost of servicing bus stops using statistical modeling in Section 5.2. The time cost of servicing bus stops should factor importantly into a decision on the number of bus stops to put along a route.

5 The speed of bus traffic on Forbes versus Fifth

Buses from Downtown to Oakland start out on Forbes Avenue. At Jumonville Street, some buses cross over to the dedicated bus lane on Fifth Avenue which moves parallel to Forbes Avenue the rest of the way to Oakland, against the direction of all other vehicular traffic on Fifth Avenue. We examine transit times for two sections of the Downtown-Oakland corridor. The larger section is from Jumonville to Bellefield (Figure 4) and the smaller section is from Craft to Bigelow (Figure 7).

5.1 The Jumonville-Bellefield corridor

Figure 5 shows that buses in this corridor go much faster on Forbes Avenue compared with Fifth Avenue. A typical trip on Forbes lasts about 7.5 minutes while a typical trip on Fifth lasts about 11.4 minutes. This result is somewhat surprising, as conventional wisdom suggests that the dedicated bus lane on Fifth should speed up bus traffic. However, it is important not to jump to the conclusion that putting a bus lane on Forbes Avenue would be detrimental to bus traffic. In Section 5.3 we discuss some reasons for the delay on Fifth that have nothing to do with the fact that Fifth Avenue has a dedicated lane.

Figure 6 shows that Fifth Avenue buses are less affected by rush hour traffic than are Forbes

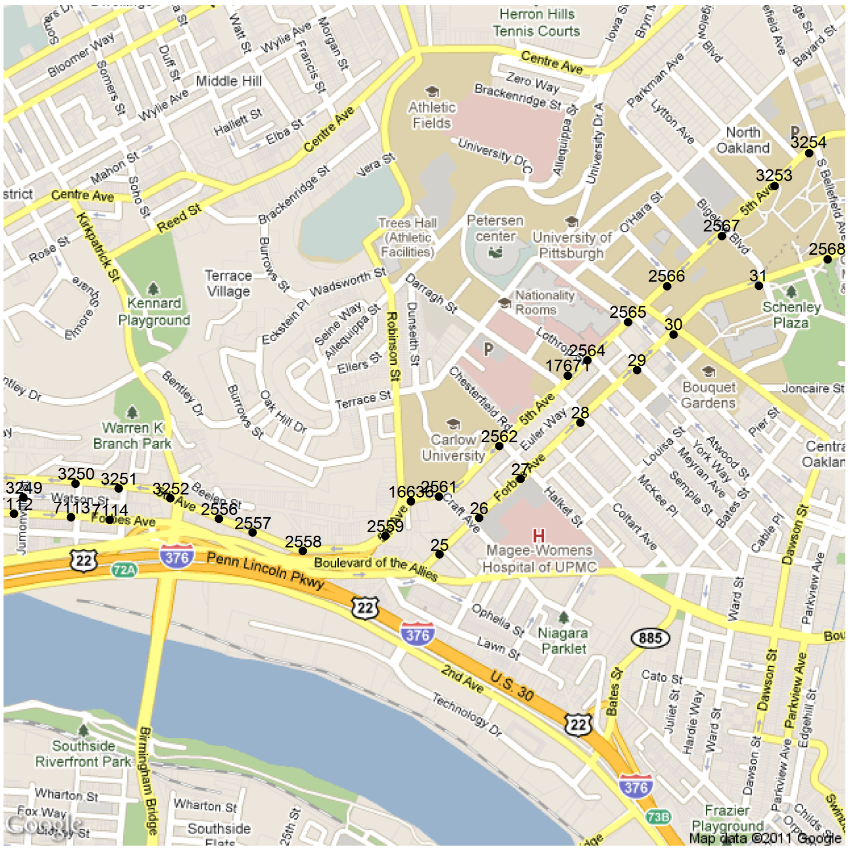
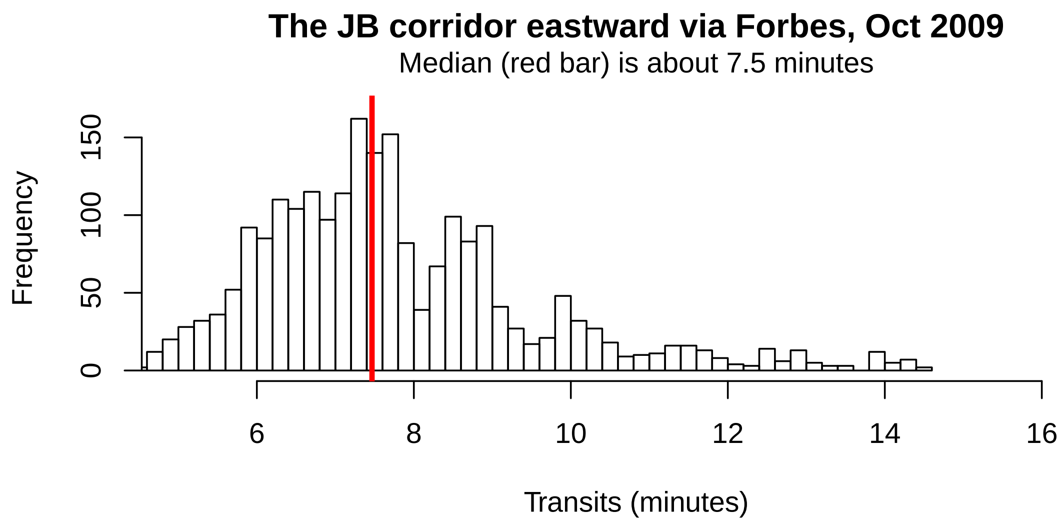


Fig. 4: *Here is a close-up for the bus stops in the Jumonville-Bellefield corridor that are serviced by eastbound buses. We want to compare the speed of bus traffic on 5th avenue to the speed of bus traffic on Forbes.*



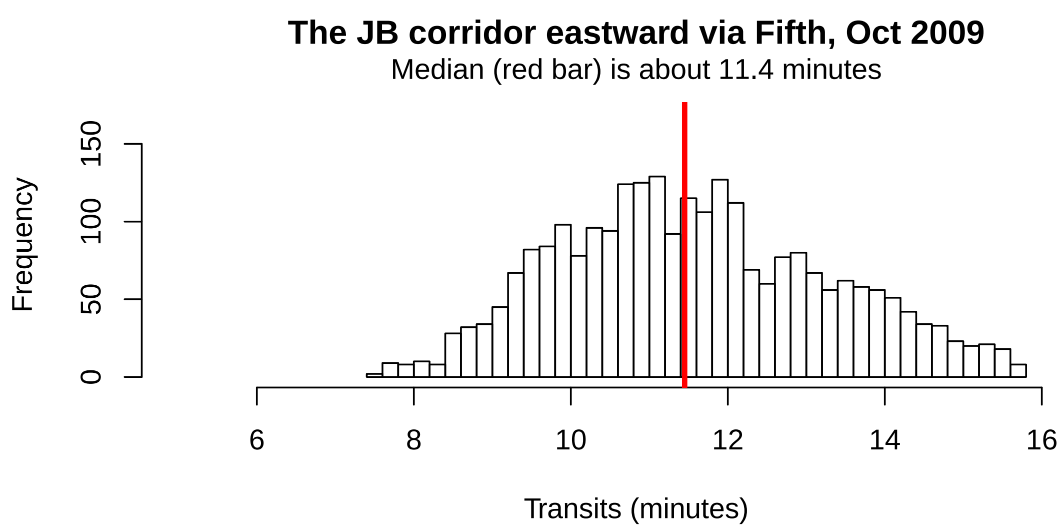


Fig. 5: *The transits vary depending on traffic conditions, hour of the day, day of the week, and other factors. The trips on Forbes Avenue on the Jumonville-Bellefield corridor typically last between 5 and 14 minutes, while trips on Fifth Avenue typically last between 6 and 16 minutes. The vertical red bars mark the median transits for each route, allowing us to conclude that trips on Fifth Avenue typically take about 4 minutes longer than trips on Forbes Avenue.*

Avenue buses. This result is to be expected, since the dedicated lane protects buses from the general rush hour congestion.

5.2 The Craft-Bigelow corridor

Figure 7 shows the bus stops from Craft to Bigelow on Forbes and Fifth. This section of the route is interesting because the section is about the same length and has approximately the same number of stoplights on Forbes and Fifth. Figure 8 shows the transit times. Trips on Fifth Avenue typically take about 5.8 minutes, as opposed to 4.1 minutes on Forbes.

Figure 9 summarizes the results of statistical models designed to isolate the time cost of servicing bus stops and the effects of rush hour traffic on Forbes and Fifth on weekdays. Likely due to Fifth Avenue having additional overlap between servicing bus stops and waiting at stoplights, the time cost of servicing bus stops on Fifth Avenue is far lower than on Forbes, about 4 seconds compared to 13 seconds.

Rush hour traffic slows buses down by about 150 seconds on Forbes Avenue, but on Fifth Avenue the effect is only about 90 seconds compared to no-traffic conditions. Even after taking into account the effects of traffic conditions and servicing bus stops, trips on Fifth Avenue typically take about 108 seconds longer than trips on Forbes Avenue due to structural factors. Specifically, we estimate that a bus on Fifth Avenue at midnight with no passengers would take about 108 seconds longer than a similar bus on Forbes Avenue. Structural factors are discussed further in the next section.

5.3 Structural differences between Forbes and Fifth

Several structural differences cause buses to take longer on Fifth Avenue. The main factors are speed limits, asynchronous stoplights, and stop signs. Fifth Avenue has lower speed limits for most of the route compared to Forbes Avenue. Stoplights on Fifth Avenue are synchronized for westbound traffic, making it impossible with the current stoplight "schedule" for buses to proceed at a reasonable speed without having to stop frequently for stoplights. In addition, two stops signs are located between Craft and Mckee Pl on Fifth Avenue, with no analogous stop signs on Forbes Avenue. All of these factors have nothing to do with the fact that buses on Fifth are in a bus lane. Therefore, a prediction of the performance of a proposed bus lane on Forbes Avenue should be based on methods other than comparing average bus speed on Fifth Avenue bus lane against speed on Forbes Avenue.

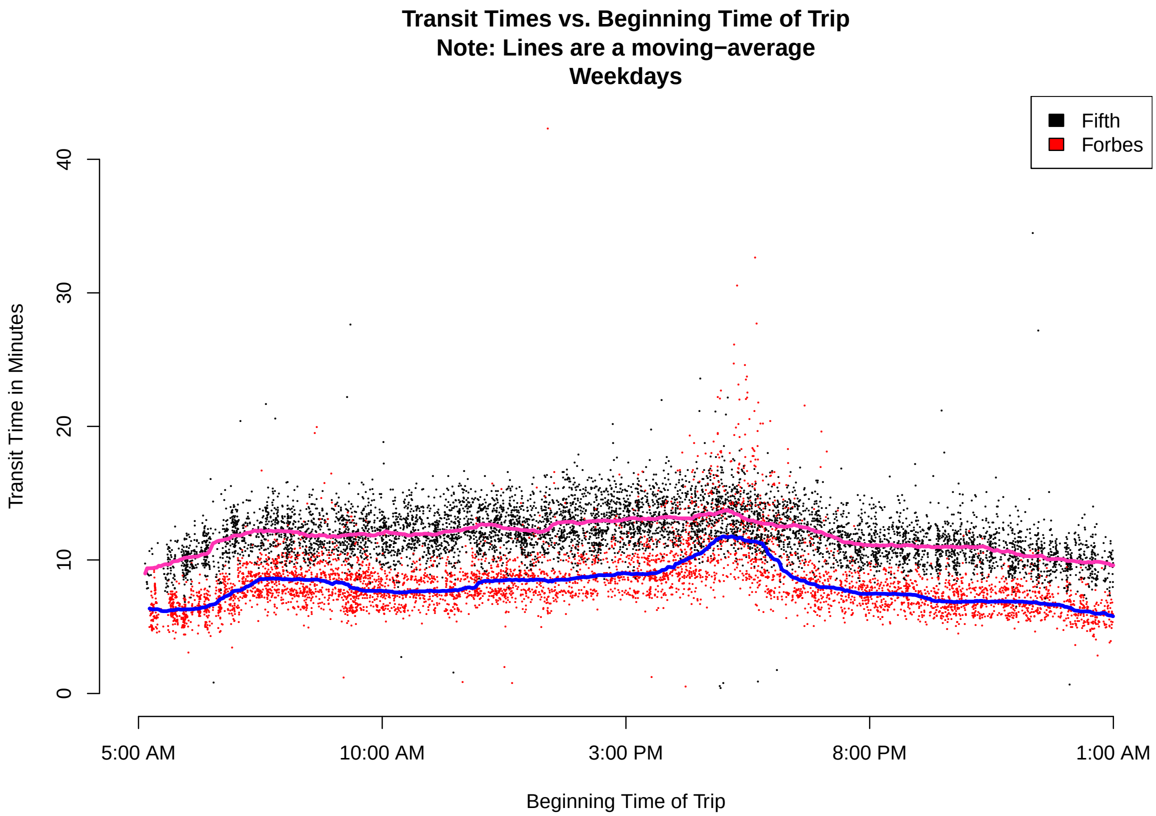


Fig. 6: *Each dot represents one trip of a bus on the Jumonville-Bellefield corridor. The horizontal axis shows the time of day that each trip started out at Jumonville, and the vertical axis shows how long it took to get to Bellefield. The black dots are for trips on Fifth Avenue, and the red dots are for Forbes Avenue. The red curve uses averages to identify the trend in the transit times on Fifth Avenue, and the blue curve is for Forbes Avenue. A striking feature of this plot is the large bump in the Forbes Avenue transits at the 5pm rush hour. The absence of such a noticeable bump for Fifth Avenue transits demonstrates that buses on the dedicated lane are not especially affected by rush hour traffic.*

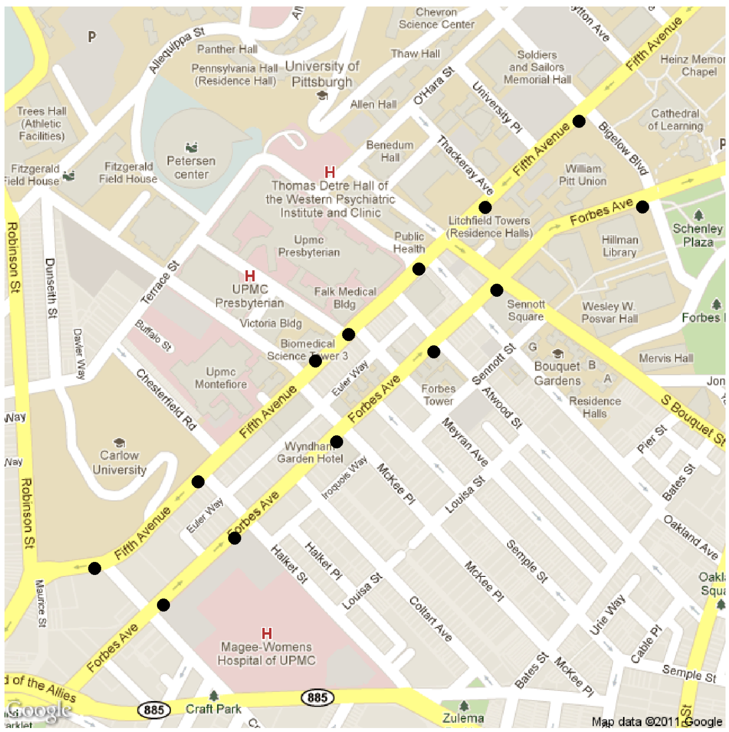


Fig. 7: *The two left-most bus stops are adjacent to Craft Avenue, and the rightmost stops are next to Bigelow Blvd. There is just one more stoplight and one more bus stop on Fifth Avenue compared to Forbes Avenue on this short stretch.*

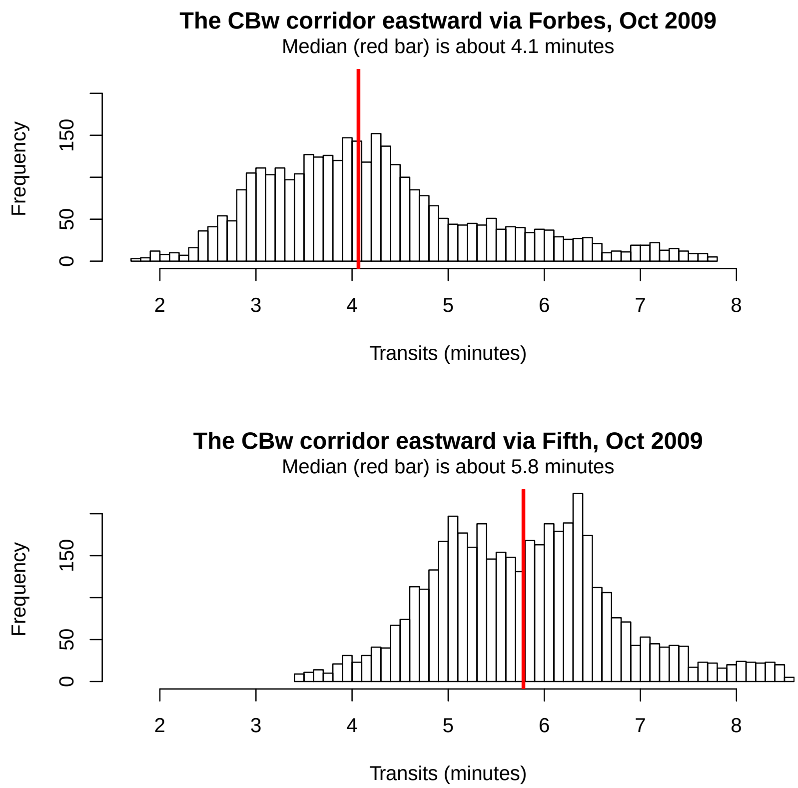


Fig. 8: *The CBw corridor runs from Craft to Bigelow. Trips on Fifth Avenue typically take about 5.8 minutes, as opposed to 4.1 minutes on Forbes. The transits vary depending on traffic conditions, hour of the day, day of the week, and other factors.*

Craft to Bigelow, weekdays

	Forbes	Fifth
Average transit time	252 sec	340 sec
Average time cost of servicing a bus stop	13 sec	4 sec
Rush hour effect (not counting the effect of servicing stops)	150 sec	90 sec

Delay on Fifth due to **structural factors**: 108 seconds.

Structural factors include stoplight asynchronization, stop signs, and speed limits.

Fig. 9: *A summary of statistical modeling results for bus trips from Craft to Bigelow on weekdays.*

6 Bus bunching

A common complaint from bus system customers regards the bunching effect. The bunching effect is the tendency of buses to group together, resulting in late bus arrivals and redundant bus service. This phenomenon is evident in a more detailed dataset that the PAAC provided for December 2009. Figure 10 shows buses moving from Craft to Bigelow on Fifth. The red lines are versions of route 71, and the black lines are all other buses. The starting position of each line above the horizontal axis is the time when the trip started at Craft, at some point between 4 and 6pm. The vertical axis is how far the bus has traveled since arriving at Craft. You can see that some of the trips are bunched together. Exploring when, how often, and why the bunching occurs is an interesting area for future research.

One way to facilitate research on bunching would be to make a small change to how the Clever Devices collect data. Buses record an observation at least once every 500 feet in the current Clever Device settings. If this maximum distance setting is adjustable, decreasing the maximum distance so that there is at least one record perhaps every 200 feet would provide more detailed information about where and when buses are moving together. Decreasing the maximum distance between records would also make it easier to address a variety of other issues, including how to optimize stoplight synchronization.

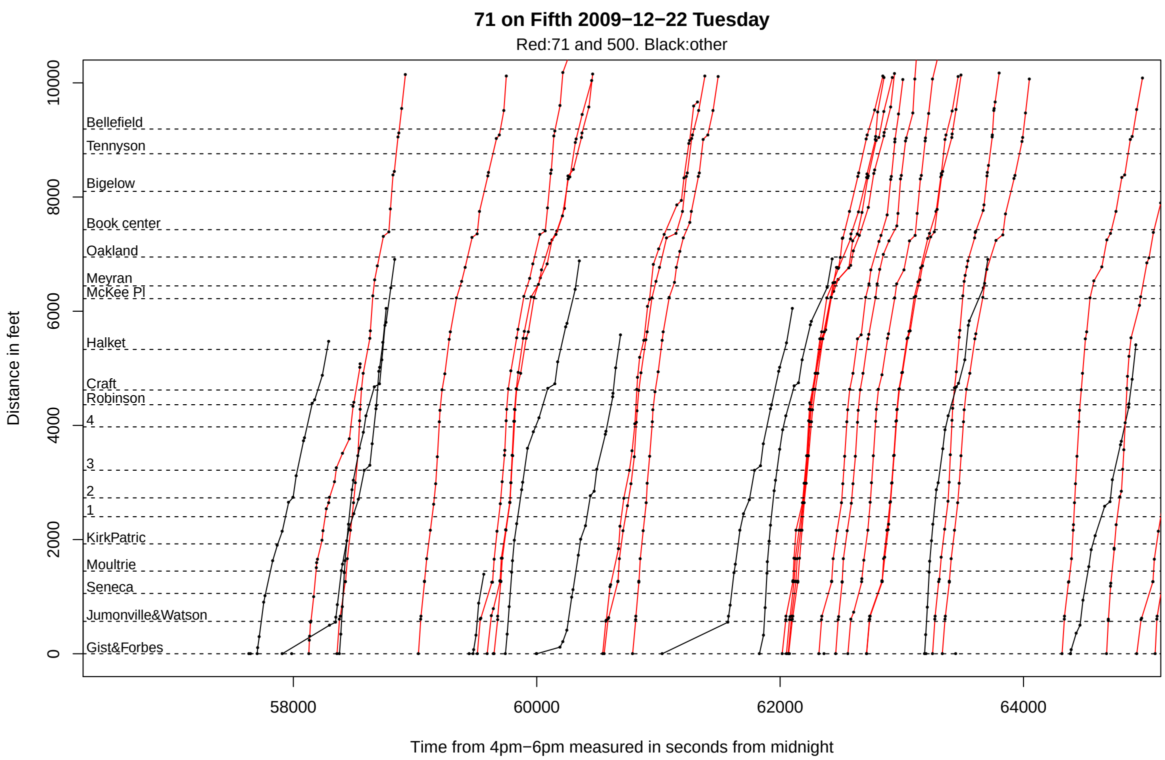


Fig. 10: *Bus bunching appears on Fifth Avenue between 4 p.m. and 6 p.m. on a Tuesday in December 2009, for example. Buses move from Craft to Bigelow on Fifth Avenue. The starting position of each slanted line at the horizontal axis indicates the time when the trip started at Craft. The vertical axis is how far the bus has traveled since arriving at Craft. Each red line represents a trip of a 71 bus. The black lines represent trips by other routes. Many of the black lines truncate near Halket Street as buses turn off of Fifth Avenue. The bunching behaviour shown here (especially near 62,000 seconds) is not atypical.*

7 Discussion and future research

The 4-minute advantage of Forbes Avenue over Fifth Avenue suggests that there may be ways to move passengers more quickly from Downtown to Oakland. Assigning more buses to Forbes Avenue instead of Fifth Avenue or exploring alternative stoplight synchronization schemes on Fifth Avenue are two examples.

We suggest additional research into several related questions to help find an optimal bus traffic design.

- What fraction of passengers on the bus lane would accept being dropped off on Forbes Avenue instead of Fifth Avenue closest to their destinations? In other words, would it make sense to shift some buses from the bus lane over to Forbes Avenue so that they can go faster, especially in non-rush hour traffic?

- A new bus lane on Forbes Avenue would likely allow buses to proceed at least as fast as they currently do, as well as freeing up the other lanes of traffic from buses. However, it is not clear whether this is preferable to simply adding another lane of traffic on Forbes Avenue and allowing buses to mix with traffic to maximize use of all roadway space by all vehicles.

- The stoplight synchronization on Fifth Avenue appears to be highly detrimental to the progress of buses on the bus lane. The synchronization scheme should be carefully reexamined to assess whether improvements are possible.

Appendices

A Estimating rush hour effects and time cost

Figures 11 and 12 display the results from linear regression software for Forbes and Fifth from Craft to Bigelow. Parameter estimates for hour1 through hour5 (1 a.m. through 6 a.m.) are highly uncertain due to a lack of data in those hours. The uncertainty in these estimates is partially reflected in the absence of many asterisks, which are used to indicate statistical significance.

A.1 Average transit time

The averages reported on Figure 9 are technically medians after excluding some outliers. These medians are computed directly from the raw data. The medians are provided to put the time cost and rush hour effect estimates in perspective. The medians are not one of the regression results.

A.2 Time cost of servicing stops

We estimate the time cost of servicing stops using the coefficient estimate for the "count_event3" variable. The variable count_event3 records, for each trip, the number of serviced stops between Craft and Bigelow.

A.3 Rush hour effect

The rush hour effect is intended to represent the bus delay that results from rush hour traffic, excluding the delay that results from the bus servicing a greater number of stops during rush hour. Roughly speaking, to estimate the rush hour effect we compare the maximum hour effect (between 4-5 p.m. or 5-6 p.m.) to the hour effect at midnight, when interference by traffic is almost negligible.

	Estimate	significance
(Intercept)	273.7	***
count_event3	3.5	***
hour1	1.3	
hour2	8.9	
hour3	92.9	**
hour4	41.5	
hour5	-12.7	*
hour6	28.8	***
hour7	60.1	***
hour8	50.9	***
hour9	57.5	***
hour10	56.8	***
hour11	66.7	***
hour12	70.9	***
hour13	75.5	***
hour14	78.6	***
hour15	79.0	***
hour16	93.1	***
hour17	80.2	***
hour18	66.5	***
hour19	36.2	***
hour20	23.2	***
hour21	14.3	**
hour22	29.0	***
hour23	18.2	***

Fig. 11: *The regression output summarizes the effects of time-of-day and and time cost for servicing stops for weekdays on Fifth Avenue from Craft to Bigelow. The intercept (273.7 seconds) is an estimate of the average transit times for buses between midnight and 1 a.m. that do not service any stops. The number next to count_event3 (3.5 seconds) is an estimate of the average time cost of servicing a bus stop. Each hour effect is an estimate of the increase in transit time for that hour compared to the midnight-to-1 a.m. hour, which is hour 0. Hour 23 is the 11 p.m.-to-midnight hour. Lots of asterisks indicate that the standard error of the parameter estimate is small compared to the size of the estimate.*

	Estimate	significance
(Intercept)	165.9	***
count_event3	12.8	***
hour1	-7.7	
hour2	34.5	
hour3	43.2	
hour4	-23.3	
hour5	0.0	
hour6	5.8	
hour7	47.1	***
hour8	48.7	***
hour9	54.5	***
hour10	46.2	***
hour11	60.2	***
hour12	82.0	***
hour13	82.7	***
hour14	105.4	***
hour15	96.8	***
hour16	140.1	***
hour17	159.9	***
hour18	98.0	***
hour19	56.8	***
hour20	41.0	***
hour21	25.1	***
hour22	25.9	***
hour23	27.3	***

Fig. 12: *The regression output summarizes the effects of time-of-day and and time cost for servicing stops for weekdays on Forbes Avenue from Craft to Bigelow. The intercept (165.9 seconds) is an estimate of the average transit times for buses between midnight and 1 a.m. that do not service any stops. The number next to count_event3 (12.8 seconds) is an estimate of the average time cost of servicing a bus stop. Each hour effect is an estimate of the increase in transit time for that hour compared to the midnight-to-1 a.m. hour, which is hour 0. Hour 23 is the 11 p.m.-to-midnight hour. Lots of asterisks indicate that the standard error of the parameter estimate is small compared to the size of the estimate.*

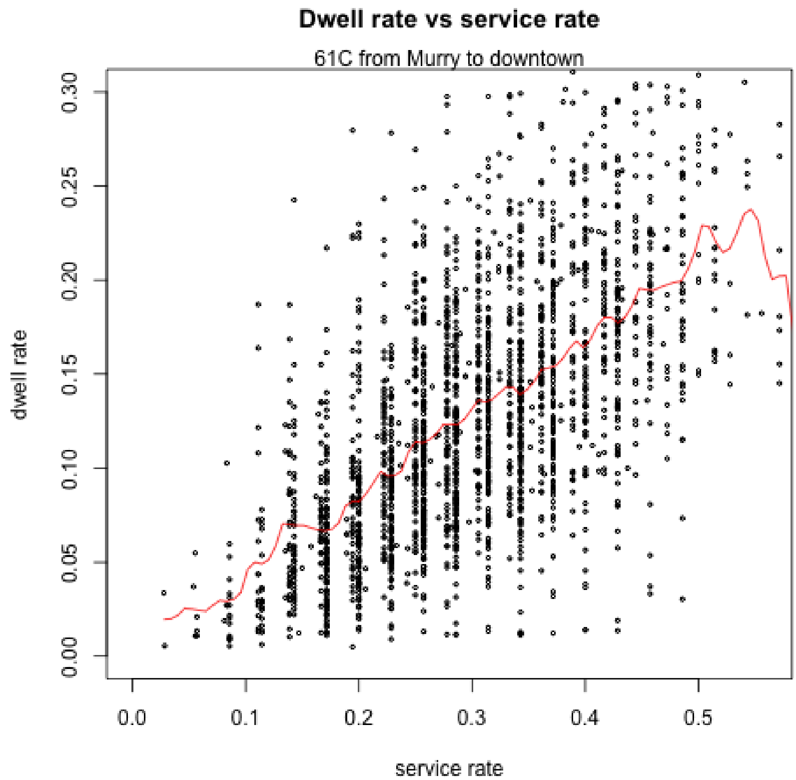


Fig. 13: *There is a strong association between the fraction of stops that are serviced and the fraction of trip time that consists of dwell time. Each circle on the plot represents a bus trip. On the horizontal axis, service rate is the fraction of bus stops that were serviced. For example, if the service rate for a trip is 0.36, then 36% of the bus stops on that trip were serviced. Similarly, on the vertical axis, dwell rate is the fraction of time that a bus spent idling at bus stops. The red curve summarizes the trend between the dwell rate and service rate.*